Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-02/1519-2		

4. Title and Subtitle	5. Report Date
THE TECHNICAL AND ECONOMIC FEASIBILITY OF A FREIGHT PIPELINE SYSTEM IN TEXAS – YEAR 2 REPORT	September 2001
	6. Performing Organization Code
7. Author(s) Stephen S. Roop, Leslie E. Olson, Jeffery E. Warner, Curtis A. Morgan, David H. Bierling, Craig Roco, Rogier Kneepkens, Ralph DeSwart, Mina Rahimian, Hammit Toliyat, Karin Shultz, and Othon Rediniotis	8. Performing Organization Report No. Report 1519-2
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 0-1519
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Research: September 2000 – August 2001 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: Freight Pipeline Feasibility Study

16. Abstract

The North American Free Trade Agreement (NAFTA) has accelerated the rate of growth between Canada, Mexico, and the United States. Tremendous quantities of goods now flow between these three trading partners, mostly transported by truck. Texas, because of its geographic location, serves as the principal land-side gateway to Mexico, and, as a consequence, hosts truck traffic from all over the U.S., Mexico, and Canada. This truck traffic is beginning to dominate certain Texas highways. It costs the state large sums of money to maintain the condition of the affected roadways. The current research is aimed at determining whether non-traditional systems can alleviate the congestion and wear problem by shifting truck-carried goods to an alternative mode. Freight-conveying pipelines are being evaluated in this context. This second year report addresses key technical issues associated with aerodynamics, vehicle design, energy consumption and availability, trucking logistics, Texas geology, system capacity, and terminal design. The report also presents a business model formulation that will serve to induce use of the system by a customer base comprising the current freight transportation industry.

17. Key Words	18. Distribution Statement
Freight, Pipeline, Underground, Freight Movement	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	244	

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

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Report 1519-2
Project Number 0-1519
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Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

September 2001

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ACKNOWLEDGMENTS

The authors wish to express their appreciation for their forward-thinking sponsors at the U.S. Department of Transportation, Federal Highway Administration and the Texas Department of Transportation, including the project director, Paula Lancaster and the project monitoring committee. The authors would also like to thank U.S. Representative Eddie Bernice Johnson of Texas for her support.

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CHAPTER 1 – SUMMARY OF YEAR 1 RESEARCH

SUMMARY OF FIRST YEAR REPORT

Focus

The first year report focused on defining underground freight transportation; its history, characteristics, and current status. In addition, the first year report detailed the process whereby the research team selected the corridor for the feasibility study and initiated the systems engineering approach to systems design. The overall study parameters, duration, cost, and non-federal sponsorship were established from the outset and served to determine the scope and emphasis of the work plan. As the non-federal sponsor, the Texas Department of Transportation (TxDOT) has been assigned oversight and management responsibility.

One of TxDOT's most serious challenges in the years ahead is the growth in trade-related truck traffic and its detrimental impact on the Texas highway system. The emphasis of this research was therefore placed on truck traffic mitigation. The research team proposed that the best way to address TxDOT's needs was to design a system that promised to divert the maximum amount of North American Free Trade Agreement (NAFTA)/trade-related truck traffic from the state's most heavily traveled trade corridor (IH-35). The systems design approach would consequently be aimed at developing a freight conveyance that would assist the department, by reducing truck traffic on a major Texas highway, in achieving its goal of providing the citizens of Texas with a safe and efficient transportation system.

Among the adverse ramifications of increasing truck traffic on the Texas highway system are the following:

- Decreased levels of safety for the motoring public and for truck drivers. It has been estimated that 68 to 70 percent of traffic collisions between trucks and automobiles are the fault of the auto. As congestion increases on our state's increasingly burdened roadways, collisions will likely increase as well.
- Increased maintenance demands on existing roadways. Trucks, due to their weight, account for a disproportionate amount of the damage to highway infrastructure. As the number of trucks increase, the pace and quantity of damage to highways will correspondingly increase.
- Increasing congestion and travel times. The level of service (LOS) on the roadway network is categorized by the number of vehicles per lane measured across a 24-hour period. Level of service is falling across most major roadways and a major contributing factor in many cases is increases in the number of trucks.

In evaluating the trade-related transportation challenge facing TxDOT, which appears to be characterized by ever-increasing numbers of trucks on Texas highways, the research team's aim has been to design a system that will both transport freight more efficiently than over-the-road shipments and interface smoothly with the existing freight transportation system.

Three principal areas of activity are involved in the approach:

- a systems engineering design for a freight conveying pipeline system tailored to the needs of Texas,
- an assessment of the economics associated with the resulting system configuration, and
- an examination and analysis of the political and institutional issues associated with implementation and operation of the system.

Systems Engineering Approach

Systems engineering is a design discipline that facilitates the development of an optimal system configuration given a wide array of design options. The current research typifies an ideal scenario for this approach in that there are a large number of options associated with almost every function and subsystem of the underground freight movement system.

The first year's effort focused on:

- establishing the need for the system,
- defining the system functionality,
- describing the subsystems necessary to carry out the mission of the system, and
- developing initial performance specifications.

The need for an alternative to over-the-road transport of goods in Texas is clear and has been addressed in previous sections of the project documentation. In a very real sense, the nature of the transportation challenge in Texas, particularly the NAFTA-related trade levels on the IH-35 corridor, has shaped every facet of system concept development and design. In addition to selecting the corridor and initiating the design, in Year 1 of the research, the Texas Transportation Institute (TTI) examined the type of freight moving on IH-35. It was established that a preponderance of the material moved was palletized. It was also determined that a significant percentage of the truck traffic on IH-35 between Dallas and Laredo had out-of-state origins or destinations.

Thus, the system evolved toward an underground conveyance that would:

- operate along the IH-35 corridor between Dallas and Laredo,
- facilitate NAFTA trade to and from Mexico, and
- move palletized freight.

An analysis of system requirements led to the definition of five sub-components comprising the overall system:

1. Underground infrastructure - the tunnel system and related conduit. The material for the conduit and its cross-sectional shape was also addressed. There was a preliminary

examination of geo-technical data as well as discussion of the two main options for constructing the tunnel: cut and cover or tunnel boring.

2. Main transport mechanism (MTM) - the MTM sub-function illustrates the vehicle options for transporting the freight through the system (the tunnel and terminal).
3. Power supply systems - the power sub-function describes the power-generating or power-supply options available to obtain the necessary power required to run the MTM and the operation of the terminals.
4. Warehousing and material handling - the warehousing and material handling system sub-function encompasses the terminal areas, a freight identification system, and loading/unloading systems.
5. Control system - the control system sub-function integrates the overall command and control of each subsystem, i.e., power source, warehousing, and material handling system as well as the MTM.

These sub-systems were further broken down with detailed requirements for each that were to be satisfied in the conceptual design. The initial evaluation examined three conceptual designs in the Power and Main Transport Mechanism design with recommendations on each design. State-of-the-art technology was to be utilized for the warehousing and material handling at the terminals and for the control systems. Further, the specific interfaces between the five sub-functions were reviewed. The issues of safety and reliability within each sub-function were addressed by means of failure modes and effects analysis and also to satisfy the design requirements. The initial evaluation was necessarily broad in scope and only limited cost analysis figures were presented. It became evident that a more detailed design specification was needed for each sub-function in order to gather realistic cost estimates.

Economics of the Prototype System

The research plan has proceeded on the assumption that both a technical design and economic evaluation is required to evaluate the overall feasibility of an underground freight transport system. It has been further assumed that if there are not compelling technical reasons why an underground transport system would not work, then the economics associated with a prototype freight pipeline system would determine the bottom-line feasibility of the system. Two categories of costs were discussed in Year 1:

- capital expenditures and
- the marginal cost of system operation.

As stated in Year 1, capital requirements to build the system will be compared to those required for highway capacity improvements. Capital costs are those costs independent of expenses associated with actual freight movement. Major capital costs are the pipe elements themselves, the guideway and propulsion systems, the terminal, and the hardware required for command and control. While these numbers are critically important, the vital, long-term economic consideration remains the marginal cost of operation or the cost to the user to move one ton of material a distance of 1 mile (a ton-mile). The marginal costs are directly impacted by the amount of freight moved since the greater the weight of freight moved, the greater the energy requirements (and hence energy costs). All of the operational costs, (i.e., energy consumption, maintenance, management, technicians, etc.) will be unitized by dollar per ton-mile for each evaluated freight pipeline sub-system. Current estimations are that the cost to accomplish freight movement with trucks is approximately $0.29 per ton-mile.

The economics of system use, should they prove favorable, will be used as an inducement to the private sector to integrate the freight pipeline into its operations. It is the current working premise that no alternative system will achieve success without the enthusiastic participation of trucking firms. The trucking companies themselves will have to benefit, as will their customers, by providing a lower-cost, higher reliability alternative to highway transportation.

Over the course of research activities in Year 2, it became apparent that a major economic consideration, while planned, had not been listed as part of the economic evaluation. The category omitted includes all the costs avoided by relying on an alternative to over-the-road transport. Among these costs are the expenses associated with highway maintenance, motorist safety, air quality, required grade separations, and congestion-related delay. These social costs will serve to offset some of the capital and operational requirements of an alternative approach.

Political and Institutional Issues

Political issues are considered to be all the concerns outside the technological and economic realm that could affect the ultimate viability of a freight pipeline system during planning, construction, or operation. Political issues are commonly the result of positions taken by various interest groups. These groups may consist of competing transportation modes, political entities, environmental groups, landowners, or others. A degree of support for an alternative freight transport system is necessary from these factions for the project to move from concept to serious consideration. This research will evaluate the predominate political issues affecting the viability of the concept and discuss approaches to overcoming resistance. A listing of the issues identified to date are included in this year's reporting as a separate product of the research and appear in this report as Appendix C.

Research Goals

The goals established for this feasibility study revolve around evaluating an underground freight conveying system meeting certain design and functional guidelines. These guidelines may be summarized as follows:

- The system will provide an alternate transportation system for moving palletized freight (48 in. x 48 in. x 60 in.) between Dallas and Laredo.
- The system should be composed of existing, proven technologies.
- The proposed system must be automated (driver-less).
- The marginal cost of operation must be very competitive with the costs of trucking freight between the same markets (< $0.10 per ton-mile).
- The system's performance must provide a high-speed (45 mph +), high-capacity substitute for trucking.
- The overall system must be environmentally sound.

- The system should be subterranean where possible so as to optimize land use and minimize contention with other transportation modes.
- The system must offer 24-hour per day service.
- Material handling at terminal locations should be as automated as possible.

Needs Statement

The above goals translate into a simple statement of needs:

To transport palletized freight in an efficient, reliable, and environmentally friendly manner. This freight transportation system (FTS) must be automated, subterranean, and economically feasible.

Needs Analysis

As stated previously, the adoption of NAFTA has resulted in a steady increase in the amount of freight transferred between the United States, Canada, and Mexico. Most apparent is the tremendous increase in the amount of goods and material carried by the trucking industry. Since Texas serves as the principal gateway to Mexico, international trade necessarily travels through Texas. The increased traffic has resulted in severe congestion on key interstate routes, increases in highway maintenance costs, degradation in safety, and will eventually necessitate the construction of additional lanes to accommodate the continually growing traffic base. When considering the high cost of constructing additional interstate highway lanes relative to the capacity added, it is expedient to evaluate higher-capacity, innovative alternatives.

The guiding design requirements for the system are based on efficiency and reliability in transporting freight. The initial conceptualization requires that the freight pipeline be integrated into the overall transportation system and, by virtue of its efficiency and reliability, induce carriers to use it as a better alternative than over-the-highway transport.

YEAR 2 RESEARCH AGENDA

The work plan for FY 2001 continued the strategy of design according to systems engineering principles. This year's efforts focused on finalizing the baseline design specifications for sub-functions identified in FY 2000. The approach enabled the research team to develop a system design suited to both the transportation challenge and the environment within which it must operate. A guiding principal in Year 2 was that the design offer the most economical option within the design parameters established for the freight pipeline. Following the approach, the research team will be able to evaluate freight pipeline options relative to traditional operations and determine the potential for significant freight diversion from IH-35 in Texas.

The work plan for the current year included four primary tasks. The fifth task was targeted at developing the documentation reflecting the year's activities. A brief summary of the work plan is presented below with a discussion of the status of the work.

Task 1 – Finalize Systems Engineering Design Specification

Sub-task 1.1 – Finalize Functional Analysis for Sub-systems

This sub-task focused on the finalization of the functional analysis for sub-systems. The functional analysis specifies what the system component must accomplish in concert with other system elements to achieve the mission of the freight pipeline system.

Sub-task 1.2 – Establish Final Functional Requirements for Sub-systems

Sub-task 1.2 elaborated on the functional analysis by defining the constraints and assumptions associated with system operations. This work included defining system dimensions and operating characteristics.

Sub-task 1.3 – Establish Final Performance Requirements for Sub-systems

Performance requirements are being finalized as an understanding is developed regarding the parameters defining a superior freight transportation option in the selected corridor. The factors addressed in the first year's report, such as speed, capacity, and security, were to be revisited and evaluated for consistency and reasonableness.

Sub-task 1.4 – Establish Conceptual Design Options for Sub-systems

Options for each sub-system were evaluated and, in many cases, final specifications were developed. The options meet the functional and performance requirements established in preceding tasks and have allowed the design team to begin a selection process based on the overall efficacy of the component.

Task 2 – Perform Trade-Off Analysis

A trade-off analysis was initiated or completed for each freight pipeline sub-system option: tunnel system, main transport mechanism, power supply sub-function, terminal and material handling sub-function, and the command and control sub-function. The trade-off analysis will help determine the preferable option for each sub-function and set the stage for initial cost analysis.

Task 3 – Begin Cost Analysis

The determination of system feasibility will ultimately be based on the costs of system design, construction, and operation. The trade-off analysis performed in Task 2 has initiated the process of cost determination, but additional data collection and projection will be performed in the coming year to augment these data. Costs were to be assessed for capital expenditures and compared to the public costs incurred for highway capacity additions and maintenance. This work will continue in Year 3. The marginal cost of operation will be initiated this year and completed in Year 4 since it will be heavily dependent on final design parameters.

Task 4 – Policy Analysis

Sub-task 4.1 – Meet with Trucking Firms to Determine Level of Interest in Freight Pipeline System and Operational Needs

Researchers interviewed representatives of major trucking firms represented on the IH-35 corridor to determine the parameters within which they would likely be interested participants. The interviews identified the trucking community's concerns, needs, and constraints relative to enhancing their profitability through integration of freight pipeline operations with their current operational strategies. In Year 3, additional data will be collected in personal interviews, by phone, or if more advantageous, by site visits.

Sub-task 4.2 – Begin Evaluation of Financing Options; Public, Private, or Public and Private

The process of financing a major capital project is complex at best. The potential magnitude of investment required for this effort in conjunction with the innovative nature of the system may introduce additional considerations that must be fully understood as operational parameters are established. A review of comparable projects was initiated to gain an understanding of the broad requirements and approaches attempted in the past. Additional work in this area will be undertaken as part of the work plan in Year 3. The information gained will help establish the recommended approach to system implementation.

Sub-task 4.3 – Initiate Dialog with the Mexican Transportation Institute Regarding Bi-National Cooperation and Cross-Border Operations

Border transportation issues continue to receive attention due to the practical, physical, and institutional impediments presented by international trade with Mexico. It was thought at the beginning of Year 2 that some of these obstacles could be minimized by physically and operationally extending the freight pipeline into a market center within Mexico. While this is still a potential area for investigation, the complexity bi-national operations and the potential political fallout that would likely result as a function of bypassing U.S. border locations, has resulted in a delay in examining this as a central facet of the current research agenda. The research team will propose to revisit this sub-task in Year 4.

Sub-task 4.4 – Begin Investigation of Use of Public Property for System Right of Way

The use of existing publicly owned right of way to construct a freight pipeline system could greatly improve the feasibility of the project by reducing cost and contention with private concerns. This sub-task was intended to initiate an investigation into the possibility of this approach and delineate the pros and cons identified. A preliminary examination of the IH-35 corridor was performed to assess if access to the public property along this route is feasible. In addition, alternative Dallas to Laredo corridor(s) were investigated.

Sub-task 4.5 – Develop an Assessment of Issues Associated with Right of Eminent Domain

The ability to condemn property for demonstrable public benefit is called the right of eminent domain. This power allows the authorized entity to identify needed property and take possession at fair market value without the consent of the private property landowners. The courts arbitrate the settlement and enforce the decisions made for the public good. Many transportation projects rely on this power and, while it is a time-consuming and difficult process, it may be critical to the success of the freight pipeline concept. This task was intended to initiate an investigation into the issues associated with eminent domain within the context of the current research. While some work was done in this area, the research team will propose that additional attention be paid to this issue in Year 3.

Sub-task 4.6 – Identify Other Regulatory and/or Environmental Issues to be Addressed

This sub-task was included to formulate a listing of the policy issues associated with a transportation project of this type. The complete listing is available as a Year 2 product as a separate document and appears here as Appendix C. The issues identified in the Year 2 work plan were:

- Drug Enforcement Administration (DEA) and
- Customs

In addition to these issues, the research team has added:

- broker interactions and
- U.S. Department of Agriculture (USDA)

Task 5 – Document Year 2 Results

The results of Year 2 work plan are documented in this interim report. The report will summarize the work accomplished, detail any adjustments to the schedule, and provide a work plan for the subsequent period of performance.

Additions and Alterations to the Year 2 Work Plan

The recognition of several factors affecting system viability not explicitly identified in the Year 2 work plan prompted the study team to include several additional research elements. The physical and operational nature of the freight pipeline requires that certain key factors be considered early in the research to ascertain whether fatal design flaws render the concept non-viable. Among these potential flaws are energy availability and geology. It was determined in Year 1 that the most efficient propulsion system for the application at hand was an electric linear induction motor. The power availability crisis in California prompted the research team to undertake an examination of electric power availability in Texas. The results are fully documented in Chapter 5.

In the same vein, as a subterranean system, the freight pipeline will require extensive trenching and excavation to put the infrastructure in place. A potential fatal flaw was, therefore, identified relative to the geology of the state. If trenching was not practical or inordinately expensive given the nature of Texas' geology in the study corridor, then an alternative approach would have to be considered. To address these issues an evaluation of the geology of Texas was performed by researchers from Texas A&M University's Department of Geology and documented in this report in Chapter 10.

In Subtask 4.3, the Year 2 Work Plan called for establishing a dialog with the Mexican Transportation Institute to explore the potential for extending the freight pipeline into Mexico to further facilitate a modal shift from highways. It was determined, however, that the issues identified by this task were better deferred to a later point in the study since they did not directly impact the technical or economic feasibility of the system. The Subtask may be reintroduced to the work plan in a subsequent year based on discussions with the sponsors.

CHAPTER 2 – FUNCTIONAL SPECIFICATIONS AND PERFORMANCE REQUIREMENTS

DISCUSSION

The functional specifications for the freight pipeline system define what the system must do in order to accomplish the overall mission of the system. Functional specifications have been developed for each subsystem and are summarized in the following sections so that the reader may familiarize himself with the system requirements that determine subsequent decisions and component selections.

TERMINAL AND MATERIAL HANDLING

A terminal/material handling system (TMHS) will be located at each end, and at specified intermediate locations, of the freight pipeline to receive and discharge palletized cargo. This system must provide temporary storage for cargo that will be placed on, or has been removed from, the MTM. Truck and rail access facilities and parking areas must also be provided as part of the TMHS.

Functional Requirements

- Provide terminal roadways, terminal sidings, or rail yardage to reach terminal loading/unloading areas.
- Provide truck and rail parking areas for access to terminal loading bays.
- Inspect and classify the security condition of each pallet that enters the pipeline.
- Adequately queue each pallet to the MTM for transport through the conduit system.
- Identify pallets unloaded from the MTM and distribute them to the correct truck or rail loading areas.
- Provide storage and maintenance facilities for MTM units.
- Provide rest facilities for truck operators.
- Provide temporary warehousing for cargo.

Truck Access Areas

Definition

Truck access areas are the structures and spaces within the terminal boundaries that allow for trucks to deliver and receive cargo at the terminal/warehouse facilities.

Discussion

Truck access areas are comprised of roadway pavements, parking lots, and loading/unloading spaces.

Subsections

- Terminal Roads,
- Truck Parking,
- Truck Loading Areas, and
- Driver Rest Facilities.

Rail Access Areas

Definition

Rail access areas are the structures and spaces within the terminal boundaries that allow for trains to deliver and receive cargo at the terminal/warehouse facilities.

Discussion

Rail access areas are comprised of rail sidings, rail yards, storage tracks, and loading/unloading spaces.

Subsections

- Terminal Sidings/Yard Tracks,
- Railcar Storage Track, and
- Railcar Loading Areas.

Terminal/Warehouse Facilities

Definition

The terminal and warehouse facilities provide structures and spaces that allow for the transfer of cargo between truck/rail and the MTM.

Discussion

Loading/unloading facilities of adequate geometric and structural design must be provided so that the relay of cargo between truck/rail and MTM is efficient and reliable. The terminal/warehouse facilities must also provide enough space for security, pallet identification, pallet distribution, queuing, and storage operations to be incorporated into the transfer of cargo.

Subsections

- Truck Loading Bays,
- Rail Loading Bays,

- Pallet Receiving and Identification,
- Security,
- Inbound Movement to MTM,
- Queue to MTM,
- Loading/Unloading of MTM,
- Incoming Pallet ID and Distribution,
- Warehousing of Pallets,
- Outbound Movement to Truck/Rail Loading Bays,
- MTM Storage/Maintenance Area,
- Terminal Warehouse Building Structure, and
- Terminal Site.

MAIN TRANSPORT MECHANISM

Discussion

The MTM serves as the mobile unit that transports freight from one terminal to another along the pipeline's route. This mechanism must deliver freight to the required destination undamaged, and with a level of reliability and economy that motivates the freight industry to use the pipeline.

Functional Requirements

- Transport freight to the required destination.
- Deliver freight free of damage.
- Carry the required freight design load and configuration.
- Start, accelerate and decelerate, and stop on command.
- Operate as an unmanned, unidirectional transport mechanism.
- Interface with other principle systems designs.

Propulsion and Control System

Definition

The propulsion and control system will provide the power and control capabilities for all operational requirements of the MTM.

Discussion

In addition to the provision of power, this system will brake and control the speed of the MTM in a reliable and safe manner. The propulsion and control system will also be required to operate at optimum energy efficiency.

Subsections

- Propulsion System,
- Braking System,
- Onboard Control and Feedback System, and
- MTM – C^3 Interface.

Suspension System

Definition

The suspension system will transmit load forces from the MTM to the running surface of the conduit system in a way that minimizes wear on the MTM and provides stability and protection to the cargo.

Discussion

It is imperative that the suspension system provides a ride quality that meets the needs of the freight industry. Energy efficiency and motion stability are considered part of this ride quality.

Subsections

- Wheels and Running Surface,
- Frame,
- Couplers/Connectors, and
- Pallet Mounts.

Fuselage

Definition

The fuselage will encapsulate and protect the MTM cargo during transport through the pipeline and will enhance the aerodynamic performance of the MTM.

Discussion

Even though the material handling system will inspect the integrity of each pallet, the fuselage must be able to restrain any loose cargo that results from a packaging failure. Also, the geometry and orientation of the fuselage should not interfere with loading/unloading operations.

OPERATING POWER

Discussion

The freight pipeline will require a constant and reliable source of power to perform as required.

Functional Requirements

- Provide a constant supply of power throughout the operating life of the pipeline that is sufficient in quantity for the pipeline to perform all required tasks.
- Minimize the emissions and hazardous materials produced during operations.
- Maximize the degree of safety to operating personnel.

COMMAND, CONTROL, AND COMMUNICATION

Discussion

The command, control, and communication system serves as the overall control grid for the freight pipeline. This system will direct the movement of pallets and MTMs within the pipeline, and will coordinate the movement and loading/unloading of trucks/railcars as they interface with the pipeline terminals.

Functional Requirements

- Direct trucks/railcars to the proper loading bay.
- Direct each pallet through the pipeline.
- Monitor pallet movement through the pipeline.
- Direct loading/unloading of MTMs.
- Control terminal arrivals/departures of MTMs.
- Control speed and spacing of MTMs.
- Control power distribution through the pipeline.

Truck/Railcar Interface

Definition

This component provides directions to trucks/railcars that arrive at a terminal to pick up or discharge freight. Each truck/railcar must be given directions to the proper loading bay and be provided a status report on its availability.

Discussion

Each truck or railcar must be directed to the proper bay at the proper time when picking-up or discharging freight. Arrival and departure windows that provide for early arrivals, or for loading/unloading difficulties, should be developed. This function may be performed using changeable message signs, automated readouts, or other methods provided by the control system.

Pallet Transport

Definition

This component provides the control system with the capacity to track pallet locations and to direct them to the proper destination within the pipeline.

Discussion

Pallets must be identified prior to transport within the pipeline, and they must be directed to an unloading bay or to temporary storage upon arriving at the correct terminal. Individual pallets should be grouped for tracking while being transported on the MTM, and then should be directed individually through the terminal.

Subsections

- Pre-tagging of Pallets,
- Pallet Direction Through System, and
- Pallet Tracking Through System.

MTM Control

Definition

This component provides the control system with the capacity to control MTM arrival/departure rates, MTM speeds, and MTM loading/unloading operations.

Discussion

The rate of actual loading/unloading must be monitored so that MTM doors are activated at the proper time. The control system must also control the spacing between MTMs in order to ensure the safe transit of freight and to coordinate arrival times.

Subsections

- Direct MTM Loading/Unloading,
- Control MTM Arrival/Departure from Terminal, and
- Control MTM Speed and Spacing within System.

Power Distribution Control

Definition

This component monitors the power requirements of the MTMs based on their speed.

Discussion

The power drawn from the power generation system must be adjusted to accommodate changing MTM speeds. For this to be accomplished, the control system must interface with the power generation system and each MTM through a feedback mechanism. MTM weight and pipeline gradient must be considered when determining this power requirement.

CONDUIT SYSTEM

Discussion

The freight pipeline conduit consists of the structure that houses the MTM throughout the length of the pipeline's route. The internal dimensions of this structure must provide sufficient clearance for MTM operations, and provide space for any required utility lines, while maximizing economy. Furthermore, the conduit must be of sufficient elevation at the loading/unloading terminals to allow for entrance/egress of the MTM at these areas. The conduit must also be designed so that maintenance personnel can access the structure at stations suitable for efficient and safe inspection and/or repair operations.

Functional Requirements

The freight pipeline conduit must perform the following functions:

- Transfer loads from MTM to soil.
- Withstand lateral/vertical earth pressures.
- Provide proper clearance for MTM operations.
- Adequately interface with loading and unloading areas.
- Provide entrance stations for maintenance personnel.
- Provide for utility transmission.

Structural Capacity

Definition

This component provides structural support for the conduit against external loads and provides for the transfer of MTM-generated loads from the conduit to the ground.

Discussion

The freight pipeline conduit will be designed as a subsurface structure. Accordingly, the conduit must comply with appropriate structural and geotechnical engineering design requirements. The structural design must also account for moving loads exerted by the MTM.

Subsections

- Foundation,
- Structural Walls, and
- Drainage.

Transport Capacity

Definition

This component provides the MTM with a conduit clearance and shape that allows it to progress unimpeded throughout the length of the pipeline's route while minimizing drag and maximizing economy. The conduit must also be designed to allow for MTM operations in dual directions simultaneously.

Discussion

Due to the inverse relationship between conduit dimensions and the induction of drag forces upon the MTM, a design clearance must be obtained that optimizes the combined costs of power for MTM operations and for conduit construction.

Subsections

- Running Surface and
- Clearance Dimensions

Operational Capacity

Definition

This component provides the space necessary for any utility lines or ventilation that must run throughout the system, and provides the space required for maintenance personnel to safely and efficiently inspect and/or repair the conduit or MTM.

Discussion

When possible, the space required for the provision of utility lines, ventilation airways, or maintenance/inspection should be designed as a multipurpose space in order to minimize costs. The operational system must be designed so that the MTM can transport cargo 24 hours per day, seven days per week.

Subsections

- Entrance Portals and
- Utility/Ventilation Easements

OPERATIONS, MANAGEMENT, AND MAINTENANCE

Discussion

An administrative staff will manage the freight pipeline for the purpose of ensuring that all budgetary and operational standards are met. This staff will be accountable to an appropriate state agency, whose obligation will be to regulate pipeline operations.

Functional Requirements

- Operate the freight pipeline within the budget prescribed by the State of Texas.
- Operate and manage the freight pipeline in a way that meets or exceeds the goals established by the public charter.
- Ensure that all transported cargo comply with size and content specifications.
- Provide equitable treatment among all users of the freight pipeline.
- Maintain all system components within prescribed standards.

PERFORMANCE REQUIREMENTS

Table 1. Performance Specifications.

Subsection	Category	Performance Specification
1.1.1	Terminal Surface Pavement	Build to provide continuous service for the pipeline life. Concrete with allowance for minimal deterioration of substructure and surface re-facing every 15 years at a design capacity equivalent to 20 million gross tons of truck traffic per year.
1.1.2	Truck Parking	Accommodate up to 64 trucks (4 %) of the daily quantity of 1600 trucks is estimated for the initial start-up period, 2-3 years. Subsequently, based on the type of operation, capacity will be reduced as industry settles into familiarity with the system and coordinates its operations with its utilization of the pipeline.
1.1.3	Truck Loading Areas	To Be Determined (TBD) - Terminals will provide initial truck-loading areas equivalent to the traffic distribution determined for the terminal.
1.1.4	Driver Rest Facilities	Minimal driver rest facilities will be provided. These may include: restrooms, a driver's waiting area outfitted with pay phones, tables with chairs where drivers can complete paperwork, a television with local and regional news and weather, snack vending machines, and soda/water/coffee vending machines.
1.2.1	Terminal Sidings/Yard Tracks	TBD – Based on railroad requirements.
1.2.2	Railcar Storage Track	TBD – Based on railroad requirements.
1.2.3	Railcar Loading Area	TBD – Based on railroad requirements.
1.3.1	Truck Loading Bays	This will be a secure area of the facility. Truck loading bays will be accessible to terminal operating personnel only. No truck driver admittance is anticipated in this secure area.
1.3.2	Rail Loading Bays	TBD – Based on railroad requirements.
1.3.3	Pallet Receiving and Identification	Current expectations have the physical application of the pallet identification mechanism being carried out through an automated system mounted on the pallet removal machine when the pallet is extracted from the truck trailer. This function will be coordinated through the C^3 system.
1.3.4	Security	TBD – There will not be any unsecured areas inside the terminal building that non-authorized personnel can gain access to.
1.3.5	Inbound Movement to MTM	Pallets will be moved within the terminal by a combination of automated processes. The specifications of this function are independent on the final Business Model adopted.
1.3.6	Queue to MTM	The number of queues required to maintain a smooth flow into the MTM loading points will be established by the Simulation Model currently being evaluated. The queue forming system to feed the MTM is expected to be a parallel group of feeders which will stage to large truck trailer quantity feeders to the MTM loading sites. The queue waiting for loading onto the MTM is expected to be on a first-come-first-serve basis, thus is dependent on the Business Model adopted. Additionally, the queue is expected to be by truck load to each MTM but, may be by priority assignment and is therefore, dependent on the Business Model adopted.
1.3.7	Loading/Unloading of MTM	This will be established by the completion of the Simulation Model. The Simulation Model will establish the number of MTM docks required to maintain optimal flow in the pipeline with reduced queue wait time.
1.3.8	Incoming Pallet ID and Distribution	Pallet ID will be tied to the trucking company, its bill of lading, time of day, customer destination, etc. Distribution will be determined by the destination terminal upon arrival. These pipeline internal decisions will be handled, maintained, and tracked by the C^3 system.

Table 1. Performance Specifications (continued).

1.3.9	Warehousing of Pallets	A minimum capacity of warehouse storage of pallets will be maintained by the terminal facilities for emergency use by the pipeline. Little to no customer storage is expected to be available at terminals. However, this functional requirement's ultimate specification is dependent on the Business Model adopted.
1.3.10	Outbound Movement to Truck/Rail Loading Bays	Pallets will be moved within the terminal by a combination of automated processes. The specifications of this function are independent on the final Business Model adopted.
1.3.11	MTM Storage/Maintenance Area	A substantial storage and maintenance facility will be required at the terminals to accommodate the fluctuation in quantities of MTMs as arrival rates vary throughout the day and week. The Simulation Model is expected to provide substantial insight into the quantity of MTMs needed to be maintained in a state of readiness for loading.
1.3.12	Terminal/Warehouse Building Structure	The specifications of the building are dependent on the final Business Model adopted.
1.3.13	Terminal Site	TBD – The site will be based on the extended life daily peak truck arrival and departure capacity anticipated by NAFTA traffic projections. Standard volume and parking capacities will be applied to determine appropriate estimates for the area required to be available for the terminal site.
2.1.1	Propulsion System	The preferred propulsion system is a linear induction motor system capable of the equivalent power of 800 horsepower. The propulsion system will provide the MTM acceleration and deceleration rates of zero to 60 mph and vice-a-versa in 30 seconds. Additionally, the system is required to maintain a continuous velocity throughout the transit period between terminals of 60 mph. This velocity is to be maintained regardless of up and down terrain. The linear induction motor system allows a 10 to one ration (10/1) of energy density for short periods of time (the duty cycle) which allows the MTM to essentially overpower itself during acceleration. This means the MTM actual motor density for constant duty can be 100 horsepower equivalent and meet the 800 horsepower needed for acceleration during the 30 second period required. All other periods of heavy acceleration will require substantially less than the initial power requirements, and duty cycle needs are not expected to be effected.
2.1.2	Braking System	Braking will be accomplished entirely through regeneration of electricity back into the power distribution system. When there is no alternative power required by the operating system, the regenerative braking energy will be dissipated in electrical resistor banks located throughout the system.
2.1.3	Onboard Control and Feedback System	This system is a part of and controlled by the C^3 system. A power supply for this system that is free from radio frequency noise is not yet clear but can be developed from standard power supply system available in the marketplace.
2.1.4	MTM – C^3 Interface	TBD – The MTM will be dependent on the C^3 system to maintain the minimum required separation distance of 325 ft between the rear of a lead MTM and the front of trailing MTM. The C^3 system will use an electrical feedback loop to monitor MTM speed and increase or decrease its velocity to maintain the separation distance.
2.2.1	Wheels and Running Surface	The steel wheel diameter is expected to be 24 inches with width yet to be determined, but expected to be 4 inches. The width of the wheel establishes the running surface wear rate due to wheel load.
2.2.2	Frame	The MTM frame is expected to be of twin beam design with lateral stringers to maintain lateral rigidity and enhance overall stiffness. The twin beam design will best accommodate the placement of the linear induction motors, provide a vertical cavity for the back-iron reaction plate and guideway device. The overall MTM system, including frame, motors, trucks, and aerodynamic skin will weigh approximately 40,000 lbs in fully operational configuration.

Table 1. Performance Specifications (continued).

2.2.3	Couplers/Connectors	The couplings at each end of the MTM will be designed so that either end can be coupled together using a pin type connection. This design will allow the coupling point to act as the suspension and pivot point for the truck. Additionally, in order to maintain even wheel and bearing load wear rates, the units need to be run in the opposite direction on the same path equally. If substantial continual running operations are allowed to take place, the MTM wheels, bearings, pivot points, and the running surface will take on a, “race track groove.” This “race track groove” phenomenon is known to cause excessive wear rates in bearings and wheels, substantially reducing life and reliability.
2.2.4	Pallet Mounts	TBD
3.0	Operating Power	The power supply for the pipeline system will be sourced from the private sector. The private sector power supply network is substantial with current deregulation projections estimating new generation capacity being added to the isolated Texas power grid in excess of 12,000 megawatts at 11 plant sites over the next two years. Over 50 % of this projection (6,600 Mws) is being added within the vicinity of the corridor selected for the freight pipeline. The current load requirement projection for the freight pipeline is less than 50 megawatts for propulsion needs. Other system power requirements have not been estimated. However, the total power load addition to the Texas grid is so small as to be insignificant from the position of the operation of the power network in the state.
4.2.1	Pre-tagging of Pallets	TBD – This refers to the possibility of having the shipper pre-tag pallets known to be destined for transfer to the freight pipeline system. Risk considerations such as security and theft continue to be under review.
4.2.2	Pallet Direction Through System	Because the pallets will be 48 inches square, there will be no requirement for directional placement or movement of the pallet.
4.2.3	Pallet Tracking Through System	Pallet tracking will be accomplished by the C^3 system.
4.3.1	Direct MTM Loading/Unloading	The MTM is expected to be automatically loaded and unloaded at the MTM dock. A specific system has not been identified for adaptation to the freight pipeline, but systems are becoming available for specialized material handling in the trucking industry. It is expected an adaptable system will be found in the near future.
4.3.2	Control MTM Arrival/Departure from Terminal	Arrival/departure of the MTM will be controlled by the C^3 system.
4.3.3	Control MTM Speed and Spacing within System	Accomplished by the C^3 system through feedback loops in the linear induction motor and wayside position detectors.
5.1.1	Foundation	The geological survey has been conducted and a comprehensive review of the survey findings is in progress. The pipeline foundation requirements are dependent on the geological characteristics in the selected corridor and the weight requirements of the tube structure. The static and dynamic loadings for the foundation are heavily dependent on weight per linear foot of the tube structure and are subsequently, yet to be determined. The dynamic loading portion due to the movement of the MTM is better understood at this time and is expected to be in the range of 17,000 + lbs/in^2.
5.1.2	Tube Structure	The pipeline tube structure will be required to provide full clear span support of the roof, prevent wall buckling due to hydraulic forces from the exterior of the tube due to rain water, clay movement during dry conditions, provide a solid base for a smooth running surface for the MTM, etc. All these loads and structural requirements to meet the loads are to be determined in Year 3.
5.1.3	Drainage	TBD based on analysis of the geological review. Drainage will be designed to move invasive water away from the conduit structure.

Table 1. Performance Specifications (continued).

5.2.1	Running Surface	The MTM running surface will be steel. The maximum static loading on the surface due to MTM and cargo weight will be 4,200 pounds per wheel, or considering the rolling cylinder contact for this diameter (24 in) and width (4 in) wheel and static loading, the stress will be approximately 17,000 + lbs/in^2. The exact configuration is irrelevant to this study as long as it is not an exotic configuration.
5.2.2	Clearance Dimensions	The overall internal dimension for the pipeline is expected to be 21 ft 4 inches wide by 10 ft in height. A minimum wall clearance to the moving MTM is 20 inches. The clearance between moving MTMs is 36 inches. The clearance between MTMs is considerably less than the wall to MTM, but because the incidence of passing is relatively infrequent compared with the total time of running and the relative turbulence effect is shown to be small in the aerodynamic study, the energy use will be insignificant compared to the overall cost extension to increase the pipeline width.
5.3.1	Entrance Portals	TBD
5.3.2	Utility/Ventilation Easements	Ventilation to meet this functional purpose means to exchange or to provide a reasonably normal ambient atmosphere in the tunnel. Some amount of ozone is expected to be generated in the tunnel by small but persistent electrical arcing through transferring power from the electrical distribution buss to the pick-up shoe or other moving connection on the MTM. Other noxious gases or fumes may collect in the pipeline and must be removed for safety purposes. The pipeline will require ventilation for worker occupation. A method to accomplish the ventilation function is yet to be determined. Utility support is primarily considered to be electricity and will require only small electrical substations to handle a combined 50 mile interval of the three hour peak traffic of 850 north and southbound MTMs. The potential occupancy at maximum density (Sim. Mdl.) occurs as the southbound traffic passes the northbound traffic 300 miles south of the Dallas departure point and 180 miles north of the Laredo entry at approximately 3:00 in the afternoon with 320 MTMs for the hour. There will be 267 MTMs between substations placed at an interval of 50 miles. Assuming a power factor of 0.6 for the system due to electrical operating factors, the system requires approximately 3.2 kilovolt amperes (KVA) (1,800 volt motors) per MTM occupancy. This amounts to 850 KVA per substation to maintain the 60 mph speed required for the MTM. This is less than one megavolt amperes (MVA), a very small energy requirement on an instantaneous basis.

CHAPTER 3 – BUSINESS MODEL FORMULATION

INTRODUCTION

The current study focuses on the technical and economic feasibility of an underground freight transportation system for Texas. A significant portion of this analysis hinges on if, and under what circumstances, a modal shift will occur with sufficient magnitude to support such a system and make it a viable adjunct to the freight transportation system in the state. There are different points of view as to how to best position a freight conveyance in order to maximize its chances of viability. These range generally from the extremes of private ownership, direct shipper contact, and competition with other modes to a publicly owned toll facility, operated by a public sector authority.

In collecting and sorting through a wide array of opinion on the matter, as well as determining what positioning of the system best achieves the goals of Texas, the research team is pursuing a business model that has the freight pipeline operating as an extension of the current freight transportation system. Among the goals set for the current research is the development of a freight transportation system that produces a favorable outcome for all the stakeholders concerned with the movement of freight in Texas, whether they are directly or indirectly involved. This strategy of producing a "winning" scenario for all participants determines, in advance, how the system will operate relative to the various interested parties.

The stakeholders identified as central to the success of the current concept include the following:

- the citizens of Texas,
- the Texas Department of Transportation,
- shippers, and
- the established freight transportation industry.

Achieving a positive result relative to an underground transportation system for all of these entities requires a business model that attunes to the particular needs and interests of each group. The challenge facing the research team reduces to how best to identify and address the critical needs of each stakeholder group without violating or voiding the needs of other interests. The first step in the formulation of a workable business model is, therefore, an articulation of each group's particular interests in freight transportation.

The Needs of the Citizens of Texas

Texans have historically enjoyed an extensive, high-quality highway system. TxDOT is viewed as a leader in highway design, construction, and maintenance, and the safety of motorists is continually the top priority of the department. The economic prosperity of the state is heavily dependent on the transportation system, and the movement of freight within Texas is viewed as the life-blood of a vigorous economy. The physical size of Texas and the rapid population growth over the last 10 years requires a roadway system that is daunting in its dimensions – over

77,000 miles of highway. This system must be maintained and, given the projections for the increase in population over the next 20 years, it must be expanded. The citizens of this state have an increasing awareness of the vulnerability of the environment to human activity, and the emphasis placed on environmentally sound transportation systems will likely increase as well.

These preeminent needs may be summarized as follows:

- the need for a safe and efficient transportation system,
- the need for a cost effective transportation system,
- the need for a transportation infrastructure of sufficient scope to support the economic goals and activities of the population,
- the need for a well maintained transportation system, and
- the need for an environmentally sound transportation system.

The Needs of the Texas Department of Transportation

The agency charged with designing, constructing, and maintaining the transportation system of the state, TxDOT, is a national leader in transportation innovation, organization, and expertise. As a department of transportation, TxDOT is charged with the all-encompassing responsibility for highways, aviation, rail, and waterways. The responsibility included passenger transportation and freight and extends to hosting a tremendous level of out-of-state highway traffic generated by the NAFTA trade with Canada and Mexico. Operating under the budgetary constraints imposed by the legislature, the department must balance the maintenance requirements of the current system with the needs of expansion, while attuning to the critical needs of safety and system reliability. The department routinely reports that it funded at levels far below the state's requirements.

TxDOT summarizes its needs as follows:

- the need for sufficient funding levels to ensure a safe and efficient transportation system,
- the need for sufficient funding levels to attune to system expansion requirements,
- the need for sufficient funding levels to attune to maintenance requirements,
- the need for measures to reduce the maintenance needs of highways, and
- the need for environmentally sound transportation alternatives.

The Needs of Shippers

The movement of goods and materials between economic centers, markets, and consumers, represents the lifeblood of the nation's and the state's economy. The transportation needs for this fundamental human activity are basic to the health and vitality of all businesses. Transportation, as a cost of doing business, must be efficient in order to promote trade and economic activity. Shippers continually seek the most cost efficient means to transport goods to market and vigorous competition within and between modes drives transportation systems toward innovation and efficiency. Shippers also require varying degrees of safety and security in their transportation selections. Damage to goods in transit adds to the cost of business and directly reduces profitability. Shippers also desire reliability in the transportation services they select. The competitive nature of business means that viability depends on customer satisfaction and repeated business transactions.

The needs of shippers may be summarized as:

- the need for low-cost transportation services,
- the need for a high-performance service,
- the need for high-reliability transportation, and
- the need for safety and security of goods in transit.

The Needs of the Current Freight Transportation Industry

The current freight transportation industry is a complex mixture of transportation modes, service offerings, and market service strategies. The industry is characterized by high levels of competition, both within, and between modes. The net result of this fierce competition is sensitivity to changes in cost structure and low profit margins. The freight transportation industry, with the exception of rail, is a publicly supported undertaking. The highway system, waterways, and airports are financed and maintained by the public sector with varying levels of contribution by the freight industry. The industry transports the raw materials, agricultural products, and manufactured goods necessary for life in a modern culture. The industry requires a safe and reliable infrastructure on which to operate, reliable systems with which to move commodities, workers, and management to effect operations, and shippers willing and able to buy their transportation services. Cost and performance, coupled with a sound operating strategy are usually the determining factors in whether a freight transporter thrives or fails.

Among the needs of the freight transportation industry are:

- a safe, sound, and reliable transportation infrastructure,
- an available source of reliable personnel,
- an operating margin sufficient to provide an operating profit, and
- equipment with which to transport the shipper’s goods and materials.

The Freight Pipeline System as an Extension of the Existing Freight Transportation Industry

In order to address the various requirements identified above, the formulation for a transportation system must include characteristics that allow it to fit into the existing freight transportation framework. A concept central to the viability of the proposed underground freight system is that the freight pipeline system operates as an extension of the existing freight transportation system rather than as an alternative competitive element. It is generally accepted that from a transportation perspective shippers are most concerned with price and performance, and that any mode offering an improved price/performance package will gain support from the shipper community. It can be concluded that everything else being equal, shippers are relatively indifferent to the mode that transports their goods. Thus, the customers for a freight pipeline system, while comprising the shippers indirectly, are the existing freight transportation companies.

While early in the formulation phase, it appears, based on discussions with representatives of select firms in the motor freight industry that if financial gain is involved, whether from savings in time or money, support for an alternative form of transport will be forthcoming. Given the fact that a fixed-in-place system such as the freight pipeline must have goods delivered to it by some other conveyance, it seems most expedient to induce use of this sector through alliance and financial incentive. If the freight pipeline can deliver goods with a price/performance package that is superior to that achievable in over-the-road transport, then use at some level seems more than just plausible. The target performance parameters of the freight pipeline being considered during design are included with this objective in mind.

The target design speed of 60 mph and the cost per ton-mile of less than $.10 per ton-mile would assure that the system was attractive to the trucking industry. One caveat should be stated here that will receive a considerable amount of attention in the coming year's work plan, namely the inherent requirement for an additional trans-loading sequence in the shipment of goods. In order to use the freight pipeline, each truckload of goods will require handling an additional time to remove the material from the truck and load it into the MTM. Terminal design and material handling techniques and technology will be critical in overcoming these additional steps in the process. Time appears to be on the side of the freight pipeline, however, since projections suggest that transit time in key NAFTA corridors will only increase over time with increasing congestion.

Thus, the business model conceived for the freight pipeline achieves for the trucking industry several of its needs. By locating a northern terminal in the vicinity of Dallas/Ft. Worth, those shipments bound for Mexico along the IH-35 corridor can choose to terminate there and finalize their transport of goods through the freight pipeline at a higher performance level than achievable over the road and at a lower cost. At the same time, the trucker may collect a return load and initiate the second leg of his transport cycle while the first leg is still being completed.

The benefits are twofold:

1. The first leg of the freight transport transaction can be completed faster and at a lower per unit cost than possible by traditional over-the-road movement, allowing a greater profit margin for the carrier and an improved competitive position due to better performance reliability and the potential to pass a portion of the cost savings along to the shipper.

2. The carrier may initiate the return leg of his trip while the first leg is still underway, improving productivity, equipment utilization cycles, and reducing wear on consumables, such as tires, engines, and brakes.

The appeal of 24-hour a day, all-weather operation combined with shipment security and ride quality is central to the business model formulation. Also key is the definition of the carrier as the principal customer. The shipper, unless operating its own dedicated fleet, would not become directly involved in a transaction with the freight pipeline. This approach ensures delivery of material to the freight pipeline and allows the system to achieve a principal aim – mitigation of trade-related truck traffic. The freight pipeline's north-south orientation and its trans-Texas positioning also accomplish an important aim for Texas and TxDOT, that of minimizing the use of Texas' highways by out-of-state trucks. The affect of the pipeline could be positive on reducing the numbers of Mexican trucks on Texas roads, as well, by displacing the need for trucks at the border to northern regions of the state. Transit of goods to their ultimate destination could be expedited in the same fashion as previously described, namely faster and at a lower cost.

The remainder of the business model, particularly terminal ownership and operational management, continues to be formulated as more information is collected. A review of the needs of each stakeholder, however, highlights how the current business model formulation addresses the needs of each. The general goals shared by each stakeholder group include the need for a transportation system that is safe, efficient, cost effective, and environmentally sound. By maximizing the use of an alternative system by trucking and other freight interests, the existing highways system may be better able to serve motorists and other users. Fewer trucks on the highway may translate into lower maintenance expenditures and less frequent repair. Reducing mobile emission sources may positively impact air quality.

Remaining Questions

Two central questions dealing with the viability of the freight pipeline concept remain to be addressed. The first has to do with whether the system is cost effective – is the cost per unit of freight transported better than that achieved by conventional transportation systems – road and rail? The second question pertains to the impact of the freight pipeline system on the overall transportation system – can a dedicated freight system, employing state-of-the-art automation and control systems, designed to facilitate the rapid movement of goods, mitigate enough trade-related freight traffic to warrant its construction? These questions are at the forefront of the research remaining in the investigation of underground freight transportation and will be addressed in detail in the proposed Year 3 work plan.

CHAPTER 4 –MAIN TRANSPORT MECHANISM (MTM) DESIGN ISSUES

OVERVIEW

A central component of the freight pipeline is the MTM. The MTM will be the vehicle that actually accomplishes the task of transporting goods from one end of the freight pipeline to the other. While a complete, detailed design of the MTM will require significant engineering, it is possible to discuss issues relevant to MTM design and from this discussion develop a conceptual design for the MTM that includes approximate component characteristics and weights. These estimates may then be used to derive an approximate cost for the MTM as well as in other analyses of a freight pipeline system.

At the most basic level, the MTM must offer a level of performance and efficiency that meets the needs of the overall freight pipeline system. Such performance requirements include design speed, cargo capacity, ride quality, long-term maintainability, energy efficiency, reliability, cost, and safety. In addition, any MTM design must be easily mass-produced.

The needs for proven reliability, known performance levels, and economy suggest that, wherever possible, MTM components should be based on existing technology that has been successfully implemented in other large-scale applications. Non-traditional technology will only be considered where it can be shown to offer clear and extensive benefits to the freight pipeline.

Any MTM design must meet certain fundamental parameters. Since the freight pipeline is intended to be equivalent to truck-based freight transportation, it is assumed that an MTM unit will handle a volume of freight that is similar to that handled by a truck. In particular, each MTM unit is expected to carry up to 25 or 30 pallets. Cross-sectional area and the associated air drag will be minimized by placing pallets on the MTM in single file. In order to be able to negotiate curves, the MTM will follow the model successfully used by America's freight railroads, i.e., the articulated five-member car. The entire MTM will be long enough to accommodate all of the pallets as well as necessary drag-resisting front and rear-end treatments outlined in the aerodynamic analysis conclusions. Therefore, each MTM car will be 30 ft to accommodate six pallets on each articulated member. The front and rear members will be the same as the other members. The lead and trailing trucks for these members will be specially designed to carry out the functional requirements of their individual assignments. The lead and trail trucks will need to fit the articulation joint while maintaining single point – end of car – support and steering functionality. Additional length will be taken up by the "nose-cone" low aerodynamic drag structure. It is assumed that the propulsion system and control components will be located on the underside of the MTM.

Propulsion

Two reasonable choices for an MTM propulsion system appear to exist. The first, more conventional approach is a standard axle slung rotating motor with a motor pinion and axle bull gear, traction motor type system. The second approach is a linear induction motor (LIM) which, while less conventional, appears appealing given the specific parameters of this situation.

The concept of the axle slung traction motor is typical of railway type equipment throughout the world. Such a system for application on the MTM would be conventional in nearly every respect. The power required to accomplish the acceleration and 4 percent grade negotiation without losing speed is a total of 840 horsepower. The tractive effort (TE) necessary to initiate acceleration of the fully loaded MTM is 65,000 lbs. Given the maximum speed of 60 mph, tractive effort of 5250 lbs is readily met with the MTM tare weight of 30,000 lbs. Tractive effort considerations are necessary when anticipating moving empty MTMs through the system. The motors with their associated mounting equipment are expected to weigh as much as 40 percent of the necessary tare weight to accomplish tractive effort requirements.

Rotating electric motors are historically reliable machines. However, the reliability and low maintenance requirements for the MTM cause concern about service inspection and life cycle longevity concerns related to the bearings of rotating motors. Since the MTM operates in a totally unmanned configuration, maintenance inspection requirements for motors present a serious reliability issue at some point in their operating life cycle. A rotating motor failure on an MTM in the pipeline will potentially cause the entire system to come to a stop.

When a rotor (the rotating part of the motor) starts to have varnish breakdown between laminations, the rotor will begin to experience localized heating as the patch increases in size between the laminations. Additionally, the heating can cause varnish breakdown between adjacent laminations, causing yet more heating. When this breakdown becomes extreme, an uneven magnetic flux distribution occurs as the moving rotor cuts through the magnetic field in the motor. If the effect continues to grow, the motor can experience an out-of-balance condition and rapidly destroy the motor's bearings. When the bearings fail, the motor can easily seize and freeze the axle gear to the motor gear causing the whole MTM to stop.

A less conventional LIM system for the MTM could provide the MTM with a self-guiding propulsion system. In fact, the LIM approach has such promising side benefits that its inclusion in the MTM is likely to be the preferred system for providing propulsion. These benefits include:

- The LIM has no moving parts, therefore no motor wear is anticipated.
- Electrical breakdown continues to be a potential with the LIM, however this potential is currently thought to be less than with conventional rotating motors.
- LIM has no requirement for adhesion to have tractive effort.
- Grade restrictions do not exist in the practical sense because the LIM can move vertically if supplied with sufficient power.
- MTM speed is not limited by motor speed, i.e., the conventional rotating motor introduces vehicle speed limitations due to the angular velocity limitations of rotating motor construction.

In the case of LIM the opportunity does not exist for potential forced stops due to motor failure. With LIM technology, electrical failures can occur, and some may present situations not yet recognized or understood. However, one or several motor failures on any MTM unit will not cause the unit to stop in the pipeline. Additionally, the other motor windings on the LIM equipped MTM will "pickup the slack" by increasing the current draw and maintaining the

MTM's required speed. This presents a major benefit for considering the use of the LIM technology in an unmanned remote system.

Negative acceleration (braking) in the pipeline is expected to be accomplished by switching the motor from a consumer of electricity and making it a generator of electricity. By converting the potential energy of the moving MTM into electricity the MTM's speed is given up. The electricity generated is directed back into the electrical distribution system in the pipeline for use by other MTMs. The speed can be reduced slowly or very fast by first changing the direction that the motor current flows and then by simply increasing or decreasing the current demand in the winding of the motor.

Suspension and Running Gear

One of the most critical aspects of the MTM design will be the suspension system. This system must afford a ride quality comparable to that of highway truck trailers at speeds of 60 to 70 mph. These requirements are necessary to ensure that the MTM is functionally competitive with other means of handling palletized freight. Furthermore, this system must be reliable, require little maintenance, have a long design life, possibly as long as 50 years, and contribute to energy efficiency. These factors will directly contribute to the operational cost-competitiveness of the freight pipeline system.

A variety of suspension-running gear systems can be envisioned that are functionally competitive. For example, Mag-Lev systems offer superior ride quality and very high operating speeds. Rubber tire systems offer improved traction and ride quality. However, when economic competitiveness is considered as well, many functionally competitive schemes become unfeasible. For instance, the lack of examples of successful, large scale Mag-Lev implementations, coupled with the cost of such a system and the fact that its performance would far outpace that required in this application, render Mag-Lev type systems infeasible. Similarly, the high-maintenance requirements and reliability issues associated with rubber tire type approaches appear to preclude such systems from being considered. In fact, it appears that a traditional steel wheel-steel rail type system is probably the system that most generally contributes to all aspects of functional and economic competitiveness.

Suspension systems must be considered carefully. A survey of available information indicates that the design of these systems is relatively complicated and subtle. At the same time, this system is central to the success of the MTM system. Given both the complexity and the criticality of a suspension system, it is suggested that a qualified expert is required for any detailed, proper discussion or design of an MTM suspension system. Not withstanding this requirement, it is still possible to make some preliminary remarks regarding a suspension system.

The first aspect of suspension design that must be considered is the functional requirements that interact with a suspension design. Obviously, ride quality requirements must be established. Ride quality requirements must describe maximum allowed levels of displacement and acceleration permitted due to transient, shock load induced vibration, steady-state vibration present during smooth rolling, and vehicle rotation about all three vehicle axes. Because different suspension system types are effective at different operating speeds, the MTM speed of operation must be considered. Other important parameters must also be considered. In particular, durability levels, acceptable maintenance levels, and levels of operation delivered during overall system failure (for example, how does an active suspension system fare during a power outage) must all be established. In addition, the costs associated with the suspension system must be considered. Costs include initial investment, operating costs associated with active type systems, and maintenance costs. Finally, a suspension system must not interfere with the propulsion system. If a linear induction propulsion system is chosen, a vertical center rail is expected to be present underneath the MTM that will pass through and be part of the LIM. This center rail is continuous and will likely project some distance above the running surface. As a result, the suspension system may have to work around the projected area of this center rail.

A more subtle parameter that must be considered is the range of possible MTM weights that may exist during operation. This range may result from variations in both cargo weight and utilization levels. Often, a suspension system design is matched to a specific vehicle weight range where it gives optimum performance. If the range of possible MTM weights during operation is large, it may become difficult to design a suspension system that meets other performance requirements over the range of all possible operating weights. An additional problem is posed by the ratio of unloaded vehicle tare weight to loaded vehicle gross weight. Even if the freight pipeline is operated in an "on-demand" manner in which only loaded MTM units traverse the conduit, one must still consider how sensitive MTM loading mechanisms will be to MTM settlement. If the tare to gross weight ratio is low, the displacement of the suspension during loading could exceed the tolerances in which an automated loading system could operate efficiently, thus dictating additional support systems at the loading and unloading bays. In addition to a well planned suspension design, one approach to mitigating the impact of weight ranges and weight ratios is, rather than minimizing vehicle tare weight, determined by an optimal vehicle tare weight which is not necessarily the minimum possible weight. This heavier tare weight would reduce the proportional increase in load induced on the suspension system by cargo weight.

Although more energy may be required to handle a heavier vehicle, performance improvements and cost savings achieved through suspension system simplifications may justify this increase in vehicle weight. As a result, an optimum vehicle weight may be found. (The additional energy cost is minimal on a per ton mile basis to the overhead cost of moving the MTM, that is, the overhead cost exceeds 1 kwh per mile for the movement due to acceleration and drag while the cost per ton mile in energy is only 0.0072 kwh. Subsequently, an increase tare weight of 10 tons for suspension considerations adds only 0.072 kwh energy requirements per mile moved. Such an overhead may be very economical considering reliability issues, maintenance, and life-cycle costs.)

Having established some of the basic issues relevant to suspension system design, it is possible to now turn attention to consideration of specific system types. While information regarding suspension system design was difficult to find, one article by J.F. Thring demonstrates the difficulty involved in suspension design and also offers some insight into a suspension solution for the MTM (*1*). Thring discusses attempts made by British Railways to design railcar suspensions capable of handling speeds of 75 mph. The railcars considered by Thring have weights ranging from approximately 40 to 100 tons. Although individual MTM vehicles are envisioned to have weights ranging from 40 to 50 tons, Thring's illustration will still be meaningful, as he considers systems with similar operating parameters and order of magnitude similarities in weight. One might disregard Thring's study as old and outdated. However, rail technology is slow to change and a realistic MTM suspension system should be based on existing technology. Therefore, we conclude Thring's study is relevant. Furthermore, Thring's report is meant only to offer insight. A thorough MTM suspension design will have to be performed at a later date (*1*).

Thring discusses the performance of both two-wheel single-axle suspension systems and four-wheel bogie suspension systems. Photographs of these two types of suspension systems are shown in Figures 1 and 2. Implemented, two-wheel single-axle systems appear to have a limited load capacity. Thring discusses systems used in handling loads up to 22.5 tons/axle. Since MTM systems can be anticipated to weigh at most 50 tons, it appears that existing single-axle suspension systems exist which can sustain the necessary loading levels. However, it is not clear that single-axle systems can meet necessary performance standards. In particular, Thring implies that single-axle suspension systems have not offered good performance at the speeds required by the MTM. At these speeds, it appears that problems develop in controlling the behavior of both the single-axle pedestal mounted wheel set relative to the track and the vehicle relative to the wheel set. In addition, the systems studied by Thring rely on leaf springs and various mechanical links that are reported to lead to performance and maintenance problems. In particular, the systems do not respond well to component wear or manufacturing variation. While it is possible that an MTM suspension system could be developed based on a two-wheel double-axle vehicle concept, it is appears that such a system would need to be very well thought-out and thoroughly tested prior to full-scale implementation (*1*).

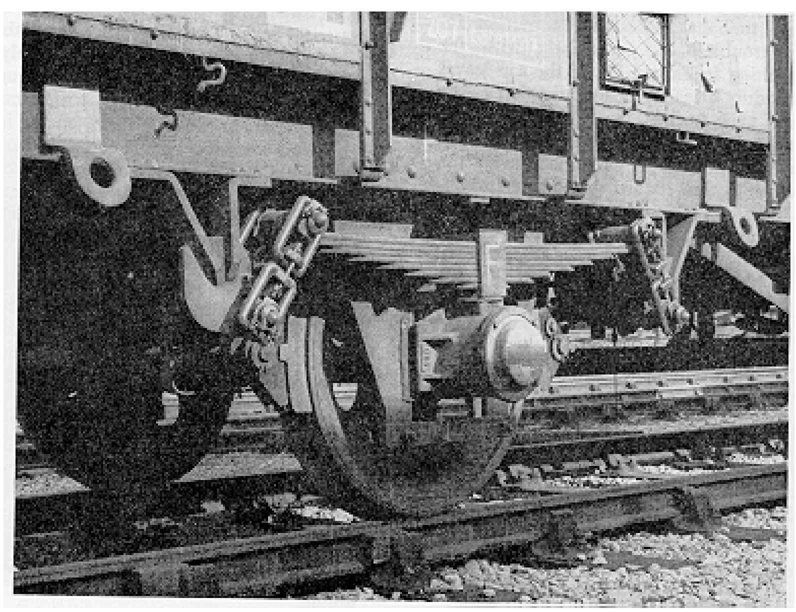

Figure 1. Single-Axle Suspension System.

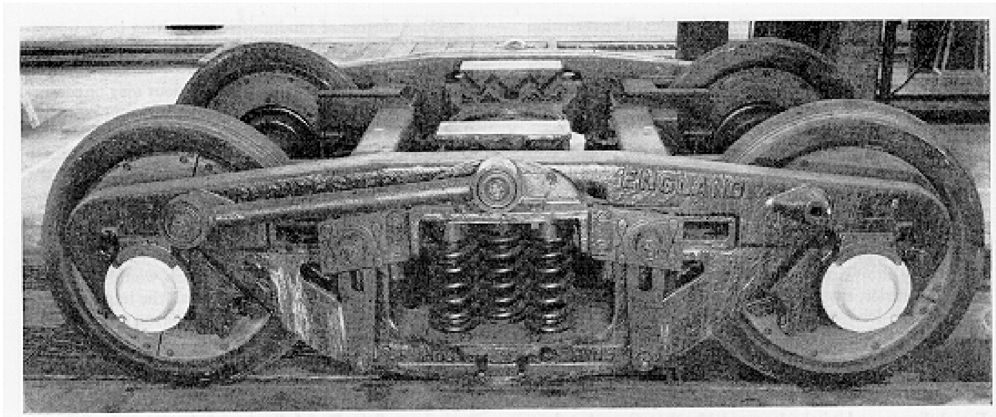

Figure 2. Bogie Suspension System.

With regard to bogie type suspension systems, Thring states that "it has long been appreciated that bogie vehicles are more attractive (than two-wheel double-axle vehicles) at higher speeds" (*1*). Bogie systems are better suited for negotiating curves, do not lead to as many of the instability modes inherent to single-axle systems, and have better vibration damping properties. Existing bogie technology in the United States is regularly used in operating systems where speeds of 60 to 70 mph are achieved.

One possible problem with existing bogie suspensions is the fact that these suspensions may only be economical for vehicles that are 50 to 100 tons in weight, whereas the MTM units are likely to be between 30 and 50 tons in weight. One possible design approach which allows the MTM to use proven, existing bogie suspension systems normally used on railroads, is depicted in Figure 3. In this approach, bogie wheelsets are shared by neighboring MTM units. This approach not only enables existing technology to be utilized, but may also mitigate certain types of vehicle rocking instability and may reduce the number of moving parts, and accompanying maintenance costs, associated with each MTM unit.

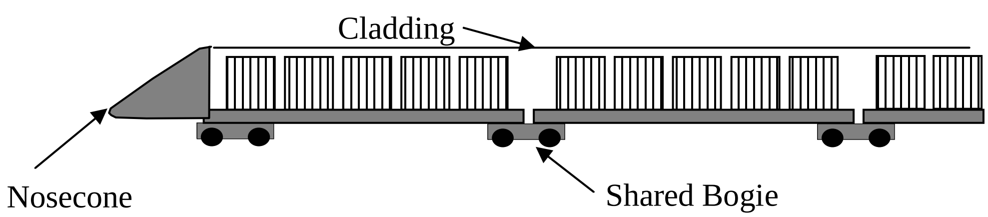

Figure 3. Shared Bogie Suspension Arrangement.

Clearly, a much more detailed assessment of potential MTM suspension designs is necessary. The purpose of this discussion has been merely to point out key issues, demonstrate the need for a well thought-out and proven design, and offer some preliminary approaches.

Fuselage/Cladding

A fuselage or cladding type system is necessary both to contribute to favorable MTM aerodynamics and to protect MTM cargo from wind buffeting that will occur at operating speeds. Two general types of cladding systems are possible: 1) those that are an integral part of the structural system, and 2) those that are separate from the structural system.

Structural cladding will lower the tare weight of the MTM unit by serving both as a structural element and a cladding element. In addition, the membrane and truss type structural systems that may result when structural cladding is used are often more rigid than the simple beam type systems that will likely result when nonstructural cladding is used. However, the benefits associated with structural cladding come with direct consequences. For instance, if structural cladding is damaged during loading and unloading operations or succumbs to vibration or buffeting induced fatigue failure, both of which are not unlikely events during the long projected design life of the freight pipeline system, the entire MTM vehicle will be structurally compromised and will have to be taken out of service for repair. Furthermore, with structural cladding, access for loading/unloading must be more carefully thought-out because no option exists for portions of cladding to be removed to facilitate these operations, as all cladding must be present at all times in order for the MTM to sustain loads during loading. Also, MTMs with structural cladding will be designed with a specific cargo geometry in mind, so that the MTM may not be easily adapted in the future to handle other types of cargo geometry without extensive refitting. While the freight pipeline in question will most likely handle a consistent cargo type over the long-term, the inflexibility of a structural cladding based system should still be borne in mind.

A nonstructural cladding system avoids many of the problems associated with a structural cladding system. Because it is not an integral part of the MTM structure, it can be removed to facilitate loading and unloading. It can also be replaced quickly and easily when it wears out or is damaged. Also, because it is not relied upon structurally it does not have to be designed with long-term structural reliability in mind. Instead, it need only be sturdy enough to serve as an effective streamliner. As a result, nonstructural cladding will likely be less expensive, more serviceable, and more accommodating to freight handling operations.

Of course, nonstructural cladding systems have their own drawbacks. Primarily, nonstructural cladding may be flimsier and less durable than structural cladding because it need not meet the design criteria that a structural cladding system has to meet. However, less sturdy components do not necessarily translate into inadequate performance or design life. For example, many automobile cladding components are nonstructural and do not wear out prematurely. Furthermore, when these automobile components are damaged they often do not interfere with vehicle operation and can be easily repaired. Although nonstructural cladding is not as structurally efficient, it is proposed that any resultant gains in vehicle weight are negligible when compared to the operational benefits derived from a well-designed nonstructural cladding system.

In either case, the cladding system must allow full access to the MTM cargo space. Access implies the cladding must be moveable. A moveable cladding system for the MTM must be considered to be automated and operate at high speeds to accommodate the unloading and loading process for the MTM to clear the terminal area. This further implies the cladding support structure and automation equipment will require maintenance.

Structure

The MTM's structural frame must be able to carry the weight of the cargo, any vehicle loads (such as the propulsion system), and its own weight without excessive levels of static deflection. Furthermore, it must offer adequate dynamic performance. In particular, resonant vibrations are to be avoided. It must have a fatigue life that meets or exceeds the intended operating life of the MTM. It has been pointed out that a nonstructural cladding system is likely to be preferable. Furthermore, a relatively open load surface is probably preferable, so that loading and unloading operations are faced with the least amount of constraints. As a result, while a frame-type structural system might offer better rigidity at a lower weight, a beam-type flatbed system is probably necessary from an operational standpoint.

A flatbed structural system could be made in many ways from many different materials. Steel is a very likely candidate and is used for a wide variety of industrial transportation applications. One could envision a stamped steel structural system, similar to an automobile frame, as one manufacturing approach. This approach allows the structure to be custom formed to the most efficient layout. In addition, because it is automated, this approach promotes economy and quality.

Having noted the likely use of a stamped steel frame, an estimate of structural weight was obtained for this report based on a frame span built using rolled steel components. Because this structural weight estimate is extremely preliminary in nature, such a substitution is reasonable. Only the span weight is estimated, and only strength requirements are satisfied. An actual structural weight is assumed to be twice the weight required for the span to support the load from a strength standpoint. It is assumed that the adjustment factor will account for several things. First, it will account for the weight of cross bracing, lateral components, and other structural components. Second, it will account for additional span weight that is incurred as deflection, vibration, and fatigue requirements are satisfied. It is assumed that I-shaped sections will be used. While the resulting estimate will be approximate, it will be reasonable and should be achievable.

Two cases are considered and are depicted in Figure 4. In the first case, each vehicle has its own pair of wheelsets. A 1-pallet width backspan is assumed. While the structural weight is only calculated for the worst load case possible, all load placement possibilities were investigated.

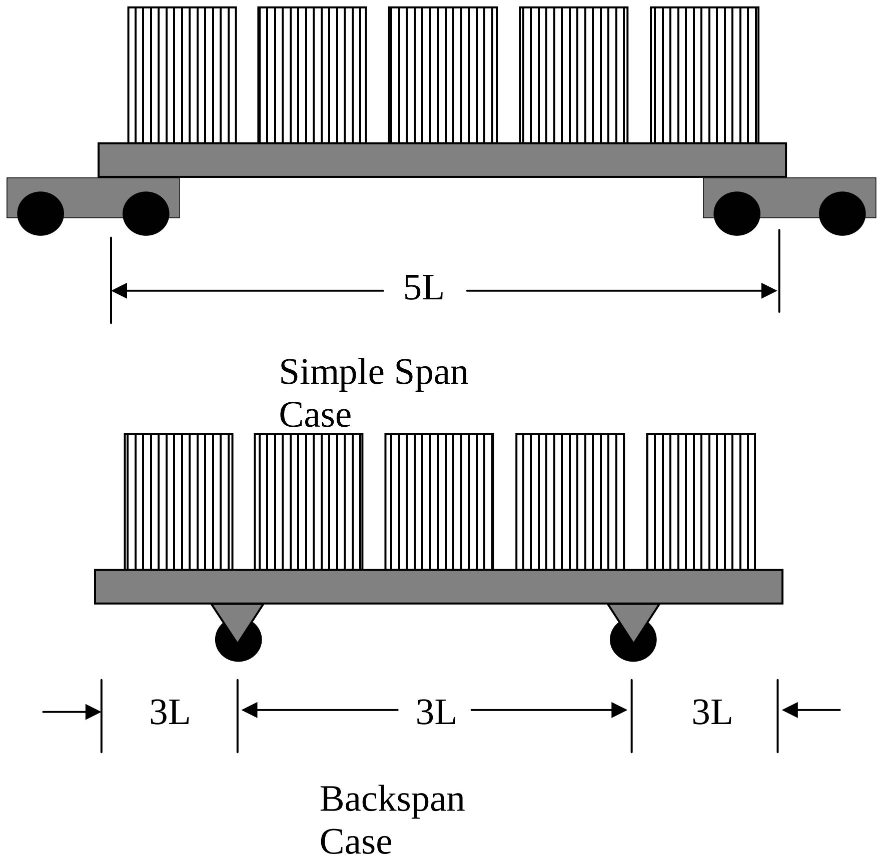

Figure 4. Structural Cases Investigated.

While it was earlier stated that the MTM is assumed to be between 25 ft and 30 ft for 5 or 6 pallets respectively, in this analysis it is assumed that each pallet occupies 5.6 ft rather than 5 ft so that clearance exists for the purposes of loading and unloading. This distance corresponds to *L*. It is assumed that both span types are pin supported. The cargo is transformed into an equivalent distributed live load of 500 lb/ft. The self weight of the span members is assumed to be 1000 lb. The weight of other structural components (bracing, lateral members, etc…) and other MTM components (motor, control systems, etc…) is assumed to be 2000 lbs. This 3000 lb total dead load is represented as a uniformly distributed load of 110 lb/ft. In reality, much of the live and dead load may be concentrated in nature, but for the purposes of a very rough initial assessment a distributed load assumption is reasonable.

The conservative load case for the simple span situation is one in which the MTM is fully loaded. In this case, the maximum bending moment is 60 k-ft and occurs at midspan. To account for the fact that the structure must satisfy vibration, deflection, and fatigue limitations this load level is doubled. While these limitations are often not expressed in terms of load, it is reasonable to assume that a vehicle designed to handle twice the normal static load should be roughly the same weight (or more) of a vehicle which has been specifically designed to satisfy these criteria. As a result, the weight of the simple span case is estimated using a bending moment of 120 k-ft. Although shear is also present, it typically does not control the final design and so is not considered here.

The conservative load case for the backspan situation is the one in which the middle three bays of the MTM are occupied by pallets, and the endspan bays are empty. In this situation, the peak bending moment is 20 k-ft and occurs at midspan of the middle bay. The bending moment used for the estimate is 40 k-ft.

Structural weight is estimated by assuming a 50 ksi structural steel shape is used. I-shape American Institute of Steel Construction (AISC) wide flange beam structural shape sections are assumed. While structural steel shapes are typically used in building construction, and stamped steel frames are used for vehicles, the frames of heavy-duty vehicles such as the MTM are composed of steel sections roughly equivalent to structural steel shapes. The weight estimates obtained here are likely conservative because they assume a constant beam cross-section is used throughout the length of the MTM. In this design approach the structural shape is sized such that it can withstand the largest load which occurs along the length of the vehicle. However, this largest load is often localized, and a variable cross-section framing system can significantly reduce structural weight.

Several different weight estimates may be made for a given case. One may either minimize structural weight or structural height (to minimize air drag). The AISC shapes that satisfy each minimization are presented in the referenced manual (*2*). In addition, one may consider a frame with one, two, three, or more beam members. By increasing the number of beams, one decreases the load on each beam, thus using a shorter cross-section. AISC cross-sections generally do not come shorter than 4 inches, although one could envision using shallower custom-made members in this situation. Table 2 presents the results obtained for the simple span case. Table 3 presents those found for the backspan case.

Table 2. Estimated Weights for Simple Span Case.

# of Beams	Parameter Minimized	Solution	Beam Height	Weight/Foot (lb/ft)	Total Beam Weight (lb)
1	Weight	W14x26	13 7/8”	26	728
1	Depth	W8x35	8 1/8”	35	980
2	Depth	W6x25	6 3/8”	25	1400
3	Depth	W5x19	5 1/8”	19	1596

Table 3. Estimated Weights for Backspan Case.

# of Beams	Parameter Minimized	Solution	Beam Height	Weight/Foot (lb/ft)	Total Beam Weight (lb)
1	Weight	W12x14	11 7/8”	14	392
1	Depth	W5x19	5 1/8”	19	532
2	Weight	W6x9	5 7/8”	9	504
2	Depth	W4x13	4 1/8”	13	728

In examining these results, it is clear the backspan case is more structurally efficient. However, a savings of 500 to 1000 lbs per MTM may not be worth the added complications encountered in the suspension system. In fact, recall that low vehicle weight may not benefit ride quality and that energy efficiencies of loaded vs. unloaded systems like the MTM are not always intuitive. Also note that the structural weight estimates obtained here are extremely rough. Considerable flexibility exists in any design that is based off of these estimates. Where it turns out that nonconservative assumptions have been made, extra capacity can probably still be obtained by improving the efficiency of other aspects of the design.

Conclusion

This discussion has not sought to provide even a rough design of the MTM. Such an effort requires a team of engineers armed with more detailed information about required operating parameters. Instead, this discussion has attempted to better define what parameters are important and to present seemingly viable options which utilize existing technology.

One general estimate remains. In order to make estimates about other systems, it is important to know the rough weight of an entire MTM unit with five cars. A clear set of boundaries on the weight can be achieved if one considers that the cargo itself will have a total weight of approximately 50,000 lbs. The MTM with cargo will not weigh less than this lower bound on weight. For an upper bound, consider that highway tractor-trailers have gross weight of approximately 100,000 lbs., and a tare weight of 50,000 lbs. While an entire MTM unit (composed of five cars) could conceivably weigh more than 100,000 lbs. this case seems unlikely given the fact that the MTM does not need to contain the weight of the cabin and other extensive driver related facilities. In addition, the MTM probably doesn’t need to have cladding that is as durable as that found on semi-trailers. Therefore it seems reasonable to assume that 100,000 lbs. is a reasonable upper bound on the MTM weight. In fact, the MTM weight will be much closer to the upper bound of 100,000 lbs. than it will be to the lower bound because the MTM must still support its cargo load and offer a ride quality comparable to that of a tractor trailer. Perhaps a rough estimate of 80,000 to 90,000 lbs. for the gross weight of an MTM (containing 25 pallets) is reasonable.

CHAPTER 5 – ELECTRIC UTILITY DEREGULATION IN THE U.S.

BACKGROUND

Three factors prompted the research team to undertake a close examination of the electric utility industry in Texas. The first factor was the selection in Year 1 of a linear induction propulsion system for the MTMs. This propulsion system derives its power from electrical energy, presumably supplied by either a commercial source or generated from a power plant dedicated to the freight pipeline system. The second factor motivating this examination was the deregulation of the electric utility industry, undertaken to allow market forces to exert their influence on supply and demand. This change would alter the dynamics of an industry that had been highly regulated for an extended period of time. The hoped-for outcome would be greater supply and lower prices for consumers.

The final factor motivating the examination of the utility industry, closely related to the second factor, was the highly publicized power shortages in California in 2001, where insufficient electrical generating capability forced periodic blackouts in much of the state. These shortages were accompanied by large price increases and a significant public outcry charging various parties with mismanagement or profiteering.

The obvious question, given California's unfortunate circumstance was, "what is the current and future status of Texas with regard to deregulation of the electrical utility industry?" In the context of a feasibility study, it is critical to understand the issues surrounding a principal assumption. If Texas is not likely to have enough power at a reasonable price for the level of use projected with the freight pipeline, then significant changes would have to be made in the design parameters previously established. Thus, TTI undertook an unscheduled study of the electrical utility industry to better understand the structure, dynamics, and forces at play that will determine the supply and price of energy in Texas in the years to come.

THEORY

We have heard the theory so often that it sounds self-evident: "Competition lowers prices and improves service" (*3*). Unfortunately, while this statement is usually true, it relies on the assumption that if an open market is available, companies will compete for control over it. In reality, the fact that a market is open does not necessarily mean there will be a rush of suppliers fighting over the newfound demand. Some industry leaders are concerned that rural electric consumers may find this out the hard way in a newly deregulated industry.

At this point, there are few who doubt that deregulation in some form or fashion will take place across the United States within the next few years. What is not certain, though, is the form that deregulation will take and its ultimate effect on consumers. It is especially important, therefore, for rural consumers to closely watch the coming discussion of electric industry restructuring.

The electric industry has historically been a regulated monopoly system. Consumers have had access only to one electricity provider (*3*). Likewise, utilities have been obligated to provide electricity to everyone in their service area. Regulatory agencies have been responsible for determining a utility's service area and the price that the utility may charge its consumers for electricity. The government, industry, and residential electric consumers have long considered this arrangement to be the only way to guarantee reasonably priced electricity for all American consumers. In recent years, thinking has changed, and many now believe that pressure of market competition would more effectively ensure lower prices (*3*).

While consumers in the restructured industry may be able to buy their electricity from any number of sources, their power will be delivered by the electric company with which they now do business. Consumers will still rely on their local utility for line repair and maintenance, new service connections, new construction, and line extensions. This dependence is because these functions are performed by a "distribution of utility," and distribution companies will remain regulated monopolies. Consumers will soon be able to choose who generates the power they buy. It may seem a difficult distinction to make because at this point in time everyone buys power from a common distribution utility. No distinction is made on electric bills to tell the consumer that they are paying for service as well as energy. The cost of service is built into the per-kilowatt-hour rate each consumer pays.

When restructuring is completed, electric bills may reflect a flat rate for line service, similar to the flat rate paid for local telephone service. Another possibility is that some services will continue to be billed on a per kilowatt basis with separate line items for service cost and energy cost. It is very likely that consumers will receive at least two electric bills: one from the distribution (and transmission) utility responsible for power-related services and one from the company that generates the power itself. Everyone involved in the restructuring process agrees that changing the industry will be complicated, and at times confusing, for consumers. Some issues will be settled before restructuring takes place, but the results of a competitive retail market are difficult to predict.

While it is possible that all consumers will eventually benefit from electric competition, conventional wisdom suggests that sparsely populated rural areas will be the lowest priority for electric marketers (*3*). Since it costs more to transmit electricity over greater distances, the cost of getting power to rural consumers will always be higher. Rural areas also offer smaller markets, and hence, smaller sources of revenue. Generation companies will have little incentive to keep rural consumers happy by offering lower prices.

Urban areas, on the other hand, are likely to be hotly contested markets. This condition results because more people can be served over shorter lines. Large commercial and industrial accounts will also give marketers even more incentive to offer city areas sweet deals. This form of "cherry picking" may shift additional cost onto rural consumers. Given the market disparities between city and country, some form of protection may be necessary to ensure that competition benefits all classes of consumers.

Under the present system, since consumers contract with only one company to arrange for generation, transmission, and distribution of power, responsibility for quality of service resides with that utility. Under the new system, different segments of the industry will be handled by different companies. Each of these companies will try to increase revenue while cutting costs. Will any of the companies involved be eager to make long-term investments that may take years to recover? Recent corporate practices suggest that most companies will be thinking only of short-term profits (*3*). Companies will face strong economic incentives to overload and poorly maintain the existing nationwide transmission network. This situation could easily result in more frequent transmission failures, including blackouts, not just in remote areas but in urban areas as well.

ECONOMICS

Among the initial market forces prompting competition are the high cost of electricity production in many states and regions and comparatively lower costs in other states and regions. Notable are the higher levels of electricity prices and costs in California and the New England states (*4*). Among the factors creating these high costs are:

- dependence upon oil-fired generating plants,
- above-cost Public Utility Regulatory Policies Act of 1978 (PURPA)-related contract proliferation, and
- high-cost nuclear plants.

By contrast, lower electricity prices in western and mid-western states have been created by factors including: availability of low-sulfur coal, competitive fuel transportation service, greater prevalence of non-profit cost of service consumer-owned systems, availability of hydro and federal preference power, and relative lack of high cost PURPA-related contracts (*4*).

The resulting difference in power prices, while not a major concern for residential and small commercial customers, has become important to large industrial and commercial customers such as General Motors and Wal-Mart, who are in a position to observe price differences on a national scale. Large retail electricity end users have applied pressure for retail electricity competition on an individual basis and collectively as members of trade associations such as Electricity Consumers of America (ELCON). The majority of this pressure has been applied to federal legislation and for retail competition in high-cost states. This pressure has increased as wholesale markets have expanded with the participation of more suppliers and marketers, and has typically moved among neighboring states.

As wholesale markets expand, there is an expectation that the price of wholesale power will decline from previous levels in high-cost states and remain stable or slightly increase in low-cost states as the market prices reflect demand and as market risk is incorporated into price. However, early experience shows a high level of volatility in these markets and an increase, rather than a decrease, in wholesale prices in high-cost states. Recent studies conducted in low-cost states have indicated the potential for substantial increases in power prices (*4*).

The opportunity for a low-cost state's generators to sell to the wholesale market can create pressure on low electric rates, depending upon the extent to which proceeds from these sales are returned to maintain or reduce current retail electricity prices. Of special significance and concern will be the extent to which a low-cost state's generating facilities are used to sell to customers outside the state to the detriment to electric rates within the state.

Benefits of Deregulation

The benefits of deregulating the electricity market fall into the following seven principal areas:

- increased competition,
- lower prices,
- lower operating costs for businesses,
- lower regional cost differences,
- more jobs,
- increased reliability of service, and
- a cleaner environment.

Deregulation will lower prices, which will empower residential consumers by letting them choose their own electric supplier to find the best service (*5*). The current regulatory system forces consumers to bear very high costs. An important study by Clemson University professors Michael T. Maloney, Robert E. McCormick, and Robert D. Sauer for Citizens for a Sound Economy, a Washington-based think tank, revealed that in the long run, the average monthly electricity bill of $69 for a typical residential customer could fall by approximately $30 – a decline of 43 percent – if consumers had a real choice in who served them. Short-run savings also would be significant. The authors estimated an average drop of $18 for those with an average monthly bill of $69. Overall, the study reported that consumers would save almost $107.6 billion annually if a truly competitive market were developed (*5*).

Such cost savings would come not only from direct competition as new firms enter the market, but also from higher quality of service that this competition will foster. Wake Forest University professor of economics John C. Moorhouse observed that "The variety of generating equipment and the large number of independent producers adds diversity to the system, lowering the probability of widespread equipment failure, and, thereby, reducing the amount of excess capacity required to provide a given level of service reliability." Moorhouse has argued that competition will mean a broadening of choices for electricity consumers and overall increase in innovation within the industry. "Under competitive electricity generation, the market will provide an array of service standards that more closely match the mosaic of consumer preferences." Furthermore, competition not only leads firms to be more responsive to consumer demands, monitor costs more closely, and compete on the basis of price, it provides an incentive to be innovative because that may be the only way to get a temporary jump on rivals. Developing a new consumer service, a better method of reducing costs, or a faster way of dealing with problems promises the innovator a competitive edge (*5*).

Deregulation will generate lower prices for commercial businesses, especially small businesses. Electricity usually represents a substantial portion of the overhead cost of doing business. Unfortunately, these costs do not disappear during the production process and are not freely absorbed. They are factored into the final cost of goods and services. Therefore, because businesses cannot shop for better electricity bargains, higher electricity prices are passed on to the customer (*5*).

THE U.S. ELECTRIC UTILITY INDUSTRY

For the last 60 years, the electric utility industry in the United States has consisted primarily of vertically integrated electric utilities, which include generation, transmission, and distribution functions. Nationally, it is a mixed system of private investor-owned companies, and federal, state, and local consumer-owned facilities. In 1995, there were 244 investor-owned private electric utilities providing power to 75 percent of the nation's consumers; 931 rural electric cooperatives providing power to 11 percent of the nation's consumers; and 2020 public power systems providing power to nearly 14 percent of the nation's consumers. Although some public power systems and rural cooperatives own generating plants, most function only as distribution systems. In addition to these utilities directly supplying consumers at the retail level, federal power agencies and independent power producers generate and sell power at the wholesale level.

The nation's power supply and distribution companies are organized into 26 power supply regions operating as part of three major grids of transmission lines: one east of the Rocky Mountains, one to the west, and one in the Texas region. They are also organized into nine regional electric reliability councils. Deregulation of the electric industry began with the passage of the Public Utility Regulatory Policies Act in 1978. This act established the basis for independent, competitive companies to enter the power generation business at the wholesale level. During the 1980s, federal regulatory efforts sought to enhance access to transmission lines for these new generators and to help establish competitive wholesale markets.

Passage of the Federal Energy Policy Act (EPAct) in 1992 set the stage for a transformation of the nation's electric industry from a regulated monopoly to a competitive market system. The EPAct set the stage for the most significant change in the electric utility industry since implementation of the Public Utility Holding Company Act of 1935.

The EPAct contains a total of 30 sections, including Title VII-Electricity. The primary purposes of the Electricity Title are to open and expand the wholesale transmission market and to encourage the development of new competitive generating companies, in particular to provide wholesale marketing opportunities for independent power producers that were defined as exempt wholesale generators. It did not mandate retail competition, and the Federal Energy Regulatory Commission (FERC) was specifically prevented from ordering retail competition. However, FERC efforts to expand wholesale markets have been accompanied by encouragement of states to establish competitive retail markets. The first major step in expanding wholesale markets and setting up retail competition is developing non-discriminatory transmission access.

The core of that transformation would expand competition among generating companies at the wholesale level through greater transmission access and participation of new suppliers. It would also create competition for customers at the retail level through an opening of distribution systems to power marketers. For many of the nation's electric utilities, the shift to competition implies a corporate and operational restructuring into separate distribution, transmission, and generation functions.

Following passage of the Energy Policy Act, the Federal Regulatory Commission established rules to enhance competition at the wholesale level and encouraged states to establish laws and rules that would facilitate competition at the retail level. Twenty-four states have undertaken such action to establish retail competition. Another 24 states are studying the issue to determine the possible impacts and options. States with high-cost electricity have taken early and aggressive action in the belief that competition may succeed in reducing costs and rates where regulation has failed to do so. Low-cost states, however, have expressed concern that their costs rise as a result of establishing competitive retail market for electric power.

While expansion of wholesale markets is underway, Congress has currently left the issue of retail competition up to the states to determine. Proposed federal legislation would allow any state to develop its own plan to prepare for competition in the electric industry.

In April 1996, FERC issued landmark orders 888 and 889 to implement open access to jurisdictional high-voltage electric transmission systems. These orders also set in place the process to develop independent system operator (ISO) organizations and independent transmission companies. The central issue is to create non-discriminatory open access for all suppliers and elimination of the ability of transmission owners to use the lines and facilities for their own strategic purposes. By January 1999, FERC had approved five ISOs: California, Pennsylvania-New Jersey-Maryland, Midwest (conditional), New York, and New England. In addition, the Texas Public Utility Commission had approved an ISO for operation within the Reliability Council of Texas.

For the states, events to date can be characterized by efforts to form regional ISOs and transmission companies, expansion of the wholesale energy and transmission markets, upward price volatility in new wholesale markets, major utility mergers and reorganizations, and the emergence of new competitive energy service companies, retail competition pilots, and limited retail markets opening in several states. In summary, for an industry that has relied upon joint planning of transmission and generation and relatively stable planning horizons, the transition to competition has created general uncertainty concerning the future.

Several key factors account for electric industry restructuring. It has generally been recognized that once transmission access began to open up and allow more wholesale transactions in the early 1990s, large industrial users and competitive wholesale suppliers in high-cost states pressed for access to develop contracts at the retail level. Supporting these efforts were advances in generating plant and transmission technologies, electricity price disparities between states and regions, and political support for the philosophy of deregulation.

DEREGULATION IN TEXAS

In June 1999, Texas Governor George W. Bush signed a bill deregulating the state's $19 billion electric utility industry. The bill, signed into law by the governor at a ceremony held at the State House in Austin, Texas, was the result of more than one year of negotiations in the Texas legislature to create a competitive electricity market for the state. Texas customers will officially have a choice of electricity provider by January 1, 2002.

ELECTRIC RELIABILITY COUNCIL OF TEXAS (ERCOT)

ERCOT is one of 10 regional reliability councils in the North American Electric Reliability Council (NERC) Organization. ERCOT represents a bulk electric system located totally within the state of Texas and serves about 85 percent of Texas' electric load. It has a generating capability of about 65,000 megawatts and experienced a 2000 summer peak demand of about 57,606 megawatts. Because of its intrastate status, the primary regulatory authority for ERCOT utilities is the Public Utility Commission of Texas (PUCT). The Federal Energy Regulatory Commission exercises limited authority. ERCOT membership currently consists of retail consumers, six cooperatives and river authorities, six municipals owning generation or transmission, four investor-owned utilities, 13 independent power producers, 23 power marketers, and 14 transmission dependent utilities.

With the introduction of competition into the electric market, the state's largest reliability council, ERCOT, has evolved into an independent system operator that oversees the reliability of the state's transmission grid. The ERCOT ISO handles security operations and coordinates day-to-day and long-term transmission and generation operations. The ISO began operating in 1996 to ensure fair, competitive treatment and reliable operations in a competitive market.

Particularly in the hot summer months, continued access to a secure source of safe, reliable electricity is of utmost importance to all Texans. Electric reliability issues can be divided into two components:

- availability of power (generation) issues involving whether there is enough electric power to meet customers' needs throughout the year, including peak times of the day; and
- delivery of power (transmission and distribution) issues including whether there are enough transmission lines to move the electricity from the power plant to the distribution lines where customers' businesses and homes are connected.

Texas electric companies strive to meet both of these needs for our state's growing electricity demand.

In 2001, the PUCT issued a statement saying the state will have plenty of power to meet peak demand during the summer and in the future. The peak demand usually occurs in late July or early August.

Today, we have a very healthy reserve, and we continue to expand it. Since January 2000, more than 4300 megawatts of additional capacity has been added to the system, and an additional 9000 megawatts will be available within the next two years.

Texas electric utilities work to ensure they have plenty of power by either producing enough electricity or buying electricity on the wholesale electric market. In 1995, Texas passed legislation to introduce competition into the Texas wholesale market. In addition, each electric company performs long-term planning to assure that adequate transmission and distribution facilities are in place before demand outstrips their ability to deliver. Each utility also conducts plant maintenance during low-use times of the year (spring and fall) in order to ensure the plants are ready to run during peak times.

Competition should encourage new companies to build additional generation plants and improve reliability. Electric competition will begin January 1, 2002, for most Texans currently served by investor-owned utilities.

Texas has traditionally had excellent electrical reliability. Not only have investor-owned utilities and state regulators always put a high value on reliability, but Texas is the only state that has its own electric reliability council and does not have to cross state lines. While Texas does have small parts of the western and southwest power pools along the periphery of the state, long-range planning for most of the state is carried out with no overlapping jurisdictions.

Looking ahead, Texas utilities will be required by law to offer more energy efficiency programs for customers. The PUCT recently adopted rules establishing statewide energy efficiency programs to offset 10 percent or more of each utility's yearly growth in demand to all customer groups. Utilities must report yearly on energy efficiency projects and include cost and energy savings information to verify the improvements.

CURRENT SITUATION IN TEXAS

The continued completion and construction of new generation plants in Texas will create an electricity supply during summer 2001, 23 percent greater than peak firm demand (*6*).

Retail electric competition begins January 1, 2002, for customers of investor-owned utilities in Texas. Pilot projects begin June 1, 2001. Customers will receive more information in their electric bill. Municipal utilities and electric cooperatives have the option of participating in retail competition. The latest information compiled by the PUCT shows new electricity sources popping up all around the state. It is happening as the Texas economy continues to grow, and the demand for electricity rises 3 to 4 percent a year.

Texas is the only state to operate its own electricity grid, which makes it less vulnerable to the various bottlenecks in the national system; it imports less than 1 percent of its power. Since open transmission access and wholesale competition began in Texas in 1995, nearly 50 new plants are either completed or under construction. More than 25 additional generation projects have been announced. The new plants will add more than 21,000 megawatts (MW) of capacity by the summer of 2002, enough to power nearly five million Texas homes on the hottest summer day (*6*).

Texans will also benefit from a diversified power supply. About 46 percent of the electricity in Texas comes from natural gas-fired plants. Coal and Texas lignite supply about 41 percent of the fuel mix, with 13 percent coming from nuclear plants. The rapidly growing renewable energy sector currently supplies less than 1 percent of the state's electricity. Already more than 20 wind projects have been proposed in West Texas, and several are under construction (*6*).

Statewide, electric demand in Texas is expected to reach 67,000 MW during summer 2001, but total generation capacity should exceed 83,000 MW for a 23 percent reserve margin (*4*).

Within the ERCOT, which is a bulk electric system serving approximately 85 percent of Texas electric load, firm peak demand is projected to reach almost 56,500 MW during summer 2001, while installed capacity will top 70,700 MW.

ERCOT's main function is maintaining a reliable, efficient transmission system. ERCOT now has many major transmission projects underway to relieve existing constraints and to connect new power plants to the system.

California vs. Texas

Every day, news media report severe electricity shortages, particularly in California. Evidence indicates this could not happen in Texas for three key reasons. First, Texas is building power plants and power lines to stay well ahead of customer needs. California is not. Recently, the PUCT issued updated figures on our power supply. Thanks to our 35 new power plants, on the hottest day of summer 2001, we should have a 23.3 percent excess power reserve above firm customer demand. That is a healthy cushion – well above the 15 percent goal used under regulation. Texas is an electricity buyer's market. California, with a reserve margin near zero, is a seller's market.

This plant construction happened because the Texas legislature allowed any company (not just utilities) to enter the power generation market in 1995. The PUCT has set out clear rules to speed the connection of new power plants to the power grid. The permitting process is also clear and focused. As a result, it takes about two years to build a clean, efficient power plant in Texas, compared to six or seven years in California.

A second key difference between Texas and California is the diversity of our power supply. Last year, about 46 percent of our power came from gas-fired plants, 41 percent from coal plants, and 13 percent from nuclear plants. (West Texas is now the hub of U.S. wind power investment, but those numbers won't show up for a couple of years) (*5*).

By contrast, California depends on hydroelectric power – including a large amount from outside the state – for 25 percent of its needs. Hydropower is great when it rains, but when it fails to rain and replenish reservoirs, the safety cushion evaporates. Texas does not rely on intermittent resources.

Finally, our focus in Texas is on implementing competition before deregulation. Workable competition is a much better regulator than government. But until there is sufficient supply of power and the wholesale market is working well, it does not help customers to deregulate a monopoly. The Texas plan has a 12-year phase-in, which began in 1995. Pennsylvania is another state focusing on competition first. As a result, customers there see savings of up to 15 percent on their monthly bills (*5*).

Texans' ability to shop and save is coming June 1, 2001. In the first few weeks of June 2001, 5 percent of the retail customers of the state's investor-owned utilities can enroll in the Retail Choice Pilot Program. Enrollment means that customers can choose their electric provider seven months before such freedom comes to other customers.

Basics of the Texas Wholesale Power Market

The following information is provided to update the electricity supply and demand situation in Texas:

- Texas started early but moved thoughtfully. Senate Bill (SB) 373 (1995) opened the wholesale generation market, and SB 7 (1999) refined the wholesale market.
- Attractiveness of the Texas market and its regulatory climate have led to significant investment in power plants:
  - 23 new plants totaling 8652 MW have come on-line since 1995.
  - 24 plants totaling 12745 MW are under construction to come on-line summer 2002.
  - 28 more plants are in the planning stage.
- Texas plant construction maintains a comfortable margin above customer demand.
- Utilities are building more transmission lines across the state.
- ERCOT ISO responsibly maintains open markets and reliability, with balanced stakeholder governance.
- Texas/ERCOT market structure is based on bilateral contracts, not a mandatory power pool, so Texas/ERCOT does not price all power at the highest price bid.
- Diversity of power generators maintains a competitive balance in the power market.
- Result: average generation prices in the ERCOT market are low and stable.

Basics of the Texas Retail Power Market

- SB7 also set the foundation for a successful retail market to open in June 2001 with the statewide pilot program, and full retail customer access to begin in January 2002 for most of Texas.
- Texas is becoming the most attractive market in the nation for retail supplier competition due to:
  - standardized commercial rules,
  - stranded cost recovery mechanism and low stranded costs,
  - restraints on dominant retailer,
  - fair certification process
  - retail pricing structure that should preserve "headroom" and facilitate price competition,
  - larger customers who are able to respond to wholesale market price signals,
  - barriers to customer use of small-scale power generation are being removed,
  - customers are empowered through an education campaign and standardized electric facts label, and as a result,
  - all Texas customers should have attractive retail choices.

Customer Protected during Transition

- Customers who do not choose a new provider will continue as a customer of their utility's affiliated retailer on January 1, 2002.
- The utility-affiliated retailer must maintain a capped rate (at December 31, 2001, base rate less 6 percent off, plus adjustment of fuel and purchased energy component) through 2007.
- A provider of last resort will serve at-risk customers.
- SB7 establishes many customer safeguards, including low-income discounts and broad-based energy efficiency programs.

Table 4. Projected Peak Demand and Generating Capacity for 2001 and 2002.

ERCOT	2000	2001	2002
Total Peak Demand	57,606	59,622	61,709
Interruptible Load	3,191	3,110	3,152
Firm Demand	**54,415**	**56,512**	**58,557**
Utility Capacity	54,780	55,265	55,255
Nonutility Capacity (net of self-use)	6,596	15,441	21,821
Total Capacity	**61,376**	**70,706**	**77,076**
Reserve Margin w/o Interruptions	**6.5 percent**	**18.6 percent**	**24.9 percent**
Reserve Margin w/ Interruptions	**12.8 percent**	**25.1 percent**	**31.6 percent**
NonERCOT	**2000**	**2001**	**2002**
Total Peak Demand	11,025	11,355	11,696
Interruptible Load	533	537	550
Firm Demand	**10,492**	**10,818**	**11,146**
Utility Capacity	10,205	10,290	10,316
Nonutility Capacity (net of self-use)	669	1,322	1,742
Capacity Purchases (nonERCOT)	738	696	582
Total Capacity	**11,612**	**12,308**	**12,640**
Reserve Margin w/o Interruptions	**5.3 percent**	**8.4 percent**	**8.1 percent**
Reserve Margin w/ Interruptions	**10.7 percent**	**13.8 percent**	**13.4 percent**
TOTAL TEXAS			
Total Peak Demand	68,631	70,978	73,405
Interruptible Load	3,724	3,647	3,702
Firm Demand	**64,907**	**67,331**	**69,703**
Existing Utility Capacity	64,985	65,555	65,571
Nonutility Capacity (net of self-use)	7,265	16,763	23,563
Capacity Purchases (nonERCOT)	738	696	582
Total Capacity	**72,988**	**83,014**	**89,716**
Reserve Margin w/o Interruptions	**6.3 percent**	**17.0 percent**	**22.2 percent**
Reserve Margin w/ Interruptions	**12.5 percent**	**23.3 percent**	**28.7 percent**

Table 5. Generation Projects Completed Since 1995.

ID No.	Company	Location (County)	Capacity (MW)	Cogen. Host (MW)	Date in Service	Interconnection	Region
	Texas A&M University	College Station	40	40	Jan-96	Brazos	ERCOT
	City of Brownsville	Brownsville	43		Jun-96	BPUB	ERCOT
	Tenaska IV Texas Partners	Cleburne	258		Nov-96	TU/BEPC	ERCOT
	CSW Energy	Sweeney	330	90	Feb-98	TNMP	ERCOT
	Calpine	Pasadena	240	90	Jul-98	Reliant	ERCOT
	New World Power (wind)	Big Springs	34		Feb-99	TU	ERCOT
	FPL Energy (wind)	Southwest Mesa (Upton)	75		Jun-99	STU	ERCOT
	National Wind Power (wind)	Culberson County	30		Jun-99	TXU	ERCOT
	BASF	Freeport	93		Jul-99	Reliant	ERCOT
	Occidental Energy/Conoco Global	Ingleside (San Patricio)	440	235	Oct-99	CPL	ERCOT
	Reliant Energy/Air Liquide	Sabine (Orange)	100	36	Dec-99	Entergy	SERC
1	LS Power	Denver City (Yoakum)	280 198		Jun-99 May-00	SPS	SPP
2	CSW Energy	Mission (Hidalgo)	344 170		Jul-99 May-00	CPL	ERCOT
3	CPS	San Antonio (Bexar)	500		May-00	CPS	ERCOT
4	Lubbock Power & Light	Lubbock (Lubbock)	43		Sep-00	LPL	SPP
5	Calpine	Pasadena expansion (Harris)	540		Jul-00	Reliant	ERCOT
6	FPL Energy/Panda Energy	Paris (Lamar)	1000		Sep-00	TXU	ERCOT
7	Tenaska Frontier/PECO Power Team	Shirow (Grimes)	830		Sep-00	Reliant, Energy	ERCTO, SERC
8	Calpine	Edinburg (Hidalgo)	500		Jun-00	CSW	ERCOT
9	LG&E/Columbia	Gregory (San Patricio)	450	50	Jul-00	CSW	ERCOT
10	ANP	Midlothian I (Ellis)	820		Oct-00	TXU	ERCOT
11	Southern Energy	Lake Whitney (Bosque)	294		Jun-00	Brazos	ERCOT
13	Texas Independent Energy	Marion (Guadalupe)	1000		Jan-01	LCRA	ERCOT
	23 Facilities Completed	**Total Capacity**	**8652**	**541**			

Table 6. Generation Projects Under Construction.

ID No.	Company	Location (County)	Capacity (MW)	Cogen. Host (MW)	Date in Service	Interconnection	Region
10	ANP	Midlothian I (Ellis)	270		Feb-01	TXU	ERCOT
11	Southern Energy	Lake Whitney (Bosque)	240		Jun-01	Brazos	ERCOT
12	Union Carbide	Seadrift (Calhoun)	40	40	Oct-00	CPL	ERCOT
14	CSW Energy/Eastman Chemical	Sweeny expansion (Brazoria)	110	35	Mar-01	TNMP	ERCOT
15	CSW Energy/Eastman Chemical	Longview (Harrison)	450	130	Mar-01	SWEPCO	SPP
16	ANP	San Marcos (Hays)	550 550		May-01 Jun-01	LCRA	ERCOT
17	Calpine/Gen Tex Power	Lost Pines (Bastrop)	520		Jun-01	LCRA/AE	ERCOT
18	Tenaska Gateway/Coral Energy	Henderson (Rusk)	845		Jun-01	CSW/TXU	ERCOT
19	Calpine	Edinburg (Hidalgo)	730		Apr-01	CPL	ERCOT
20	Calpine	Houston (Harris)	560	160	Jun-01	Reliant	ERCOT
21	Texas Independent Energy	Odessa (Ector)	500 500		Jul-01 Oct-01	TXU	ERCOT
22	Conoco Global	Orange (Orange)	420	70	Aug-01	Entergy	SERC
23	Reliant Energy/Equsitar	Channelview (Harris)	172 608	293	Sep-01 Apr-02	Reliant	ERCOT
24	Tractebel	Ennis (Ellis)	350		Oct-01	TXU	ERCOT
25	ANP	Midlothian II (Ellis)	550		Nov-01	TXU	ERCOT
26	Calpine	Baytown (Chambers)	700	300	Jan-02	Reliant	ERCOT
32	Enron/Austin	Austin (Travis)	180		May-01	AE	ERCOT
33	Garland Power & Light	Garland (Collin)	75		Jun-01	GP&L	ERCOT
35	Renewable Energy Systems (wind)	(Pecos)	160		Jul-01	WTU	ERCOT
38	Skygen/Citgo	Corpus Christi (Nueces)	500		Jul-02	CPL	ERCOT
39	FPL Energy/Coastal Power	(Bastrop)	535		Jun-02	AE/LCRA	ERCOT
40	Constellation Power	Seguin (Guadalupe)	800		Jun-02	LCRA	ERCOT
45	Calpine	Fairfield (Freestone)	500 600		Jul-02 Sep-02	TXU	ERCOT
47	AES-Wolf Hollow Power Plant	Granbury (Hood)	730		Aug-02	TXU	ERCOT
	24 Facilities Under Construction	**Total Capacity**	**12745**	**1028**			

Table 7. Recently Announced Generation Projects.

ID No.	Company	Location (County)	Capacity (MW)	Expected Construction Date	Expected Date In Service	Region
27	Enron Wind Corp (wind)	Sweetwater	150	N/A	After 2001	ERCOT
28	Orion Energy (wind)	Indian Mesa (Pecos)	80 45	Sep-00 N/A	3Q-01 N/A	ERCOT
29	Renewable Energy Systems (wind)	King Mtn. (Upton)	225	Nov-00	Dec-01	ERCOT
30	Fina BASF	Port Arthur	80	N/A	Mar-01	SERC
31	Orion Energy	(Culberson)	170	N/A	2002	ERCOT
34	York Research Group (wind)	(Ector, Winkler)	250	N/A	Jul-01	ERCOT
36	Texas Independent Energy	Wichita Falls (Archer)	500 500	Sep-01	Apr-03 2004	ERCOT
37	Enron Wind Corp. (wind)	Indian Mesa (Pecos)	25 130	Oct-00 Apr-01	Dec-00 Dec-01	ERCOT
41	Duke Energy	(Jack)	500	N/A	N/A	ERCOT
42	Duke Energy	(Bell)	500	N/A	N/A	ERCOT
43	Cobisa	Forney (Kaufman)	1,650	4Q-00	1Q-03	ERCOT
44	Duke Energy	(Kaufman)	500	N/A	N/A	ERCOT
46	ANP	Houston (Harris)	1650 550	Nov-00 N/A	Nov-02 N/A	ERCOT
48	ANP	Edinburg (Hidalgo)	550	May-01	May-03	ERCOT
49	ANP	El Paso (El Paso)	430	4Q-00	4Q-02	WSCC
50	Constellation Power	Gilmer (Upshur)	800	Dec-00	Dec-02	SPP
51	Dynergy	Lyondell expansion (Harris)	155	N/A	May-03	ERCOT
52	KN Power	Boonsville (Wise)	510	N/A	N/A	ERCOT
53	Sempra Energy Sources	(Harris)	578	N/A	May-03	ERCOT
54	Sempra Energy Sources	Montgomery	578	N/A	May-03	ERCOT
55	Newport Generation	Palestine (Anderson)	1600	Jan-02	Jun-03	ERCOT
56	Tractebel	Bridgeport (Wise)	800	Spring 01	Jul-03	ERCOT
57	CCNG Inc.	Duval	385	N/A	Jan-04	ERCOT
58	ANP	Mont Belvieu (Chambers)	1100	N/A	N/A	ERCOT
59	ANP	San Marcos (Hays)	550	N/A	N/A	ERCOT
60	Texas Wind Power Company (wind)	White Deer (Carson)	80	Jan-01	Jul-01	SPP
61	Avista-Steag	Ft. Bend	633	Jan-01	Jan-03	ERCOT
62	AEP (wind)	Trent Mesa	130	Nov-00	Aug-01	ERCOT
	28 Facilities Announced	**Total Capacity**	**16385**			

CHAPTER 6 – NUMERICAL STUDY OF THE AERODYNAMICS OF AN MTM IN THE FREIGHT PIPELINE

INTRODUCTION

Chapter 6 contains the results from a study of the aerodynamics of a freight pipeline system. In order to minimize operating costs, it is necessary to decrease the energy expenditure of the MTMs as they navigate the pipeline. The selection of a conduit system containing bi-directional traffic and transport mechanisms that must operate in a air-filled environment, means that appropriate attention during system design to the aerodynamics of the MTMs will minimize drag and reduce the energy required to accelerate the MTMs and maintain target operational speed.

Simplified expressions are presented, which in concert with results from computational fluid dynamics (CFD) analysis, allow the formulation of guidelines to design a low-drag system. These expressions explicitly suggest a method to optimize the drag. Traditionally, the design of new aerodynamic systems has been achieved through the use of experimental testing. However, economic considerations have generally seen a decline in the use of experimental methods, especially with the maturation of CFD. CFD allows greater flexibility in configuration optimization at greatly reduced cost and, as such, is an excellent tool. For exact determination of a configurations property though, it is imperative to complete any CFD analysis with experimental verification.

This study employs a Navier Stokes solver to:

- Verify its viability as a design/optimization tool.
- Initiate optimization of MTM design and run numerical experiments to ascertain design guidelines.

Engineering guidelines are presented to aid in the selection of an MTM design. Both practical and economic factors dictate these guidelines.

ANALYSIS

The preceding analysis (Appendix A) has shown that in the optimization of a freight pipeline, aerodynamic drag minimization is primarily associated with reducing skin friction and pressure drag.

Skin Friction

This drag component is due to viscous shear over the exposed surfaces of the MTM. It is proportional to the square of the MTM speed. For a given required "length" of the transport mechanism, connecting the individual vehicle components to form a continuous surface minimizes skin friction. In addition, the skin friction drag has been shown to be proportional to $1/(1-\beta)^2$, where β is the blockage ratio and is defined as the ratio of the cross-sectional MTM area to that of the tunnel. Thus, as β reduces, so does the skin friction drag.

Pressure Drag

The preceding analysis has shown that pressure drag is highly dependent on β. It has been shown that both skin friction and pressure drag reduce significantly if β is kept below 0.3. The analysis that yielded these results, however, is not amenable to divulging the effects of specific configuration variables, e.g., MTM profile and eccentricity.

MTM Profile

STARCD, a Navier-Stokes solver, was used to gain insight into the effects of the MTM profile on drag. Initial results (see Appendix A) showed that the use of a sharp inclined front incurred little drag penalty compared to an elliptical front. The use of a similarly configured tail was also shown to reduce pressure drag. Consequently, researchers performed additional analysis using a MTM profile similar to the Eurostar trains, which consists of two circular arcs joined by an inclined flat plane. This configuration is aerodynamically viable and should be attractive economically for manufacture (see Figure 5). The numerical experiments aimed at establishing design guidelines were conducted using the following vehicle geometry:

- Four MTMs/train;
- MTM length = 1.52 m;
- MTM width = 1 m;
- MTM height = 1.22 m;
- Clearance from right hand side of tunnel = 1.3 m; and
- Values of β ranged from 0.2 – 0.3.

Figures 6 and 7 show details of the computational grids employed to run the simulations. Grid points were densely packed in regions of high gradients to adequately resolve the flow features.

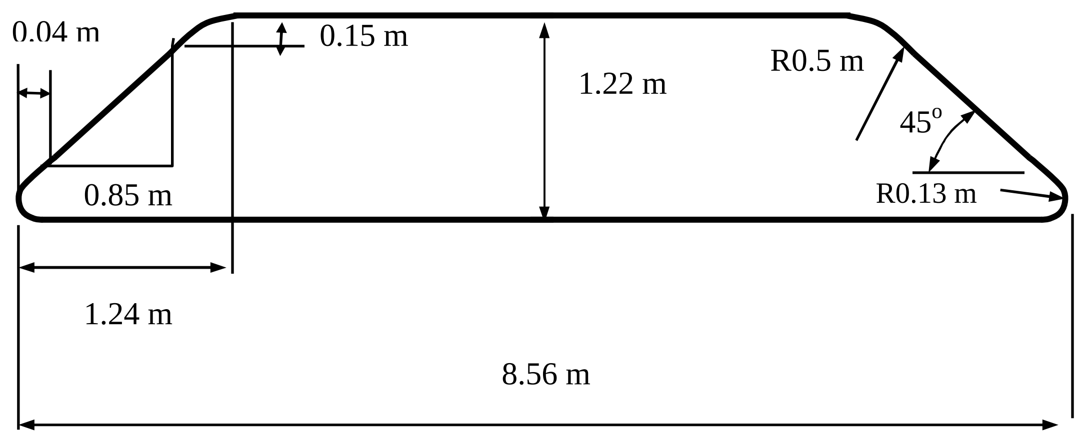

Figure 5. MTM Profile (not to scale).

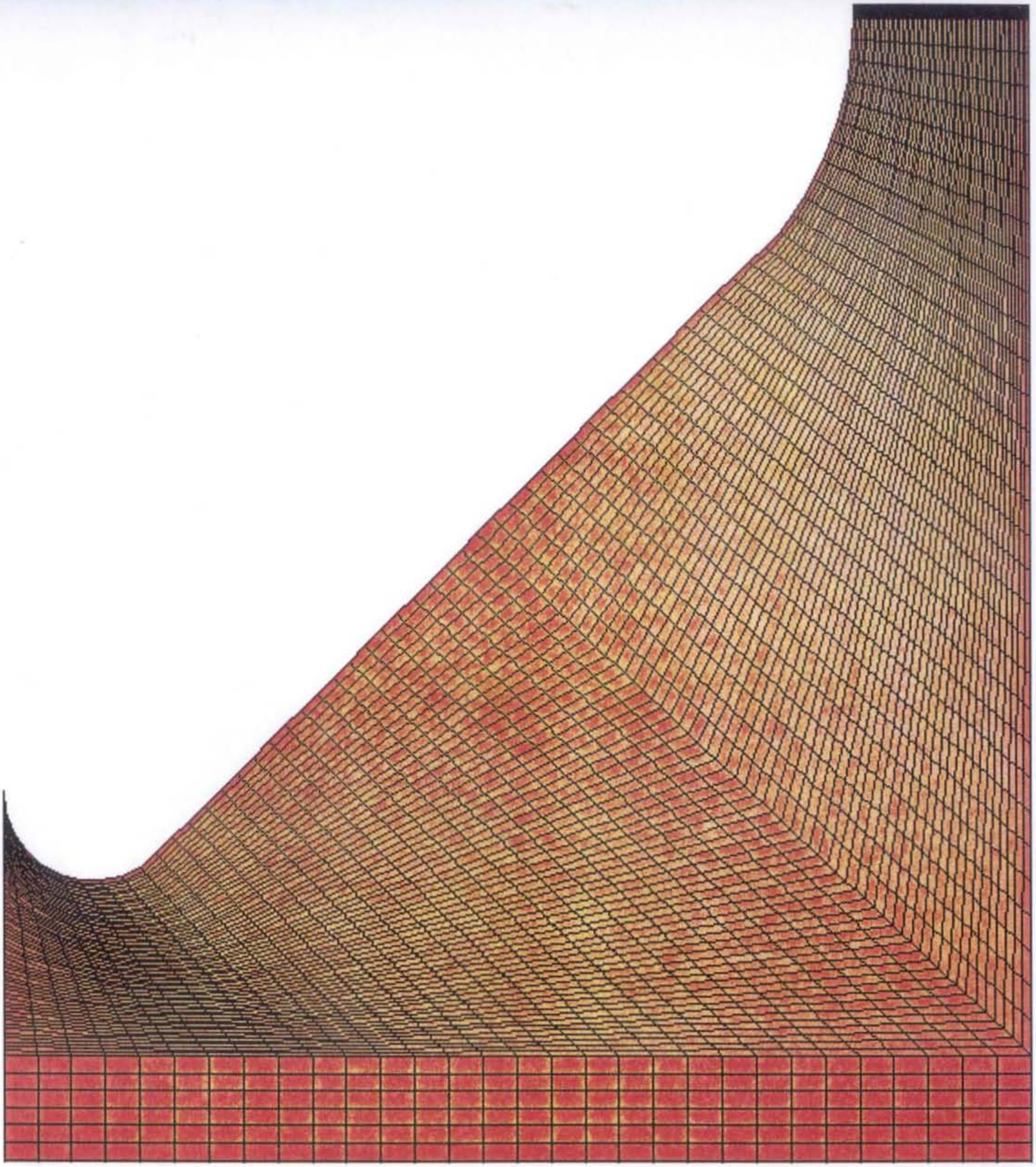

Figure 6. Computational Grid Density of MTM Profile – Front and Rear Treatments.

Figure 7. Computational Grid Density for Overall MTM Profile.

Tunnel Profile

Research into the cost and construction of the conduit shows economic reality dictated a tunnel with an essentially rectangular shape. Thus, *tunnel shape* was not pursued as a design variable. However, researchers investigated displacement of the MTM from the roof and side wall. Figure 8 displays the computational grid surrounding the MTM used to simulate the tunnel.

MTM Eccentricity and Roof Gap

The underground freight line will be at least a dual or potentially three-line tunnel. Consequently, β will implicitly be small. However, the effects of MTM proximity to the roof and tunnel side wall are still a design parameter. The selected MTM shape has curvature essentially only in profile. This curvature was selected due to:

- simplicity of manufacture, and
- reduced lateral velocity gradients.

The research shows that the Eurostar type of configuration generates little lateral flow, with most of the air displaced by the train passing over the roof section. At present, prediction of the effects of two trains passing each other in a tunnel represents the bounding state of the art of CFD development. At present the Aerospace Engineering Department does not have the facilities to compute these interactions. However, the selected profile by virtue of its minimal lateral fluid displacement and hence velocity should *minimize* interaction between passing MTMs, as will be elucidated later.

Tests using the Navier-Stokes solver were undertaken to determine the eccentricity effects. The considerable time required in setting up the grids and physically performing the computations (approximately one case per two days) limited the number of tests that could practically be performed. Researchers instituted a test matrix to minimize the required number of tests while concurrently elucidating the major variable dependencies. Results are presented in Figures 9 and 10. Figure 9 presents the calculated MTM drag as a function of distance from the side of the tunnel. Data are presented for roof clearances of 0.25, 0.5, and 0.75 m. The data suggest that increasing clearance reduces drag, with greater roof clearance enhancing this effect. The effect of reducing drag with clearance is seen to be most marked for initial displacement from the wall. Figure 10 presents the effect of clearance from the roof to the top of the MTM for three side clearances. Drag is seen to behave in an analogous fashion to that for side clearance, except that the drag demonstrates a greater dependence on roof clearance. This follows from the design of the MTM in that most of the displaced fluid is “vented” over the top of the vehicle.

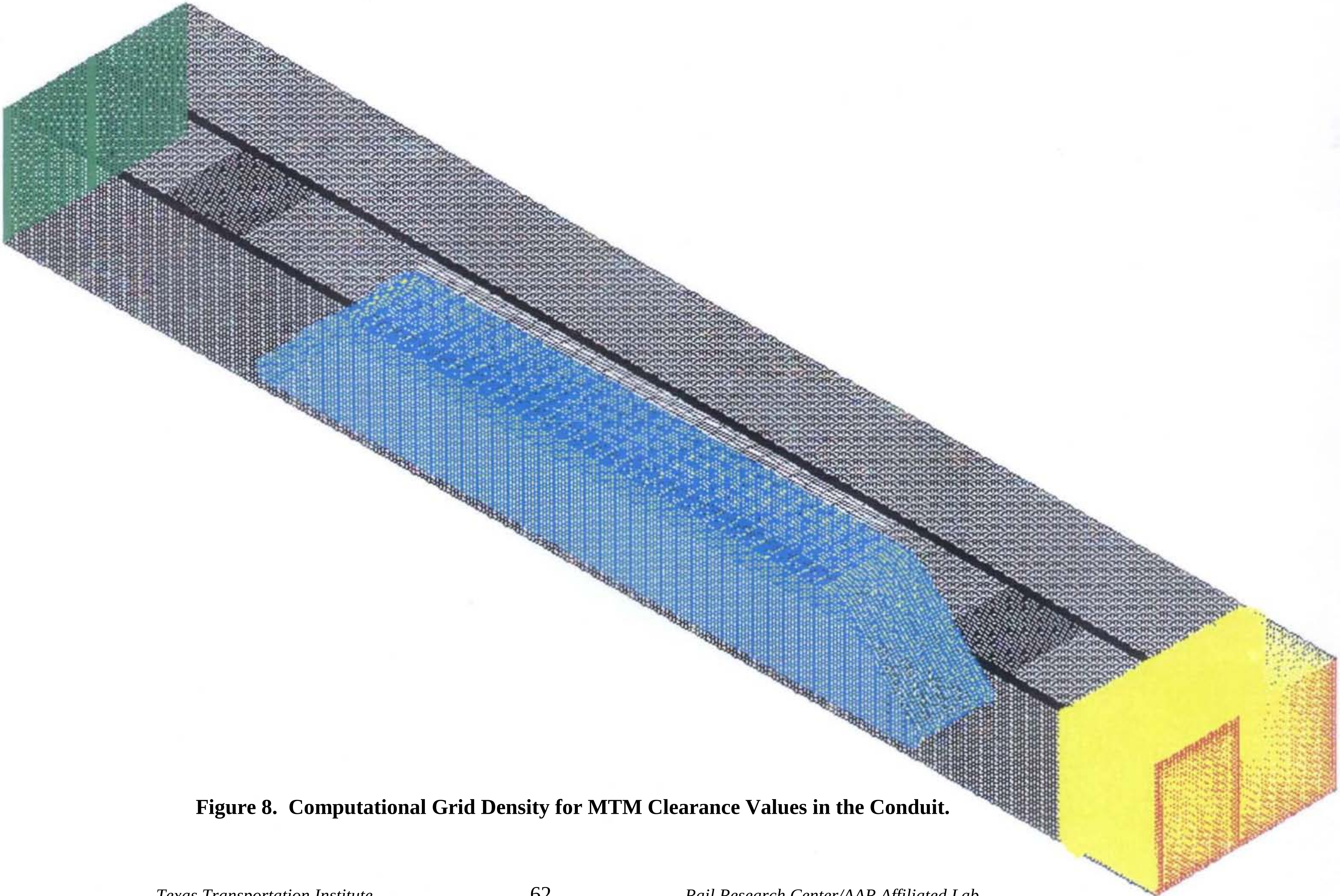

Figure 8. Computational Grid Density for MTM Clearance Values in the Conduit.

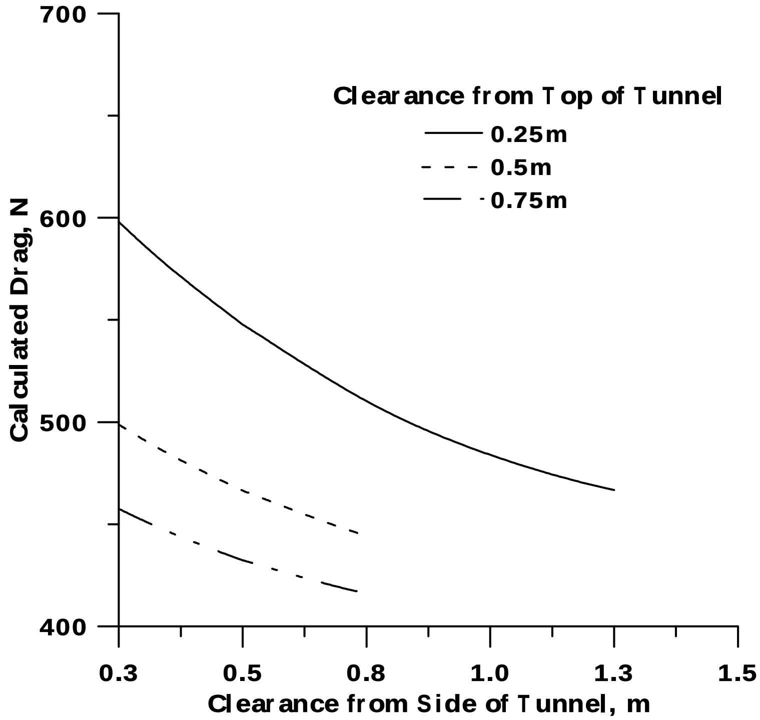

Figure 9. Calculated MTM Drag as a Function of Distance from the Side of the Tunnel.

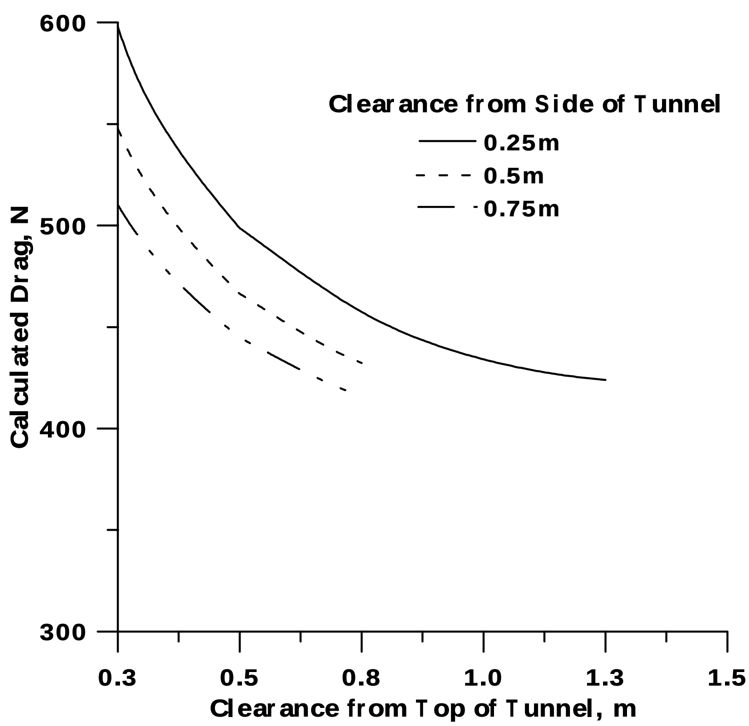

Figure 10. Effect of Clearance from the Roof to the Top of the MTM.

The data in Figures 9 and 10 clearly show that aerodynamic drag is reduced by both greater side clearance and clearance from the roof, with relative drag gains reducing as the MTM moves farther from the walls. Without experimental confirmation, however, the magnitude of the trends (and that of the predicted drag) should be treated with caution. The trends, however, will be representative.

Velocities and Pressures

Figures 11-15 show detailed results of the velocity and pressure fields calculated over the MTM train. These results are presented for a roof clearance of 1.25 m. The train velocity was 20 m/s.

Figure 11 shows the front of the train (motion is from left to right). Over the front portion of the train, the flow is seen to partially stagnate, which is reflected in the pressures in this region (see Figure 12). The flow then accelerates around the top of the train with a commensurate drop in pressure. The velocity in the channel between the train and the roof has a higher velocity than the train speed, approximately 30.5 m/s, indicating the presence of “jet” type flow. Simple 2D continuity considerations would suggest a velocity of approximately 39.5 m/s. The difference is due to viscous effects, as well as a 3D relieving effect around the side of the train. Figure 9 presents calculated velocity vectors around the nose of the train.

Figures 13 and 14 show the axial velocity and pressure at the aft section of the train. Comparison of Figures 11 and 12 and 14 and 15 shows a lack of symmetry in the fore and aft velocity and pressure distributions, which is the physical manifestation of pressure drag due to flow separation. However, the lack of symmetry is moderate, and there is evidence of reasonable pressure recovery over the aft section by reducing the pressure drag (the pressure is less negative over the rear of the MTM with distance from the roof). Figure 16 shows the velocity vectors over the aft section of the MTM. It is clear that no large-scale separation exists, and only a small bubble is visible near the intersection of the vehicle and the floor. This result suggests that this aft profile is not only economically efficient (as it is the mirror image of the front section), but it is also aerodynamically viable and should not cause large pressure drag.

Figures 17-19 present velocity magnitudes in cross-flow planes towards the aft of the train. The viewer is located behind the train as it passes and is looking in the direction of its motion. These figures show the clear formation of separation vortices from the aft side edge of the train. A vortex also forms between the train and the sidewall on the left-hand side. Of significance in these figures is the minimal side-wash velocity. This velocity is important in that it suggests that the train displaces most fluid over its roof and not laterally. This displacement would be of significant benefit in reducing interaction between passing trains.

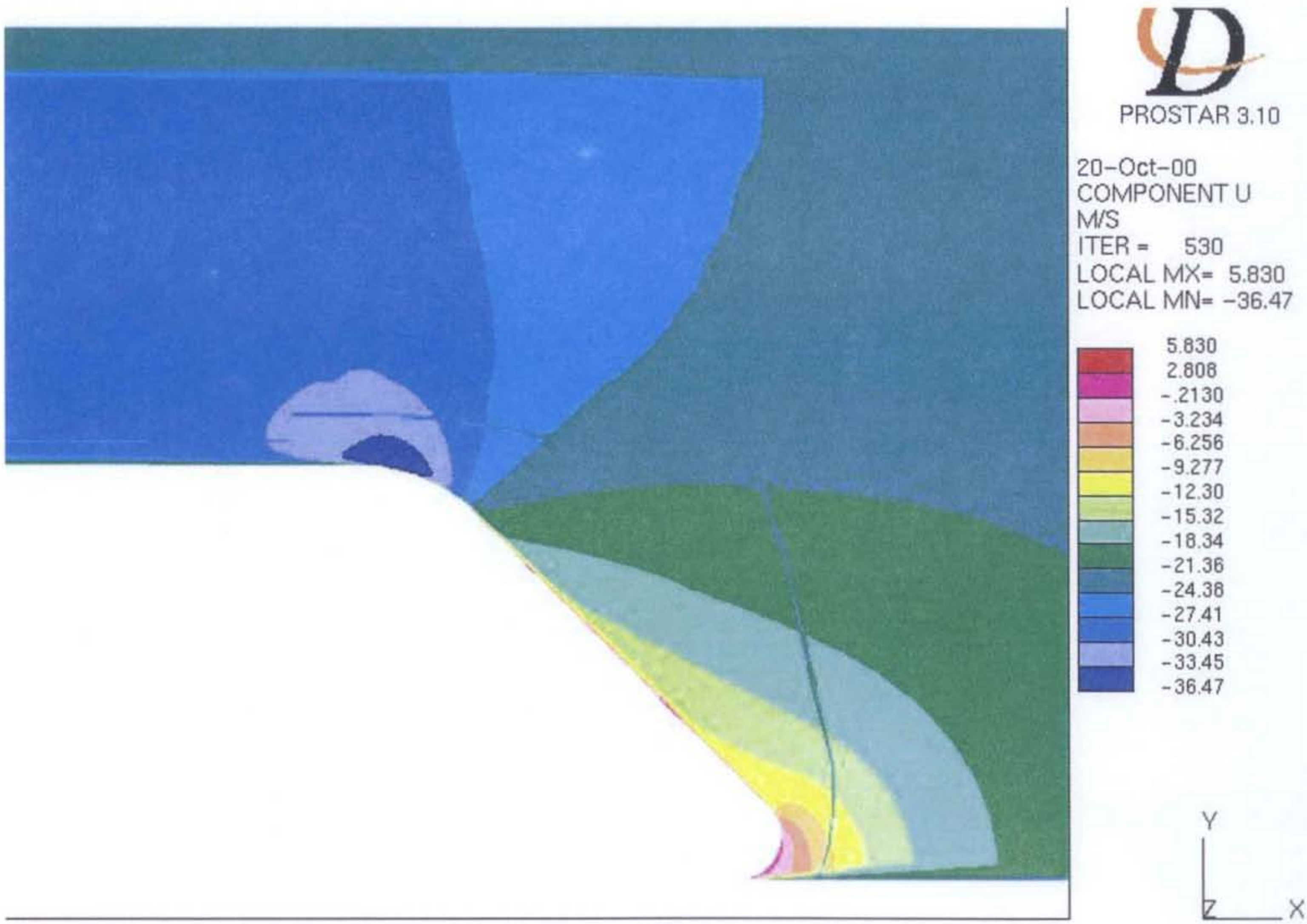

Figure 11. MTM Frontal Air Flow Velocity Diagram.

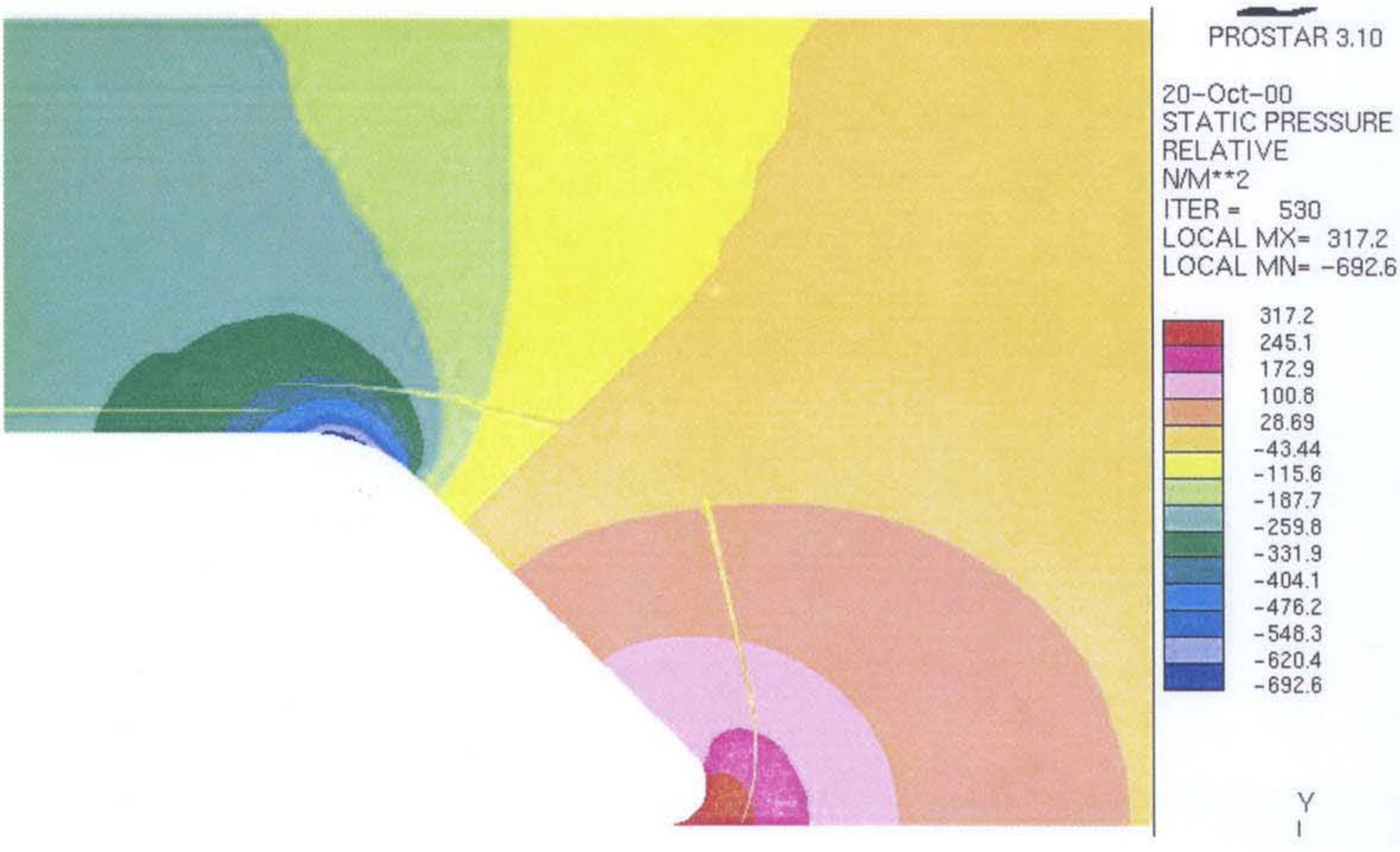

Figure 12. MTM Frontal Relative Static Pressure Diagram.

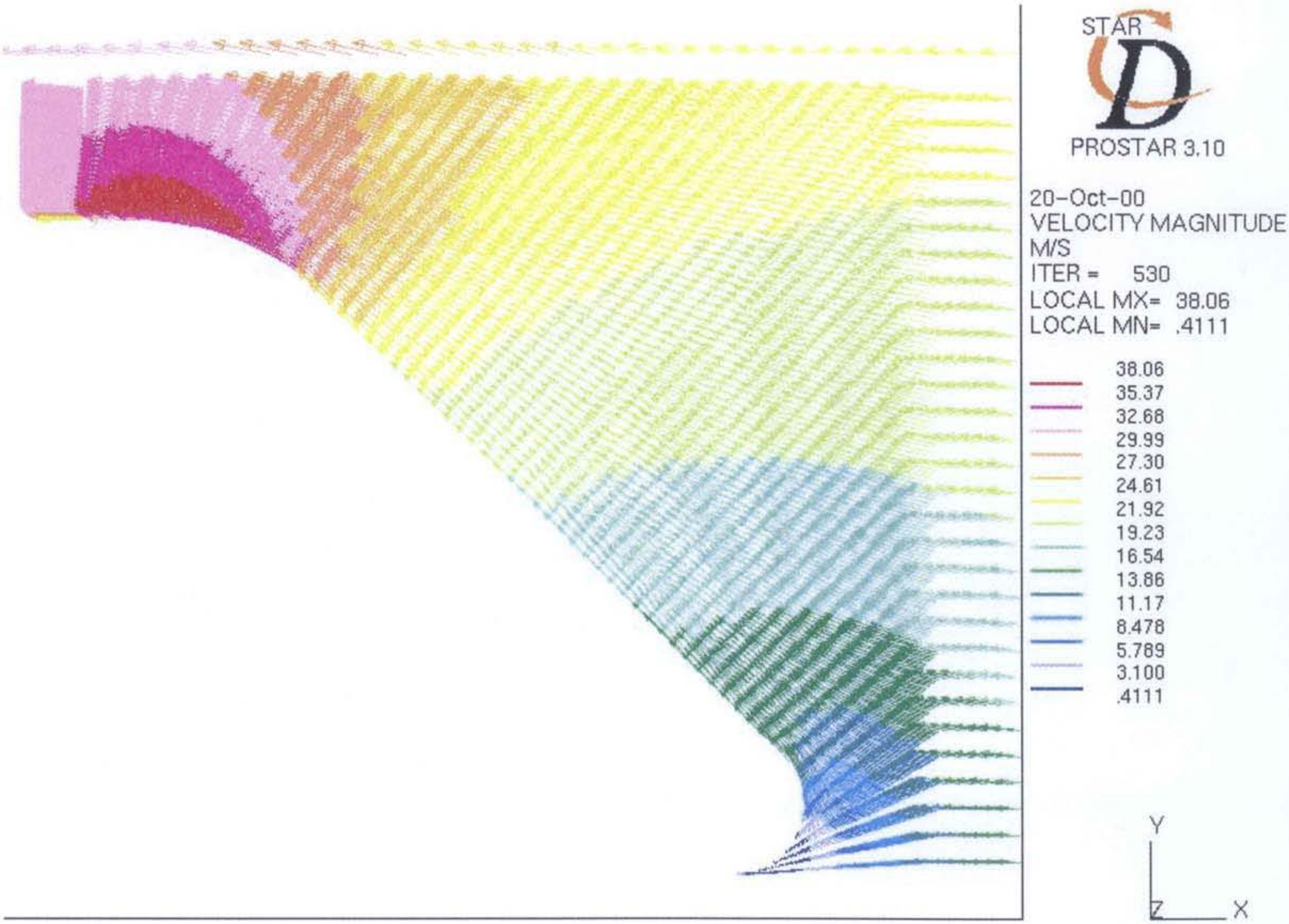

Figure 13. Air Velocity Magnitude Relative to Front of MTM.

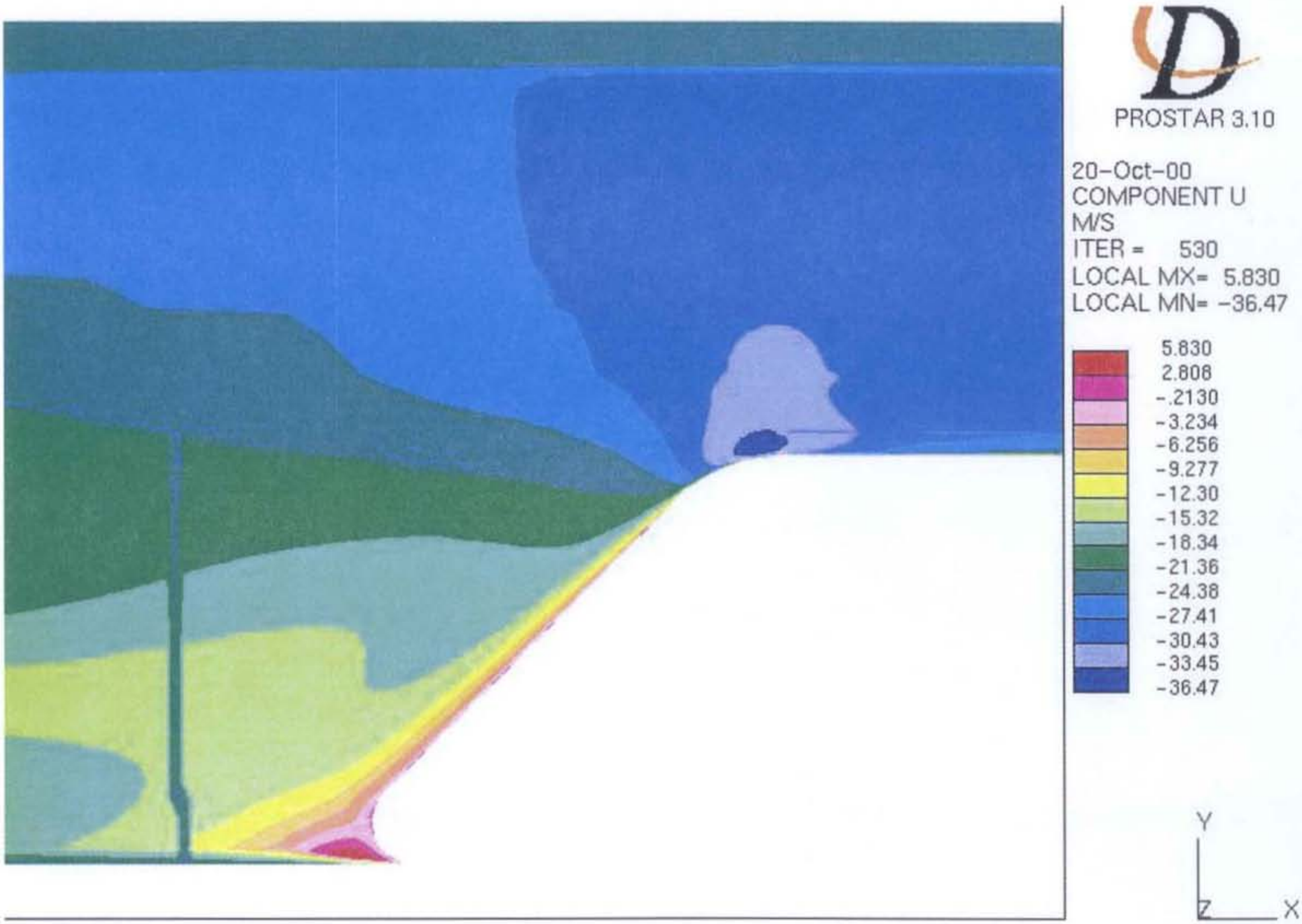

Figure 14. MTM Rear Flow Velocity Diagram.

Figure 15. MTM Rear Relative Static Pressure Diagram.

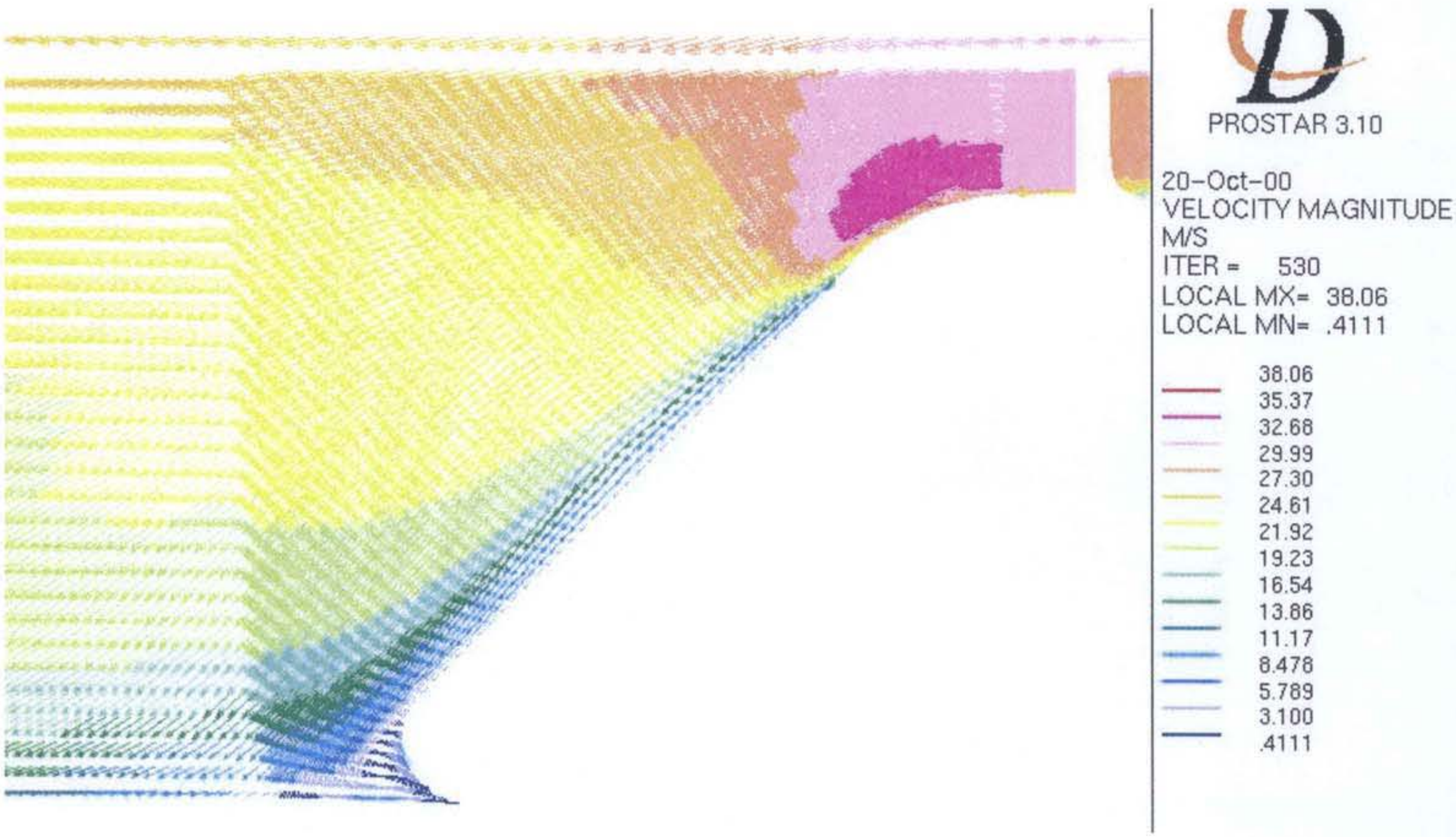

Figure 16. Air Velocity Magnitude Relative to Rear of MTM.

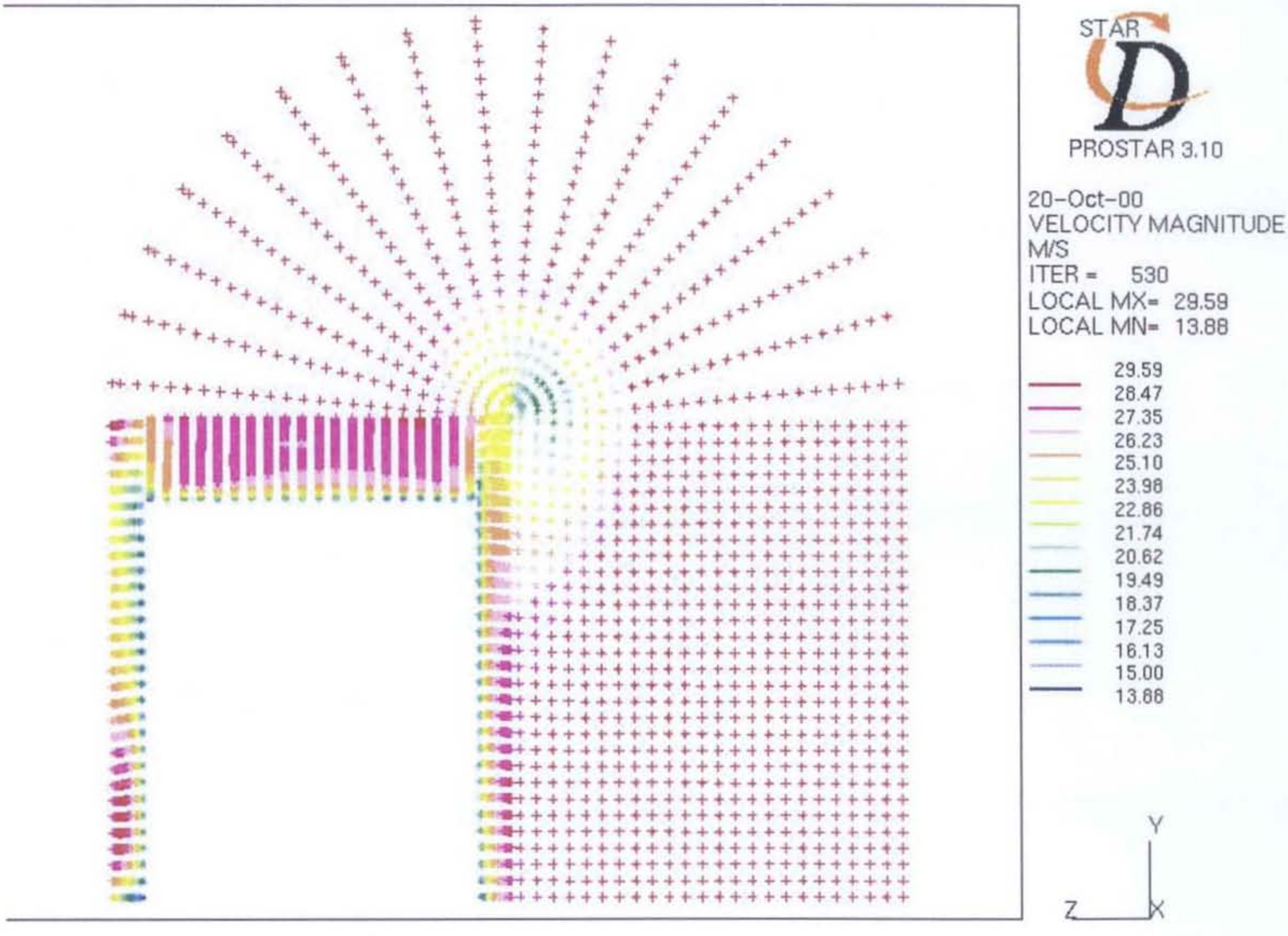

Figure 17. Air Velocity Magnitude at Rear of MTM, No Exposure.

Note: This figure represents the viewer slice being taken before any of the rear-end treatment is exposed.

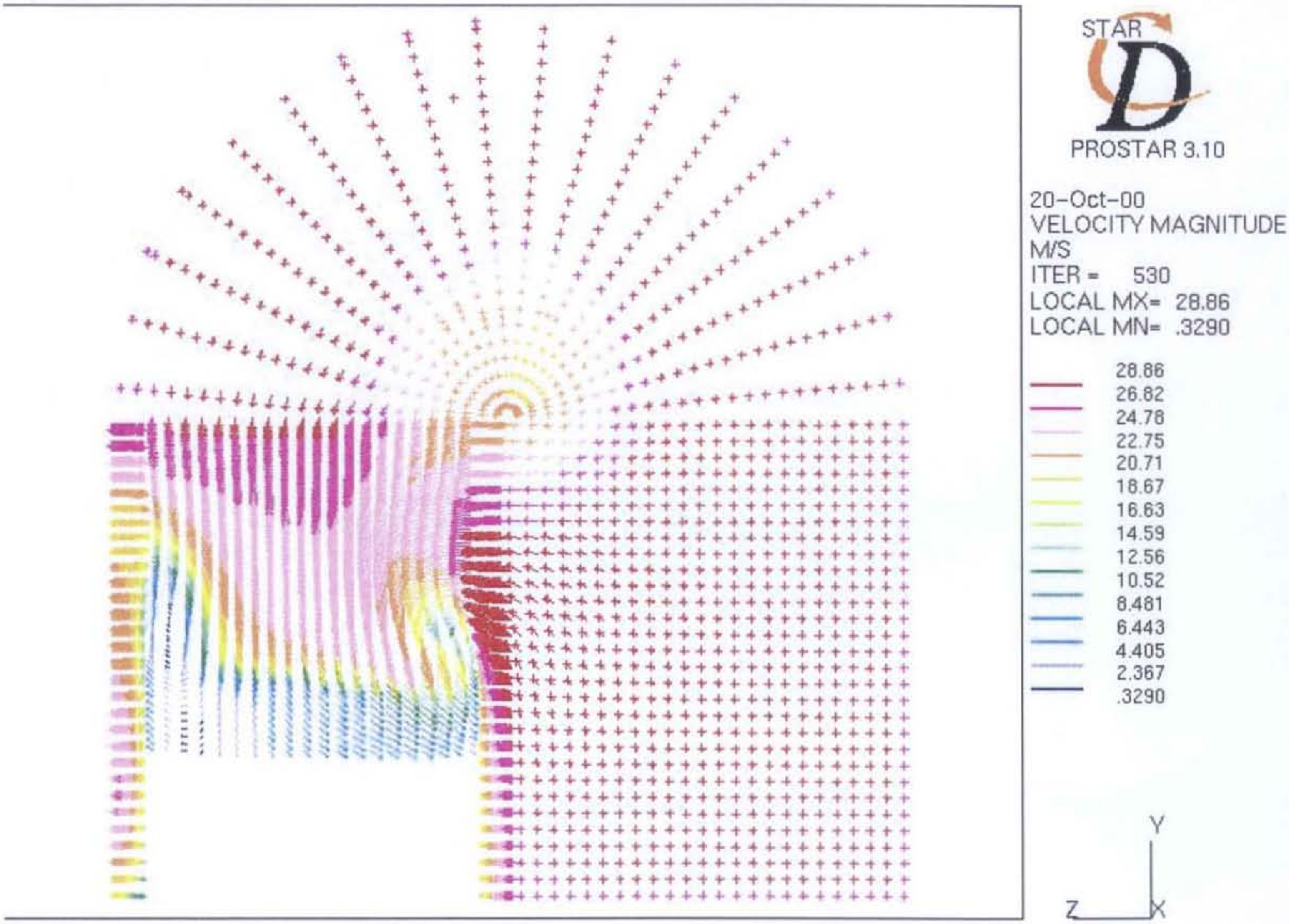

Figure 18. Air Velocity Magnitude at Rear of the MTM, Half Exposed.

Note: This figure depicts the viewer slice taken after one-half of the rear-end treatment has become exposed.

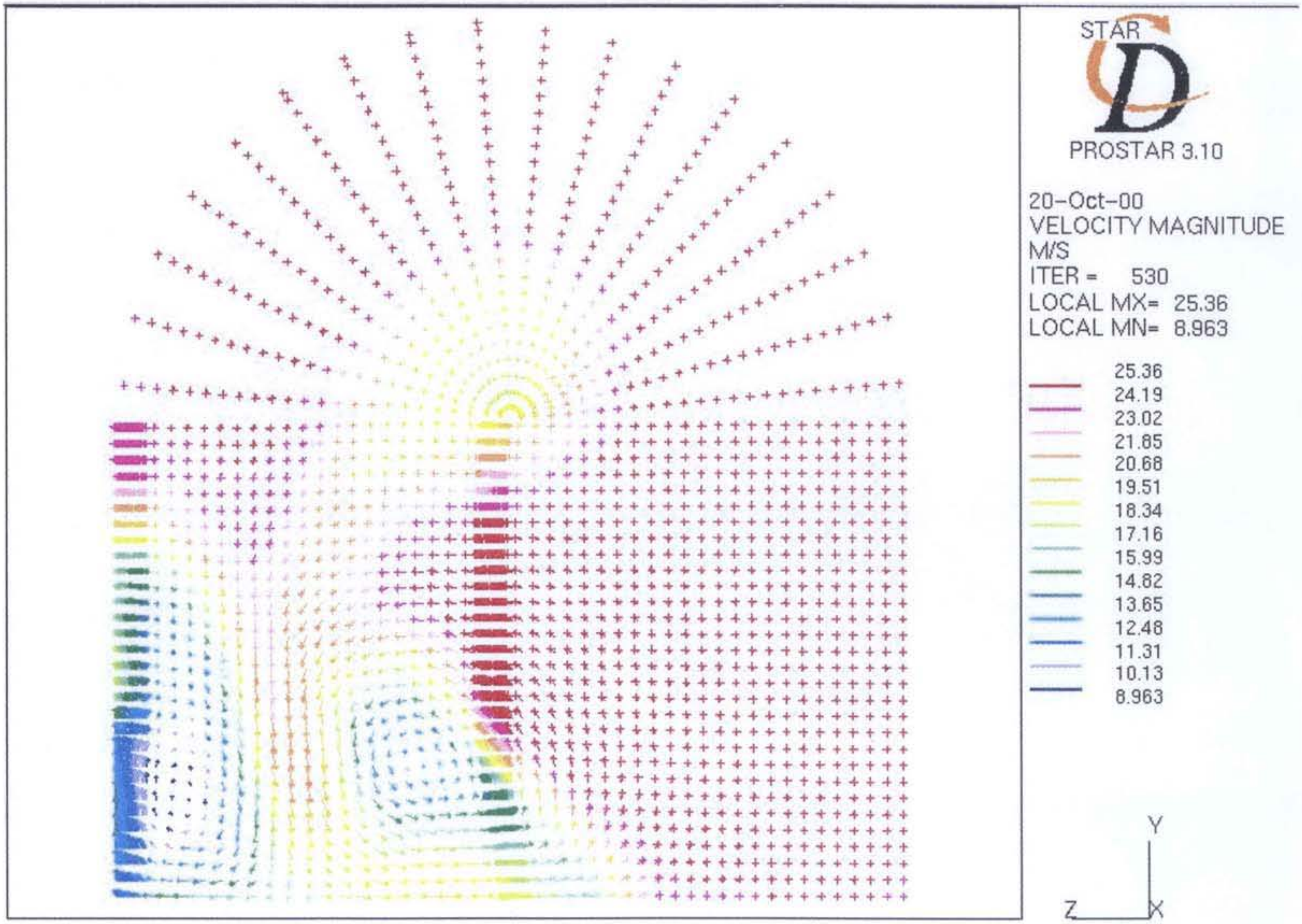

Figure 19. Air Velocity Magnitude at Rear of the MTM, Full Exposure.

Note: This figure depicts the viewer slice at the moment of full exposure of the rear-end treatment of the MTM.

GENERAL DESIGN RECOMMENDATIONS

To minimize aerodynamic drag:

- Use a continuous MTM configuration with the surface of the separate MTMs blended.
- Use a rectangular MTM (in cross section) with curvature in profile. A suitable low-drag profile is formed from two circular arcs joined by a flat section.
- Blockage ratios (β) should be kept below 0.3.
- Clearance between the upper surface of the MTM and the tunnel roof should be greater than 3 ft.
- Clearance between the tunnel side wall and the train should be greater than 3 ft.

CONCLUDING REMARKS

An analysis using computational tools has been undertaken to provide insight into the aerodynamics of a proposed freight pipeline. Researchers identified and evaluated major parameters affecting aerodynamic efficiency. Where feasible, expressions were derived to estimate these components. Analysis showed that a MTM profile consisting of an inclined flat section faired with circular arcs should provide an effective and economic configuration. Guidelines are also presented to aid in MTM-to-tunnel sizing and relative placement.

CHAPTER 7 – ENERGY CONSUMPTION FOR A FREIGHT PIPELINE SYSTEM

INTRODUCTION

In order to offer a viable alternative to truck transportation of freight, the freight pipeline must be able to compete in terms of cost per ton-mile. A significant factor determining cost per ton-mile is the amount of energy consumed by the MTM. The results of the evaluation regarding the amount of energy consumed by MTM will be reported in three parts:

- the required energy for the MTM to maintain the maximum speed of 60 mph, and no elevations with two different types of motor drives: a traction motor drive and a linear motor drive;
- the required energy for the MTM to maintain the speed of 60 mph per foot of elevation change with two different types of motor drives: a traction motor drive (4 percent slope) and a linear motor drive (30 percent slope); and
- the required energy for an acceleration of 0-30 mph in 15 seconds with two different types of motor drives: a traction motor drive and a linear motor drive.

The study used two assumptions:

- Each MTM has a total length of 125 ft and is made up of five platforms that are each 25 ft long. The entire MTM has a total weight of 50,000 lb. The weight of the cargo is also 50,000 lb, and it is evenly distributed along the length of the MTM.
- The drag forces and associated energy effects are those given in the preceding Chapter of this report as determined in the aerodynamic study carried out by the Texas A&M Aerospace Engineering Department. The aerodynamic data was supplied to the Texas A&M Department of Electrical Engineering for the following analysis.

THE REQUIRED ENERGY FOR CRUISING AT MAXIMUM SPEED

An electric motor provides the required force to sustain the MTM at maximum velocity. When the MTM reaches the maximum speed, no further acceleration is needed, and therefore, the only force that is required for cruising at this speed is the force to overcome different types of resistances. These resistances consist of the rolling resistance, the climbing resistance, and the aerodynamic drags. For this part of the analysis, the researchers assume that there are no changes in elevation; therefore, the climbing resistance is zero. Viscous shear and normal pressure load cause the aerodynamic drag on a MTM. The aerodynamic drag includes skin friction, pressure drag, and shock losses.

Skin Friction Drag

Viscosity causes a deceleration of airflow close to the capsulate wall. The resultant shear stresses acting over the capsulate surface cause the skin friction drag. The drag associated with each MTM surface may be assumed to be:

$$D_s = \frac{0.031 \rho V_1^2 W l}{(1-\beta)^2 \operatorname{Re}^{1/7}} \quad \text{(Eq. 1)}$$

where,

W= MTM width
V_1= MTM speed
l = The length of the top surface of the MTM
ρ = Air density
β = Blockage ratio
Re= Reynolds number

The Reynolds number is given by:

$$Re = \frac{\rho V_1 l}{\mu(1-\beta)} \quad \text{(Eq. 2)}$$

where μ is the air viscosity.

The Reynolds number per unit length, at a speed of 60 mph (27 m/s) and with a zero blockage ratio is 1.8×10^6/meter.

The MTM has a total length of 125 ft (37.5 m) and is made of five platforms that are each 25 ft (7.5 m) long. The cross section of the MTM is a 1.5 m × 2 m square, and the elliptical front arc is 2 m × 4 m. Figure 20 shows the side view and the cross section of the MTM, assuming the gaps between the MTMs are eliminated and the MTMs are smoothly blended.

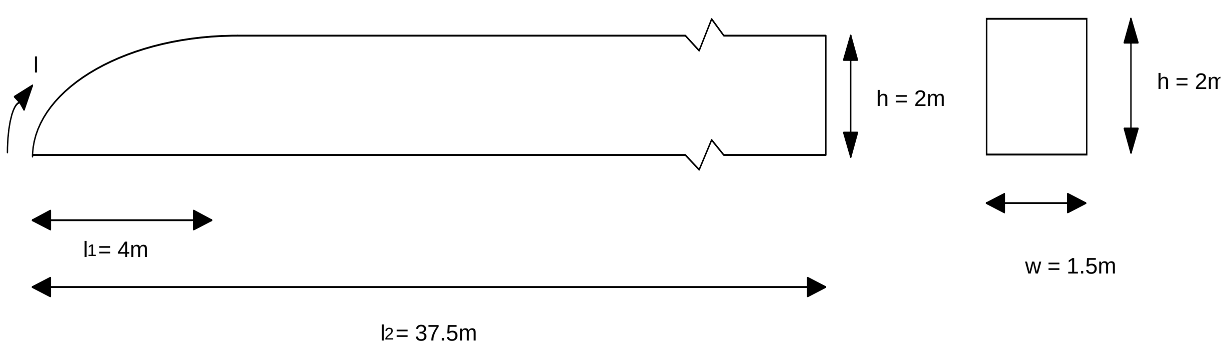

Figure 20. Side View and the Cross Section of the MTM.

The study conducted by the Department of Aerospace Engineering at Texas A&M University shows that to minimize skin friction and pressure drag, the blockage ratio should be less than 0.3. The blockage ratio β is defined as:

$$\beta = \frac{A_c}{A_t} \qquad \text{(Eq. 3)}$$

where,

A_c = The MTM cross section
A_t = The tunnel cross section

Assuming a blockage ratio of 0.3, the MTM speed of 60 mph, and the MTM dimensions shown in Figure 20, use Equation 1 to calculate the skin friction drag. D_{s1} is the skin friction on the top surface, and D_{s2} is the skin friction on the two side surfaces.

$$D_{s1} = \frac{0.031(1.2)(27)^2(1.5)(38.2)}{(1-0.3)^2(\frac{1.8x10^6 x38.2}{1-0.3})^{1/7}} = 228 \quad Newton$$

$$D_{s2} = 2\frac{0.031(1.2)(27)^2(2)(40)}{(1-0.3)^2(\frac{1.8x10^6 x38.2}{1-0.3})^{1/7}} = 639 \quad Newton$$

Pressure Drag

The first component of the pressure drag is caused by the acceleration of the flow around the sides of the train. If the flow separates from the back of the MTM, the pressure on the rear of the train is reduced. This is called Borda-Carnot condition and may exist on a MTM with a flat tail.

The maximum pressure drag (with no aft streamlining) is given by:

$$D_{p1} = \frac{\rho A_c V_1^2 \beta^2}{(1-\beta)^2} \qquad \text{(Eq. 4)}$$

Use Equation 4 to determine the pressure drag due to Borda-Carnot condition.

$$D_{p1} = \frac{(1.2)(1.5x2)(27)^2(0.3)^2}{(1-0.3)^2} = 482 \quad Newton$$

The other component of pressure drag is due to development of the boundary layer along the MTM. The reduced velocity of the fluid in the boundary layer causes the velocity of air outside the layer to increase and induces jetting. The pressure drag due to boundary layer can be obtained as:

$$D_{p2} = \Delta p.A_c \qquad \text{(Eq. 5)}$$

where,

$$\Delta p = \frac{1}{2}\rho V_1{}^2\{\frac{1}{(1-\beta)^2} - [\frac{L}{(1-\beta)(L-\delta)(1+\frac{7\delta}{8(L-\delta)})}]^2\} \qquad \text{(Eq. 6)}$$

L is the clearance between the top of the MTM and the tunnel roof, and δ is the boundary layer thickness which can be approximated as:

$$\delta = \frac{0.16l}{\mathrm{Re}^{1/7}} \qquad \text{(Eq. 7)}$$

The pressure drag component induced by jetting can be determined using Equations 5 through 7.

D_{p2} = 320 Newton

Shock Loss

This loss is due to the gaps between the MTMs. This component can be significantly reduced if the MTMs are smoothly blended.

Rolling Resistance

The rolling resistance includes friction encountered in the wheel bearings, resistance between rails and the flanges, and rolling resistance between the steel wheels and the rails due to deformation. This drag may be estimated as:

$$D_R = 3.82\frac{capsule-mass}{424.4} + 39x10^{-6}\frac{capsule-mass}{424.4}V_1 \qquad \text{(Eq. 8)}$$

The dynamic component of the rolling resistance is negligible at the speed of 60 mph.

With the total MTM mass of 50,000 lb and the cargo mass of 50,000 lb, this drag can be calculated using Equation 8.

$$D_R = 3.82\frac{100{,}000x0.45}{424.4} = 405 \ \ Newtons = 8.12 \ \ Newtons/ton$$

Total Resistance

The net force, F-F_w, accelerates (or decelerates) the train.

$F\text{-}F_w = ma$

where, F is the total motive force of the system. At a constant speed of 60 mph (no acceleration), the total force F equals the resistance force F_w.

The energy required for the MTM to maintain the speed of 60 mph is consumed in overcoming the aerodynamic drag forces and the rolling resistance. This energy per ton-mile is the sum of W_1, the energy per mile to overcome the aerodynamic drag forces and W_2, the energy per ton-mile to overcome the rolling resistance. W_1 depends on the traveling distance of the train, and W_2 depends on the traveling distance and the total weight of the train.

$$W_1 = F.d = (D_{s1}+ D_{s2} +D_{p1}+D_{p2}).1\ mi =(228+639+482+320)(1609\ m)$$
$$=2772\ kws/mi = 0.77\ kwh/mi$$

$$W_2 = F.d = D_R\ .1\ mi = 8.12\ (1609\ m) = 13.07\ kws/ton\text{-}mi = 0.0036\ kwh/ton\text{-}mi$$

$$W_o = 0.77\ kwh/mi + 0.0036\ kwh/ton\text{-}mi \qquad \text{(Eq. 9)}$$

For the total mass of 100,000 lb (50 tons) and the 450 mi distance between Laredo and Dallas, the energy required to overcome the drag forces is:

$$W_o = 0.77\ (450) + 0.0036\ (50)(450) = 427\ kwh$$

Type of the Motor Drive, Linear, and Traction Motors

In conventional rotating motors, the only degree of mechanical freedom is rotation; that is, the rotor evolves with respect to the stator. Linear electric motors are also possible, with the only degree of mechanical freedom being that of translation; that is, the moving member moves linearly with respect to the stationary member. Obviously, in a linear motor, the stationary member must extend over the entire range of motion of the moving member. The topology of linear electric machines has been known for the past several decades, and conceptually all types of motors (dc, induction, synchronous, and reluctance) are possible in a linear configuration. However, the dc motor and the synchronous motor require double excitation (field and armature), making the hardware application complex unless permanent magnet synchronous motors are used. The reluctance motor has no secondary excitation, either induced or external, and thus has a poor thrust characteristic. Hence, most attention has been focused on LIMs. The primary of LIM can be imagined to result from a rotary configuration that is cut radially and unrolled. The secondary is a linear version of a squirrel-cage rotor; that is, discrete conductors, embedded in laminated iron and shorted on both sides by end-bars. The secondary can also be made of a very simple configuration consisting of a sheet of conducting material, backed by iron. Normally, a nonmagnetic material such as aluminum is used from the sheet secondary, although a magnetic material such as iron can be used. The back iron can be solid or laminated, and can be eliminated if the conducting sheet is itself made of magnetic material.

A LIM can be either a short-primary LIM or a short-secondary LIM, depending on whether the primary or the secondary is the shorter. Furthermore, in both types of LIMs, either the primary or the secondary can be the moving member.

The problem of controlling the mechanical clearances of a linear motor is more difficult than with a rotating motor. Consequently, the linear motor must operate with a larger air gap.

The operating principles and characteristics of a linear motor are essentially similar to those of a rotating motor. The primary windings in a rotating motor close on themselves, and hence, the electromagnetic fields in the air gap are periodic in space, with the half-period being equal to the pole pitch. The short member of a linear motor, however, has a finite length and is open ended; its leading and trailing edges can be clearly defined. The electromagnetic fields in the air gap of a linear motor are, therefore, not continuously periodic in space but vary over the length of the motor and extend beyond the motor's length at both ends. This phenomenon is generally called the end effect in linear motors. The end effect is not symmetrical, extending more beyond the trailing edge. A linear motor and a rotary motor both have a finite width in the transverse direction, but the resulting effect, called the edge effect, is more pronounced in a linear motor because of the large air gap. Also, the efficiency and the power factor of a linear motor are generally poor compared to those of a rotating motor because of the large air gap.

An induction motor draws power from the primary source and transfers it to the secondary circuit across the air gap by induction. The difference between the power transferred across the air gap and the rotor losses is available as mechanical energy to drive the load. From the point of view of energy conversion, the primary resistance and the leakage reactance of the primary and the secondary circuit are not essential. Furthermore, the energy conversion efficiency is improved as the mutual reactance X_m of the motor is increased and the secondary circuit resistance R_2 is decreased. For a basic motor, therefore, one could define a goodness factor $G=X_m/R_2$; the motor performance is better when the value of G is higher.

Considering a simplified LIM topology, Laithwaite (*8*) defines a goodness factor G for a linear motor is:

$$G = \frac{2\mu_0 f \tau^2}{\pi \rho_s g} = \frac{\mu_0}{\pi \rho_s} . v_s . \frac{\tau}{g}$$

where

f = source frequency

τ = pole pitch of the primary winding

ρ_s = surface resistivity of the secondary conducting sheet

g = air gap

μ_0 = permitivity of free space

v_s = linear synchronous speed

It can be seen that a linear motor is a better energy conversion device at high synchronous speeds, and when the ratio τ/g is large. This observation can also be explained from more fundamental considerations. For example, a linear motor, just like any other electromagnetic device, has an inherent force density limitation imposed on it by the design constraints of electric and magnetic loadings. With the resulting thrust limitations, high power (thrust times speed) for a given size of motor is possible only at high speeds. Also, if the ratio τ/g is small, the primary leakage flux is large. Consequently, the effective magnetic coupling between the primary and the secondary circuits is reduced, and the LIM thus shows poor performance. The air gap is usually determined by mechanical considerations. Hence, for a given linear synchronous speed, the pole pitch, and therefore the ratio τ/g are reduced as frequency is increased.

Linear motors have been investigated for a variety of industrial applications. Some of the more exotic applications include liquid-metal pumps for sodium and sodium-potassium alloy in the nuclear industry and molten metal stirring in the steel industry. Other industrial applications include shuttle propulsion and threading guides for package winders for the textile industry, industrial conveyors, and actuators. However, the most extensive application of LIMs has been in the field of ground transportation. These applications include low-speed and high-speed transportation of passenger and booster-retarders for classification yards.

For linear motor applications in ground transportation, the nominal air gap is governed by operational and mechanical considerations – not by electromagnetic considerations. The LIM air gap is, therefore, quite large (up to 20 mm) compared to that of a rotary motor, which is typically of the order of 1 mm. With such a large gap, LIMs are used where a rotating motor – limited by operational considerations such as a necessity for contactless propulsion, a low-profile vehicle, a light truck design, and so on – cannot do an adequate job. Recently there has been a growing interest in permanent magnet synchronous motors, since the large air gap in these motors is not detrimental. The reason is that there is no need for the magnetizing current to be supplied by the primary winding, and the secondary flux is developed by the secondary magnets.

Conclusions

The energy W_o calculated in the section on total resistance is the energy that should be provided at the output of the motor to maintain the speed of 60 mph. The energy consumed by the motor at the input depends on the motor efficiency:

$$W_{in} = \frac{W_0}{\eta}$$

where η is the efficiency of the motor.

Generally, the efficiency of linear motors is lower than that of rotary motors. On the other hand, there is no gear loss involved with the linear motors. For this part of the analysis, we can assume that the energy loss in the gears attached to a traction motor is about the same as the energy loss due to the lower efficiency of a linear motor.

The typical value of the efficiency for a linear induction motor is about 0.5. Therefore, for cruising at the maximum speed of 60 mph using a linear motor drive, the MTM consumes about twice the energy per ton-mile given by Equation 9.

w_{in} = 1.54 kwh/mi + 0.0072 kwh/ton-mi (Eq. 10)

For a traction motor drive, the efficiency is higher, but the gear loss has to be included. For more precise comparison of the energy consumptions of the two different types of motor drives, we need to know the parameters and characteristics of the linear motor and the type of gears used in the traction motor.

THE REQUIRED ENERGY FOR CRUISING AT MAXIMUM SPEED PER FOOT OF ELEVATION

In this section, we will determine the required energy for the train to travel an incline up at the constant speed of 60 mph. We will calculate this energy assuming a slope of 4 percent for a traction motor drive and 30 percent for a linear motor drive.

TRACTION MOTOR DRIVE

When the MTM is traveling the inclined up road with the rate of 4 percent change of elevation, the component of weight in the direction of the incline, *(m.g.sinα)* works against its movement. The aerodynamic drag is independent of the slope, and it is only a function of the speed, the blockage ratio, dimensions of the MTM, and the size of the tunnel as discussed earlier in this report. The rolling friction is a function of the weight, the angle α, and the coefficient of friction.

Figure 21 shows the free body diagram of the train. Applying the equation of motion along the inclined path, we have:

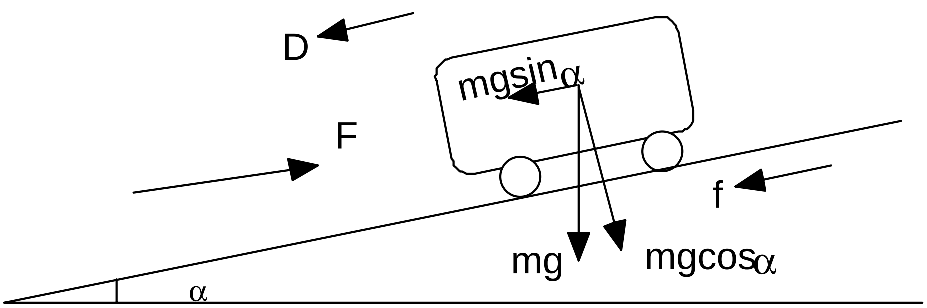

Figure 21. Free Body Diagram.

$$F - D - f - mg \sin \alpha = ma = 0 \quad \text{(Eq. 11)}$$

The aerodynamic drag *D* includes the skin friction and the two components of the pressure drag. As calculated earlier in this report:

$$D = D_s + D_{p1} + D_{p2} = 228 + 693 + 482 + 320 = 1669 \quad \text{N} \quad \text{(Eq. 12)}$$

The rolling friction drag is determined by the component of weight perpendicular to the incline. This requires the MTM mass in Equation 8 to be multiplied by $\cos\alpha$.

$$f = D_R = 3.82\frac{m\cos\alpha}{424.4} + 39x10^{-6}\frac{m\cos\alpha}{424.4}V_1 \qquad \text{(Eq. 13)}$$

For a slope of 4 percent, α is given by:

$$\alpha = \tan^{-1} 0.04 = 2.3^{\circ} \qquad \text{(Eq. 14)}$$

Since α is small, the second term in Equation 13 is negligible at the speed of 60 mph (27 m/s). Therefore, the rolling friction drag is:

$$f = 3.82\frac{100{,}000 x 0.45 x \cos(2.3^{\circ})}{424.4} = 404.7 \ \ Newtons = 8.1 \ \ Newtons/ton \qquad \text{(Eq. 15)}$$

The component of weight in the direction of the incline is:

$$mg\sin\alpha = 100{,}000\, x\, 0.45\, x\, 9.81\, x \sin 2.3^{\circ} = 17716 \quad \text{N} \qquad \text{(Eq. 16)}$$

Therefore, the motive force F is:

$$F = 1669 + 404.7 + 17716 = 19789.7 \quad \text{N} \qquad \text{(Eq. 17)}$$

The distance that the train travels on a 4 percent incline ($\alpha = 2.3^{\circ}$) per foot of elevation is:

$$d = \frac{1}{\tan\alpha} = 24.9 \ \ ft \ = 24.9\, x\, 0.3 = 7.47 \ \ m \qquad \text{(Eq. 18)}$$

Therefore, the energy required for the MTM to travel at the constant speed of 60 mph on a road with a slope of 4 percent, per ton per foot of elevation, is

$$\begin{aligned} W_o &= 1669\, N\, x\, 7.47\, m/\ ft\ of\ elevation + (8.1 + 354.3)\, N/ton\, x\, 7.47\, m/\ ft\ of\ elevation \\ &= 12.47\, kws/\ ft\ of\ elevation + 2.707\, kws/ton - \ ft\ of\ elevation \end{aligned} \qquad \text{(Eq. 19)}$$

This result is the required energy at the output of the motor to overcome all the opposing forces. The input energy consumed by the MTM depends on the efficiency of the traction motor. Assuming 50 percent efficiency (including the gear loss), we need to supply twice the energy calculated in Equation 19 per foot of elevation, per ton:

$$\begin{aligned} w_{in} &= \frac{w_o}{0.5} \\ w_{in} &= 25 kws/\ ft\ of\ elevation + 5.4\, kws/ton - \ ft\ of\ elevation \end{aligned} \qquad \text{(Eq. 20)}$$

Linear Motor Drive

One of the advantages of using a linear motor drive for the MTM is the capability of handling sharp inclined pipeline without slipping. If the MTM pipeline system is powered by a linear electric motor, the primary windings of the linear motor are attached to the MTM and the secondary windings are located on the rails. Therefore, it is the magnetic force that pushes the MTM forward, and the wheels just help to maintain the air gap.

In the case of a traction motor drive, the torque is applied to the wheel axle by a rotary motor, and therefore we need enough frictional force between the wheels and the rails to push the MTM forward. The coefficient of friction for the steel wheel-steel rail surface is very small. Because of the low friction and heavy weight of the MTM and cargo, it cannot travel on a sharp inclined pipeline.

The energy calculation of the MTM powered by a linear motor is similar to that of the traction motor. With a linear motor drive, the MTM can handle a higher rate of elevation. In this section, we will determine the energy consumption for the freight pipeline system using a linear motor drive and a slope of 30 percent.

The aerodynamic drag is independent of the slope, and it will be the same as the drag calculated in Equation 12, which is given by:

$$D = 1669 \quad \text{N}$$

For a slope of 30 percent, α is:

$$\alpha = \tan^{-1} 0.30 = 16.7^{\circ}$$

The distance that the train travels on a 30 percent inclined pipeline ($\alpha = 16.7^{\circ}$) per foot of elevation is:

$$d = \frac{1}{\tan\alpha} = 3.33 \ \ ft \ \ = 24.9 \ ft \, x \, 0.3 \ m/ft = 1 \ m$$

The rolling friction drag is:

$$f = 3.82 \frac{100{,}000 x 0.45 x \cos(16.7^{\circ})}{424.4} = 388 \ \ N = 7.76 \ \ N/ton$$

The component of weight in the direction of the incline is:

$$mg \sin\alpha = 100{,}000 \, x \, 0.45 \, x \, 9.81 \, x \sin 16.7^{\circ} = 126{,}855 \ \ N \ = 2537.1 \ \ N/ton$$

Therefore, the motive force *F* that is the sum of all the opposing forces is:

$$F = 1669 + 388 + 126{,}855 = 128{,}912 \quad \text{N}$$

Therefore, the energy required for the MTM to overcome the drags and the weight while traveling at the constant speed of 60 mph on a road with a slope of 30 percent, per ton per foot of elevation, is:

$$W_o = 1669\,N\,x1\,m/\,ft\,of\,elevation + (7.76 + 2537.1)\,N/ton\,x1m/\,ft\,of\,elevation$$
$$w_o = 1.67\,kws/\,ft\,of\,\,elevation + 2.54\,kws/ton -\,ft\,of\,\,elevation$$

Assuming a minimum efficiency of 50 percent the energy consumed by the freight pipeline system per foot of elevation, per ton, is:

$$w_{in} = 3.34\,kws/\,ft\,of\,\,elevation + 5.08\,kws/ton -\,ft\,of\,\,elevation \qquad \text{(Eq. 21)}$$

CONCLUSION

The energy consumed by the freight pipeline system has been determined for two different types of motor drives, the traction motor drive with a 4 percent rate of change of elevation and the linear motor drive with a 30 percent rate. Equations 20 and 21 show that the linear motor drive is more energy efficient for traveling up the inclined pipeline because of its capability of handling a higher rate of elevation change. For example, the energy required for a 100,000 lb MTM to increase its elevation by 10 ft, at the constant speed of 60 mph, with a traction motor drive and a slope of 4 percent can be compared to that energy with a linear motor drive and a slope of 30 percent.

Traction motor drive (4 percent slope):

$$w_{in} = 25kws/\,ft\,of\,\,elevation + 5.4\,kws/ton -\,ft\,of\,\,elevation$$
$$= (25 + 5.4\,x\,50\,ton)\,x10\,\,ft = 2950\,kws = 0.82\,kwh$$

Linear motor drive (30 percent slope):

$$w_{in} = 3.34\,kws/\,ft\,of\,\,elevation + 5.08\,kws/ton -\,ft\,of\,\,elevation$$
$$= (3.34 + 5.08\,x\,50\,ton)\,x10\,\,ft = 2573\,kws = 0.71\,kwh$$

Therefore, the MTM powered by a linear motor (30 percent slope) is about 15 percent more efficient than MTM powered by a traction motor (4 percent slope) when traveling up the inclined pipeline. In addition to the higher energy consumption, we need to increase the length of the pipeline to decrease the rate of elevation change for the case of a traction motor drive. This will increase the cost of the construction of the pipeline.

CALCULATION FOR THE POWER REQUIRED TO TRANSPORT A PALLET

It is assumed that the pallets are loaded on the MTMs. The power required to transport the MTM is determined by knowing the weight of the MTM. The weight of each MTM is determined by the number of pallets carried. Each MTM can vary from one to six pallets.

The main criteria in determining the power required are the drag force (Fd) and rolling friction (f).

Weight of the MTM = 2000 to 4000 lb (assume 2000 lb in this case for one pallet). The MTM should attain a velocity of 50 mph in 60 seconds.

The drag force Fd = 0.1 $\times$ (velocity)^2 , where the drag coefficient = 0.1.

The rolling resistance f = $\mu_R \times$ weight,

μ_R = 0.02 to 0.04 for pneumatic tires on smooth road,
μ_R = 0.001 to 0.005 for hardened steel on steel.

Assume μ_R = 0.05 (with an extra factor).

Therefore,

V = 50 mph = 22.35 m/s
t = 60 s
N = M $\times$ g = 2000 lb
= 2000 $\times$ 4.45 = 8.9 kN
M = 907 kg

Figure 22 shows the relationship of the forces impacting the power requirements.

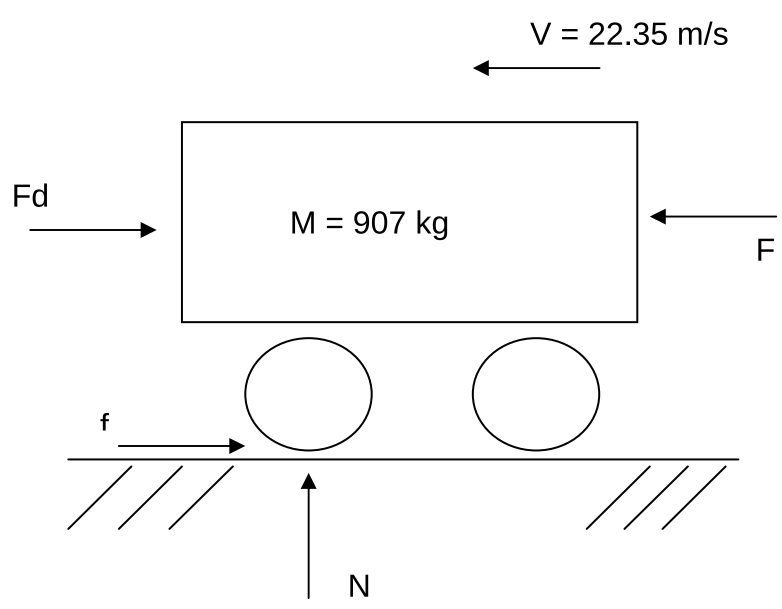

Figure 22. Forces Impacting Power Requirements.

Power Required (Pmax) to Accelerate the MTM from 0 to 50 mph in 60

Applying Newton's laws,

$$\begin{aligned} F_{max} &= M \times dV/dt + F_d + f \\ &= (907)\times(22.35/60) + 0.1 \times (22.35)^2 + 0.05 * (8900) \\ &= 832.8\ \text{N} \end{aligned}$$

Power: $$\begin{aligned} P_{max} &= F_{max} \times V \\ &= 832.8 \times 22.35 = 18.6\ \text{kW} \end{aligned}$$

Pmax = 24.95 HP

Power Required to Maintain the Velocity at 50 mph

The force is needed only to overcome friction and drag force.

$$\begin{aligned} F &= F_d + f \\ &= 0.1 \times (22.35)^2 + 0.05 * (8900) \\ &= 495\ \text{N} \end{aligned}$$

Power, $$\begin{aligned} P &= F \times V \\ &= 495 \times 22.35 = 11.1\ \text{kW} \\ &= 14.8\ \text{HP} \end{aligned}$$

Hence, to calculate the power required for the pallet movement, only the Pmax needs to be considered. Additional calculations are given in Table 8. The values for drag coefficient and the rolling resistance can be suitably changed. In this example, the worst case is considered.

To Calculate the Power for Six Pallets

We multiply the power for one pallet by six to calculate the power required for the MTM to transport six pallets.

Table 8. Summary of Power Requirement Calculations.

1. Power Calculations per Pallet

	Weight of the pallet	2000	3000	4000	lbs
N =	x 4.45 kN	8900	13350	17800	N
	Mass of the pallet	907.2	1360.9	1814.5	kgs
	Velocity	50			mph
V	x 0.447 m/s	22.35			m/s
t	Time	60			secs
Fd	Drag Force = 0.1 * (velocity)^2			50.0	N
	Rolling friction = .05 * (weight of the pallet)				
f		445	667.5	890	N

1 The Max. driving force F needed to accelerate the pallet from 0- 50mph

F = M* dV/dt + Fd + f

dV /dt = 0.3725 m/s^2

Fmax.	F =	832.9	1224.4	1615.8	N
	Power required: F x velocity				
	P =	18.6	27.4	36.1	kW
Pmax		**25.0**	**36.7**	**48.4**	**HP**

2 The force required to keep the pallet moving at a constant velocity

F = Fd + f

F2	F =	495.0	717.5	940.0	N
	Power required:				
	P =	11.1	16.0	21.0	kW
P2		14.8	21.5	28.2	HP

Since Pmax > P2, the required power considered is only Pmax.

THE REQUIRED ENERGY FOR THE MTM TO ACCELERATE FROM 0 TO 30 MPH IN 15 SECONDS

In this section, we will determine the required energy for initial acceleration and design of the proper electric motor to provide this energy. The initial acceleration force takes the MTM from standstill to its rated velocity, Vrv, in some specified time, t_a seconds. This force is supplied entirely by the electric motor.

Assuming that the MTM speed reaches its maximum of 60 mph (27 m/s) in 30 seconds, and the weight of the MTM and the cargo together is 100,000 lb, researchers can determine the required force for the initial acceleration:

$$a = \frac{27}{30} = 0.9 \quad {}^{m}\!/_{s^2}$$

$$F = m\,a = 100{,}000\,lb \times 0.45\frac{kg}{lb} \times \frac{27\,{}^{m}\!/_{s}}{30\,s} = 40{,}500 \quad \text{N} \qquad \text{(Eq. 22)}$$

The energy associated with the initial acceleration is the product of the force by the distance that the MTM travels before reaching the speed of 60 mph:

$$w = F.d$$

To find the distance, we should integrate the acceleration twice:

$$d = \int_0^{30} \int a \ dt = \int_0^{30} 0.9t \ dt = 405 \ m$$

Therefore, neglecting the drag forces and assuming a level tunnel during the initial acceleration, the energy required for acceleration is:

$$w = 40{,}5000 \times 405 = 16{,}403 \ \ kws = 4.6 \ kwh$$

This is the energy that accelerates a 100,000 lb (50 ton) MTM over a distance of 405 m (0.25 mi) traveling in 30 seconds. Therefore, the acceleration energy per ton-mile is:

$$w = \frac{4.6}{50 \times 0.25} = 0.36 \qquad {}^{kwh}\!/_{ton-mi} \qquad \text{(Eq. 23)}$$

The energy required to overcome the drag and rolling resistance at the constant speed of 60 mph is given by Equation 9. To include the drag, since the speed is varying during the initial acceleration, add approximately half of this energy to the acceleration energy:

$$w_a = 0.36\ \frac{kwh}{ton-mi} + \frac{1}{2}\left(0.77\ \frac{kwh}{mi} + 0.0036\frac{kwh}{ton-mi}\right)$$

$$= 0.39\ \frac{kwh}{mi} + 0.36018\ \frac{kwh}{ton-mi} \qquad \text{(Eq. 24)}$$

This is the energy required for the initial acceleration at the output of the MTM system. To determine the required energy at the input, we should include the efficiency of the electric motor and the gear loss. The power loss in the gears depends on the force applied to the gears and the speed of the gears. Therefore, we need to estimate the power and the speed of the electric motors in our designed system.

System Design

A typical torque speed profile of a variable speed electric motor is shown in Figure 23. The electric motor during its normal mode of operation can provide constant rated torque up to its rated speed. At this speed, the motor reaches its rated power limit. The operation beyond the base speed and up to the maximum speed is limited to this constant power region. The range of the constant power operation depends primarily on the particular motor type and its control strategy. However, some electric motors digress from the constant power operation, beyond a certain speed, and enter the natural mode before reaching the maximum speed. The maximum available torque in the natural mode of operation decreases inversely with the square of the speed. This range of operation is neglected in our analysis. It is assumed that the electric motor operates in the constant power region beyond the base speed and up to the maximum speed.

In order to free up the motor speed from the vehicle speed, for design optimization, gearing between the motor shaft and the drive shaft is required The gear ratio and size will depend on the maximum motor speed, maximum MTM speed, and the wheel radius. Higher maximum motor speed, relative to train speed, means a higher gear ratio and a larger gear size.

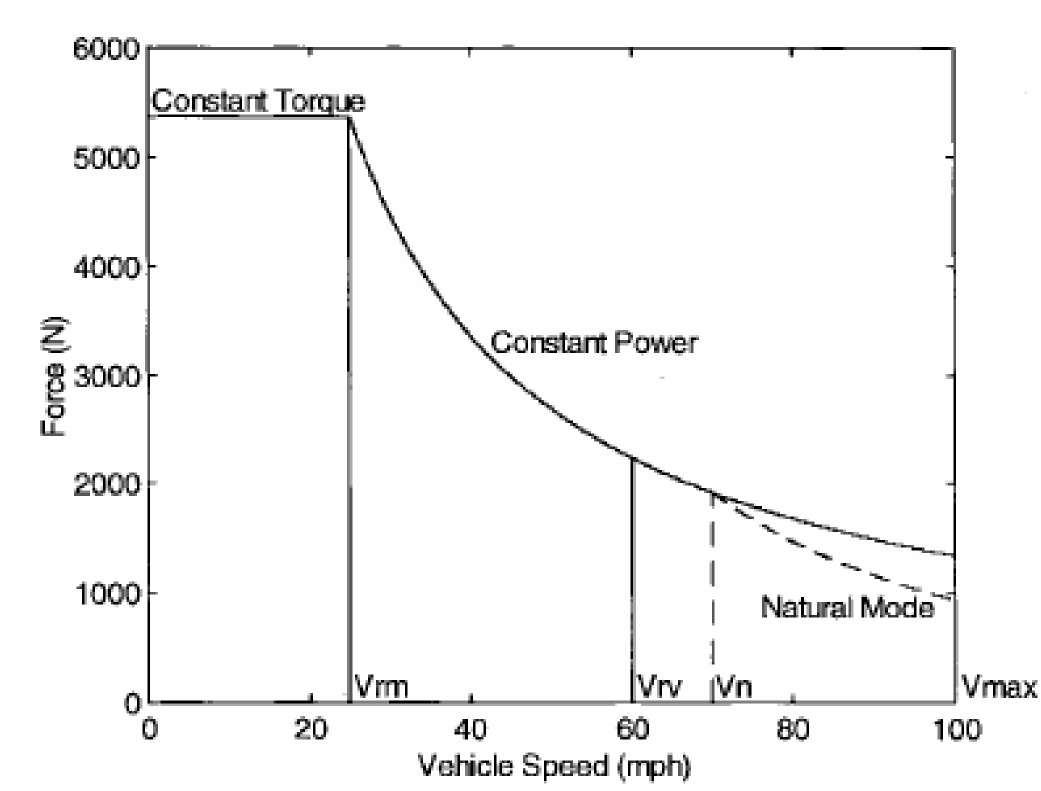

Figure 23. Typical Torque-Speed Profile of Electric Motor in Terms of Tractive Force and Vehicular Speed.

Initial Acceleration

In the torque speed curve of Figure 23, Vrm is the motor rated speed, and Vrv is the MTM rated speed. The range of operation for initial acceleration is 0 - Vrv. In the constant torque region (0 - Vrm), F = P_m /Vrm, and in the constant power region (Vrm-Vrv), F = P_m /V.

$$F - F_w = ma = m\frac{dv}{dt} \qquad \text{(Eq. 25)}$$

F is the motive force from the electric motor, and F_w is the running resistance (drag forces). The boundary conditions are:

at t =0, MTM velocity V= 0; and
at t= t_a, MTM velocity V= Vrv.

Solve Equation 25 by simplifying assumptions during the initial acceleration:

- MTM is on level ground.
- Running resistance F_w is zero.

With these simplifying assumptions the governing differential equation reduces to:

$$a = \frac{dv}{dt} = \frac{F}{m}$$

The differential equation is solved with the previous boundary conditions and the torque-speed profile of Figure 23 given by:

$$m \int_0^{V_{rv}} \frac{dv}{F} = \int_0^{t_a} dt$$

The left-hand side integral is broken into two parts, the (0 - V_{rm}) constant torque operation and the (V_{rm} - V_{rv}) constant power operation:

$$m \int_0^{V_{rm}} \frac{dv}{P_m / V_{rm}} + m \int_{V_{rm}}^{V_{rv}} \frac{dv}{P_m / V} = t_a$$

Solving for P_m, reveals:

$$P_m = \frac{m}{2 t_a} (V_{rm}^2 + V_{rv}^2) \quad \text{(Eq. 26)}$$

For minimum power, differentiating with respect to V_{rm} and setting it to zero gives:

$V_{rv} = 0$

This establishes a theoretical limit for minimum motor power. Therefore, the motor should operate entirely in the constant power region for minimum power. Of course, operation entirely in the constant power region is not practically realizable. However, this theoretical discussion demonstrates that longer constant power range of operation will lower the motor power.

The driving force of the MTM is provided by 12 electric motors. Equation 26 can be used to determine the power rating of the MTM motors. In this equation, the total mass 'm,' the acceleration time 't_f,' and the MTM speed 'V_{rv}' are known. The rated motor speed 'V_{rm}' depends on the range of the constant power region. For example, if the MTM rated velocity is 60 mph, and constant power region is extended to 10 times the rated motor speed (K=10), the rated motor speed V_{rm} in Equation 26 is 6 mph. The power rating calculations are summarized in Table 9 for different values of 'K.' The corresponding angular rated motor speed ω_{rm} is also given for two different wheel diameters 'd' and four different gear ratios 'g.' K is the ratio of the motor speed when the MTM has its rated speed, to the rated motor speed. It determines the length of the constant power region in Figure 23. A larger K indicates a longer constant power range of operation. Simplify Equation 26 as:

$$P_m = \frac{m}{2t_a}(V_{rm}^2 + V_{rv}^2) = \frac{m}{2t_a} V_{rv}^2 (1 + \frac{1}{K^2})$$

$$p_m = \frac{100{,}000\,lb \times 0.45\,{}^{kg}\!/_{lb}}{2 \times 30\ s} \times (27\ {}^{m}\!/_{s})^2\ (1 + \frac{1}{K^2}) = 546{,}750\ (1 + \frac{1}{k^2}) \qquad \text{W}$$

$$= 546{,}750\ w \times \frac{1hp}{746\,w}\left(1 + \frac{1}{k^2}\right) = 732.9(1 + \frac{1}{k^2}) \qquad \text{hp} \qquad \text{(Eq. 27)}$$

Table 9. Motor Power and Speed Ratings Required for the Initial Acceleration with Different Ranges of Constant Power Region, Wheel Sizes, and Gear Ratios.

K	Pm (w)	Pm (hp)	Wrm (rpm) d=12", g=2	Wrm (rpm) d=12", g=3	Wrm (rpm) d=12", g=5	Wrm (rpm) d=12", g=10	Wrm (rpm) d=24", g=2	Wrm (rpm) d=24", g=3	Wrm (rpm) d=24", g=5	Wrm (rpm) d=24", g=10
10	546,750	61.7	344	517	860	1,720	172	259	430	860
8	555,293	62	430	645	1,075	2,150	215	323	537	1,075
5	568,620	63.5	688	1,032	1,720	3,440	344	516	860	1,720
3	634,230	70.8	1,376	2,064	3,440	6,880	688	1,032	1,720	3,440
2	789,750	88.2	2,293	3,440	5,733	11,467	1,147	1,720	2,867	5,733
1	1,093,500	122.2	3,440	5,160	8,600	17,200	1,720	2,580	4,300	8,600

The MTM rated angular velocity ω_{rv} , in terms of the wheel diameter, can be determined as:

$$\omega_{rv} = \frac{V_{rv}}{\pi\, d} \times 60 \qquad \text{rpm} \qquad \text{(Eq. 28)}$$

At the speed of 60 mph, a wheel diameter of d = 12 inches, yields ω_{rv} = 1720 rpm and a wheel diameter of 24 inches, yields ω_{rv} = 860 rpm. The rated motor speed ω_{rm}, which depends on the gear ratio 'g' and the velocity ratio 'K' can be determined as:

$$\omega_{rm} = \frac{\omega_{rv}}{K} \times g \qquad \text{(Eq. 29)}$$

Table 9 demonstrates that longer constant power range of operation (larger K) will lower the motor power. The power requirement is not a function of the motor maximum speed. Motor maximum speed only affects the gear size. However, maximum speed has a pronounced effect on the rated torque of the motor. Low-speed motors with extended constant power ranges have a much higher rated shaft torque. Consequently, they need more iron and copper to support this higher flux and torque. Therefore, although the power requirement will decrease with increasing constant power range, the motor size, volume, and cost will increase with increasing constant power range. The motor size can only be reduced in this case by increasing the maximum speed of the motor. The motor maximum speed on one hand cannot be increased indefinitely without incurring more cost. On the other hand, high maximum motor speed would require a big transmission. Hence, a multitude of system level conflicts exist with the extension of the constant power range. However, it is possible to arrive at an optimum value of the constant power range based on the cost and the performance analysis. Extended constant power range, on the other hand, will increase drive shaft torque and stress on the gear. Hence, another design trade-off is involved between the gear stress and the extended constant power range. It can be seen from the results of Table 9 that after a certain point, there is no appreciable power reduction with extended constant power range. Any further extension of constant power range beyond this point will adversely affect the gearing and the drive shaft torque without reducing the power requirement. This will set the upper limit of the extended range of the constant power operation.

An optimum choice for the MTM motors from Table 9 can be 12 motors at the rated power of 70.8 hp, the rated speed of 1032 rpm with a gear ratio of 3, and the wheel diameter of 24 inches. With this choice, the motor will operate within the constant power range up to three times the base speed.

Gear Loss

Power losses in gear trains are associated principally with two factors: tooth friction and churning losses. Churning losses are relatively independent of the nature of the gear train and the reduction ratios, and for this reason, they tend to be less significant in the design stage than frictional losses. The frictional losses, which are strongly dependent on the arrangement of the gear train and the reduction ratios, have been the subject of considerable investigation. Tables are available for calculating the energy lost by friction during tooth engagement for a single mesh as a function of pressure angle, gear ratio, gear size, and an assumed average value of the coefficient of friction. These tables involve an analysis of the contact forces and sliding velocities occurring between contacting gear teeth. The choice of an average coefficient of friction is based on the materials involved, the lubricant, if any, service conditions and experience.

For preliminary design calculations, the significance of power-loss determination can be particularly high in gear arrangements involving split power paths and/or large reductions, such as can occur in planetary gear trains and differentials. In such trains power loss due to friction can be critical and needs to be estimated in order to size both the gears and the capacity of the motor or other driving element.

In order to arrive at an estimate, which provides a good first approximation with minimum calculation, we follow the recommendation of Buckingham, which is still a good one even today. This, in effect, states that for average operating conditions, the power loss at each mesh can be approximated as 1 percent of the potential power transmitted through the mesh. Figures quoted in the literature vary from less than 0.5 percent to 2 percent, and the reader can always adjust the percentage if desired (*9*).

The concept of potential power, explained in the following paragraph, provides an estimate of power loss, which is acceptable for preliminary design purposes.

The Basic Principle of Power-Loss Determination

Every spur gear train consists of a combination of simple meshes consisting of two meshing gears and the associated arm, as shown in Figure 24. Except in very rare cases, the arm is either stationary or rotating about a fixed axis (the axis of one of the gears). Once we can determine the power loss in this simple system, we can determine the power loss in an entire planetary or other gear train.

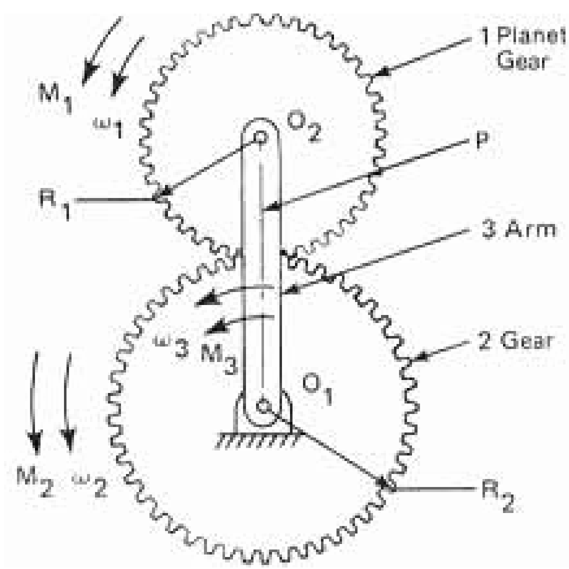

Figure 24. Planetary Spur Gear Train (*9*).

In Figure 24, both gears and the arm are rotating. The tangentially transmitted force, F_{12}, between gears 1 and 2 can be determined. According to Buckingham, the rate at which power is lost in friction is proportional to the product of the tangentially transmitted force and the velocity of tooth engagement. The linear velocity of tooth engagement is equal to the product of the pitch radius and the angular velocity of tooth engagement (*9*).

If the arm was stationary, the linear velocity of tooth engagement would simply be the velocity, v_{12}, of the pitch point P. The magnitude of the product of F_{12} and v_{E12} is the potential power according to Buckingham (*9*). The power loss due to tooth friction is proportional to this product and estimated at 1 percent. Thus, denoting the power loss by ΔP_{12}, we have:

$$\Delta P_{12} = | F_{12} . V_{E12}| (0.01) \quad \text{(Eq. 30)}$$

Consider the simple spur gear train in Figure 25, which shows the pitch circles and nomenclature. A driving torque, M_1 (positive counterclockwise) acts on gear 1, and a load torque, M_2 (also positive counterclockwise), acts on driven gear 2.

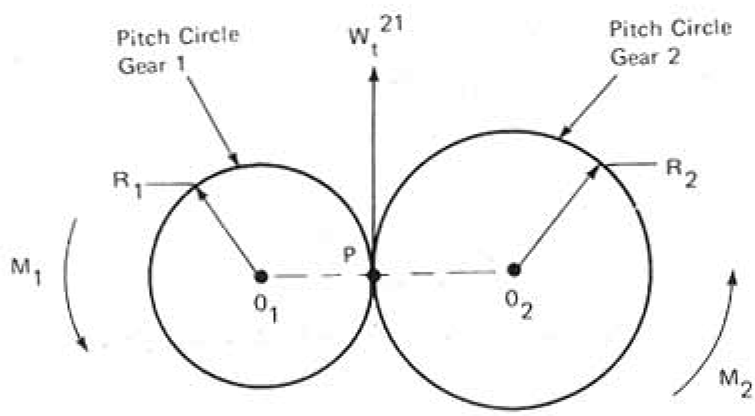

Figure 25. Nomenclature for a Spur Gear Mesh (*9*).

Let W_t^{ij} = tangential force transmitted by gear i to meshing gear j, acting at the pitch line. In Figure 6, W_t^{21} is positive when vertical and up, as shown.

For static equilibrium of gear 1, we have:

$$M_1 + W_t^{21} R_1 = 0$$

where R_1 denotes the pitch radius of gear 1 and moments have been taken about axis 0_1 of gear 1. Hence:

$$W_t^{21} = -\frac{M_1}{R_1}$$

Since action and reaction are equal and opposite, we have:

$$W_t^{12} = -W_t^{21} = \frac{M_1}{R_1} \quad \text{(Eq. 31)}$$

From Equations 30 and 31, we can approximately determine the gear loss. Notice that the tangential transmitted force W_t^{12} in Equation 31 is identical to F_{12} in Equation 30:

$$P_g = | F_{12} . V_{E12}| (0.01) = (\frac{M_1}{R_1})(R_1 \omega_1) = M_1 \omega_1 \qquad \text{(Eq. 32)}$$

Traction Motor Energy Calculation Including Gear Loss

During the constant power operation, $M_1\omega_1$ is equal to the rated power of the motor. Therefore, the gear loss is approximately 1 percent of the rated power. Assuming that 12 traction motors with the power rating of 70.8 hp (or 634,230 watts) are driving the MTM, the gear loss during acceleration is:

$$P_g = 12\ [0.01\ (634{,}230)] = 76107 \quad \text{W}$$

Therefore, the energy associated with the gear loss during acceleration (30 sec) can be determined as:

$$W_g = \Delta P_{12}\ .t = 76107 \text{ x } 30 = 2283 \text{ kws } = 0.634 \text{ kwh}$$

During acceleration, the 50-ton MTM travels 405 m or 0.25 mi. Therefore, gear loss per ton-mile during acceleration can be calculated as:

$$W_g = \frac{0.634}{0.25 \times 50} = 0.05 \quad \text{kwh / ton-mi} \quad \text{(gear loss during acceleration)}$$

Adding this energy to the energy calculated in Equation 24 yields the total energy required for the initial acceleration, including drag and gear loss at the output of the system:

$$W_o = W_a + W_g = 0.39 \frac{kwh}{mi} + 0.36018 \frac{kwh}{ton-mi} + 0.05 \frac{kwh}{ton-mi}$$

$$W_o = 0.39 \frac{kwh}{mi} + 0.4102 \frac{kwh}{ton-mi}$$

The typical efficiency for a rotary induction motor is 0.8. Hence, we need to supply the input energy of:

$$W_{in} = \frac{W_o}{0.8} = 0.49 \frac{kwh}{mi} + 0.5128 \frac{kwh}{ton-mi} \quad \text{(traction motor)} \qquad \text{(Eq. 33)}$$

Including Gear Loss in Our Previous Calculations

As reported earlier in this chapter, the gear loss was neglected when MTM was cruising at a constant speed. At this point, the researchers can determine the gear loss and recalculate the energy requirement including gear loss, when MTM is cruising at a constant speed of 60 mph with and without an incline. The gear loss during constant MTM speed can be determined as:

$$W_g' = 76107 \ w \times \frac{1 hr}{60\, mi \times 1000 \times 50\, ton} = 0.025 \ \frac{kwh}{ton-mi}$$

$$= 0.025 \ \frac{kwh}{ton-mi} \qquad \text{(Eq. 34)}$$

The energy required for cruising at a constant speed at the output is given by Equation 9.

The typical efficiency of a rotary induction motor is 0.8. With an efficiency of η= 0.8 and including gear loss, the energy required for cruising at a constant speed with and without an incline when traction motors are used, is:

$$W_{in} = \frac{0.77 \frac{kwh}{mi} + 0.0036 \frac{kwh}{ton-mi} + 0.025 \frac{kwh}{ton-mi}}{0.8}$$

$$= 0.96 \frac{kwh}{mi} + 0.0358 \frac{kwh}{ton-mi} \ \text{(no incline)}$$

$$W_{in} = \frac{12.47 \frac{kws}{ft\ of\ elevation} + 2.707 \frac{kws}{ton-\ ft\ of\ elevation} + 1.179 \frac{kws}{ton-\ ft\ of\ elevation}}{0.8}$$

$$= W_{in} = 15.59 \frac{kws}{ft\ of\ elevation} + 4.858 \ \frac{kws}{ton-\ ft\ of\ elevation} \qquad \text{(with an incline)}$$

Linear Motor Energy Calculation

For the linear induction motor, the efficiency is typically 0.5. However, there are no gears involved in the system when linear motors are used. Therefore, there is no gear loss and the total output energy is the same as the energy given by Equation 24. Assuming an efficiency of 0.5 for the linear motor, we need to supply the input energy of:

$$W_{in} = \frac{W_o}{\eta} = \frac{W_a}{0.5} = 0.78 \ \frac{kwh}{mi} + 0.7204 \ \frac{kwh}{ton-mi} \quad \text{(linear motor)} \qquad \text{(Eq. 34)}$$

With an efficiency of 0.5 for the linear motor, the energy required for cruising at a constant speed remains the same as given by Equation 10 without an incline, and Equation 21 with an incline.

Summary

Table 10 summarizes the results of the energy calculation for two types of electric motors.

Table 10. Energy Calculation Results.

	Traction Motor	***Linear Motor***
Constant speed	$0.96\frac{kwh}{mile}+0.0358\frac{kwh}{ton-mile}$	$1.54\frac{kwh}{mile}\;0.\;\frac{kwh}{ton-mile}$
Constant Speed (with an incline)	$15.59\frac{kws}{ft\,elev.}+4.858\frac{kws}{ft\,elev}$	$3.34\frac{kws}{ft\,elev.}+5.08\frac{kws}{ton-ft\,elev}$
Initial Acceleration	$0.49\frac{kwh}{mile}+0.5128\frac{kwh}{ton-mile}$	$0.78\frac{kwh}{mile}+0.7204\frac{kwh}{ton-mile}$

CONCLUSION

Table 10 demonstrates that when the MTM cruises at the constant speed of 60 mph on a level tunnel with the total weight of 100,000 lb, the linear motors are more efficient than the traction motors.

When it is traveling up an inclined tunnel with a slope of 30 percent, the linear motor requires about the same amount of energy, as the traction motor needs to travel up a 4 percent incline. If the MTM is not fully loaded, the traction motor requires more energy per foot of elevation compared to the linear motor. Therefore, the linear motor drive is more energy efficient for traveling up the inclined pipeline, and it has the capability of handling a higher rate of elevation change.

During the initial acceleration, the traction motor is more efficient than the linear motor. However, since it takes only 0.25 mi to reach 60 mph, the energy consumption during acceleration is not as significant as the energy during constant speed.

For a fully loaded MTM (100,000 lb), with the acceleration of 60 mph/30sec, the total energy consumption during acceleration and constant speed together, on a level pipeline, can be compared for two different types of motor drives:

$$W_{total}=90.2\,kwh+1.9\frac{kwh}{mi}$$ (Linear motor) (Eq. 35)

$$W_{total}=75kwh+2.75\frac{kwh}{mi}$$ (Traction motor) (Eq. 36)

From Equations 35 and 36, we can conclude that the linear motor drive is more efficient than the traction motor drive, when the traveling distance is longer than 40 miles.

CHAPTER 8 – TRUCKING INDUSTRY AND TERMINAL DESIGN CONSIDERATIONS

INTRODUCTION

An important consideration for design of the terminal and pipeline system is the volume of traffic that might potentially utilize the system and impact of freight logistics on terminal design. Information from the Reebie Transearch 1998 Database and the 1998 Surface Transportation Board Carload Waybill Sample was analyzed in order to further characterize truck and rail freight movements. This chapter focuses on the trade flows of truck and rail carriers on the IH-35 corridor, and a discussion of freight transportation logistical issues relative to terminal design and usage.

TRUCKING INDUSTRY ANALYSIS

Categories

In the trucking industry there are two general categories of trucking companies: For-Hire Carriers and Private Carriers. The characteristics of each are discussed below.

For-hire Companies

In the For-Hire category of the trucking industry, two types of services can be distinguished: truckload (TL) carriers and less-than-truckload (LTL) carriers. Each of these services can be individually segmented into short-haul and long-haul movement. TL services are primarily for large shipments from origin-to-destination, for example, raw materials for a plant. Small fluctuations in the weight are not charged, and the costs are dependent on miles traveled and weight-per-distance.

The LTL is a quantity of freight less than required for the application of a truckload rate. This means that LTL carriers transport small shipments of freight, generally in units of between 250 lb and 12000 lb. LTL shipments are generally composed of general freight from several shippers and have many destinations. To reduce line-haul miles and handling of freight, LTL carriers setup hub and spoke systems that operate similar to airline passenger networks. Costs of LTL shipping are primarily based on weight and usage of space in the truck.

Private Carriers

Private Carriers are companies that own and operate their own fleet of trucks, such as grocery stores, retail chains, and food processing companies. Private carriers travel approximately 53 percent of all the U.S. miles traveled for medium and heavy-duty trucks (*10*).

Truck Freight Analysis

Data from the 1998 Reebie Transearch Database were evaluated according to Standard Transportation Classification (STC) codes and origin/destination to determine the quantities of freight that *might* utilize the underground freight transportation system. To determine the portion of freight that might be palletized, commodities associated with the codes were evaluated based on their potential to be shipped by pallet. Freight volumes for commodity codes were then totaled for the respective categories. It should be noted that the estimates for palletized freight are based on a perceived potential for palletization based on the characteristics of commodities included in the STC codes.

Data from the 1998 Reebie Transearch Database were also evaluated based on origin/destination. It was assumed that out-of-state freight bound for Laredo from a north or northeast angle to Dallas might potentially use the system. For in-state freight shipments, it was assumed that all Laredo-bound freight originating from above an imaginary horizontal line through Temple, Texas, would utilize a Dallas-based UFT system, rather than ship by truck to Laredo, based on potential cost-savings offered by the system.

Southbound Freight

Table 11 shows characteristics of southbound truck freight over the IH-35 corridor between Dallas and Laredo, based on the perceived potential for commodity palletization and analysis of the freight movement data from the 1998 Reebie Transearch Database.

Table 11. 1998 Southbound Truck Freight Characteristics.

Category	Weight (Tons)	Weight Percentages	Number of Trips	Trip Percentages
Palletized	1,125,456	46.0	77,162	45.6
Non-Palletized	1,320,436	54.0	92,206	54.4
Total	2,445,892		169,368	0

Table 12 shows weights and number of trips for carriers of southbound palletized truck freight through Laredo over the IH-35 corridor, based on the 1998 Reebie Transeach Database analysis. Table 13 shows averaged weights per trip for southbound palletized truck freight carriers.

Table 12. 1998 Southbound Palletized Truck Freight Carriers.

Carrier	Weight (Tons)	Weight Percentages	Number of Trips	Trip Percentages
TL	867,259	77.1	59,224	76.8
LTL	157,167	13.0	11,672	15.1
Private	101,030	9.0	6,267	8.1
Total	1,125,456		77,163	

Table 13. 1998 Southbound Palletized Truck Freight Average Weight Per Trip.

Carrier	Weight (Tons)	Number of Trips	Weight Per Trip (Tons)
TL	867,259	59,224	14.64
LTL	157,167	11,672	13.47
Private	101,030	6,267	16.12
Total	1,125,456	77,163	14.59

Table 14 shows origins and weights of southbound palletized freight handled by different carriers over the IH-35 corridor, based on the 1998 Reebie Transearch Database analysis. The data are categorized according to freight originating in Texas (above Temple, Texas, as discussed above) and freight originating outside of Texas. Table 15 shows the origins and number of trips of southbound palletized freight for the carriers over the IH-35 corridor, based on the 1998 Reebie Transearch Database analysis.

Table 14. 1998 Southbound Palletized Truck Freight Origins – Weights.

Origin	Weight (Tons)			
	TL	LTL	Private	Total
Texas	83,052	5,454	93,625	182,130
Other States	784,207	151,713	7,406	943,326
Total	867,259	157,167	101,030	1,125,456

Table 15. 1998 Southbound Palletized Truck Freight Origins – Number of Loads.

Origin	Number of Loads			
	TL	LTL	Private	Total
Texas	4,965	378	5,379	10,722
Other States	54,259	11,293	888	66,441
Total	59,224	11,672	6,267	77,163

Northbound Freight

Table 16 shows characteristics of northbound truck freight over the IH-35 corridor between Laredo and Dallas, based on the perceived potential for commodity palletization and analysis of the freight movement data from the 1998 Reebie Transearch Database.

Table 16. 1998 Northbound Truck Freight Characteristics.

Category	Weight (Tons)	Weight Percentages	Number of Trips	Trip Percentages
Palletized	1,947,837	55.5	122,565	55.2
Non-Palletized	1,560,592	44.5	99,287	44.8
Total	3,508,428		221,852	

Table 17 shows weights and number of trips for carriers of northbound palletized truck freight between Laredo and Dallas over the IH-35 corridor, based on the 1998 Reebie Transearch Database analysis. Table 18 shows averaged weights per trip for northbound palletized truck freight carriers.

Table 17. 1998 Northbound Palletized Truck Freight Carriers.

Carrier	Weight (Tons)	Weight Percentages	Number of Trips	Trip Percentages
TL	988,137	50.7	61,899	50.5
LTL	127,806	6.6	8,470	6.9
Private	831,893	42.7	52,196	42.6
Total	1,947,836		122,565	

Table 18. 1998 Northbound Palletized Truck Freight Average Weight Per Trip.

Carrier	Weight (Tons)	Number of Trips	Weight Per Trip (Tons)
TL	988,137	61,899	15.96
LTL	127,806	8,470	15.09
Private	831,893	52,196	15.94
Total	1,947,836	122,565	15.89

Table 19 shows destinations and weights of northbound palletized freight handled by different carriers over the IH-35 corridor, based on the 1998 Reebie Transearch Database analysis. The data are categorized according to freight with destinations above Temple, Texas, and freight with destinations outside of Texas. Table 20 shows the destinations and number of trips of northbound palletized freight for the carriers over the IH-35 corridor, based on the 1998 Reebie Transearch Database analysis.

Table 19. 1998 Northbound Palletized Truck Freight Destinations – Weight.

Destination	Weight (Tons)			
	TL	LTL	Private	Total
Texas	520,850	20,481	725,529	1,266,860
Other States	478,604	113,040	109,977	701,620
Total	999,454	133,521	835,506	1,968,481

Table 20. 1998 Northbound Palletized Truck Freight Destinations – Number of Loads.

Destination	Number of Loads			
	TL	LTL	Private	Total
Texas	32,502	1,274	45,350	79,127
Other States	30,023	7,632	7,091	44,745
Total	62,525	8,906	52,441	123,872

Data Interpretation

In summary of the information presented in the above tables, approximately 46 percent (77,162 trips) of the southbound truck freight over the IH-35 corridor through Laredo was palletized (or had the potential for palletization) in 1998. Of this, approximately 92 percent (70,896 trips) was hauled by for-hire carriers and 9 percent (6,267 trips) by private carriers. Over 92 percent (65,552 trips) of the southbound for-hire palletized freight traffic originates outside Texas. Nearly 84 percent (59,224 trips) of the southbound for-hire palletized freight traffic is hauled by TL carriers.

Approximately 55 percent (123,872 trips) of the northbound truck freight over the IH-35 corridor through Laredo was palletized (or had the potential for palletization) in 1998. Of this, approximately 58 percent (71,431 trips) was hauled by for-hire carriers and 42 percent (52,441 trips) by private carriers. Approximately 53 percent (37,655 trips) of the northbound for-hire palletized freight traffic has a destination outside Texas. Over 87 percent (62,525 trips) of the northbound for-hire palletized freight traffic is hauled by TL carriers.

There is a significant difference in the estimated total trips of southbound and northbound freight traffic over the IH-35 corridor between Dallas and Laredo. There are an estimated 169,368 southbound truck trips and an estimated 221,852 northbound truck trips over the corridor. However, there are similarities in the quantities of trips for certain categories of palletized freight transport. For example, for palletized for-hire freight, there were an estimated 70,896 southbound and an estimated 71,431 northbound trips. Similarly, there were an estimated 59,224 southbound trips and an estimated 62,525 northbound trips of palletized freight handled by TL carriers over the IH-35 corridor between Laredo and Dallas.

There was some difference in the ultimate locations of freight origins/destinations, with a large majority (92 percent) of southbound palletized freight originating outside Texas but only a slight majority of (53 percent) of northbound palletized freight terminating outside Texas. The average truck weight per trip for palletized freight was 14.59 tons for southbound traffic and 15.89 tons for northbound traffic. For TL carriers, the average truck weight per trip for palletized freight was 14.64 tons for southbound traffic and 15.96 tons for northbound traffic.

RAILROAD INDUSTRY ANALYSIS

Approximately 197,000 miles of railroad track are maintained in the U.S., with over 12,000 miles of mainline track located in Texas. Three Class I Railroads currently operate in Texas: Burlington Northern Santa Fe (BNSF), Kansas City Southern (KCS), and Union Pacific (UP). In addition, the Texas Mexican Railway (TMRW) specializes in handling Texas-Mexico traffic.

Currently, the UP is the only Class I Railroad that operates along the IH-35 corridor between Laredo and Dallas. Figure 26 is a map showing the locations of railroads in Texas.

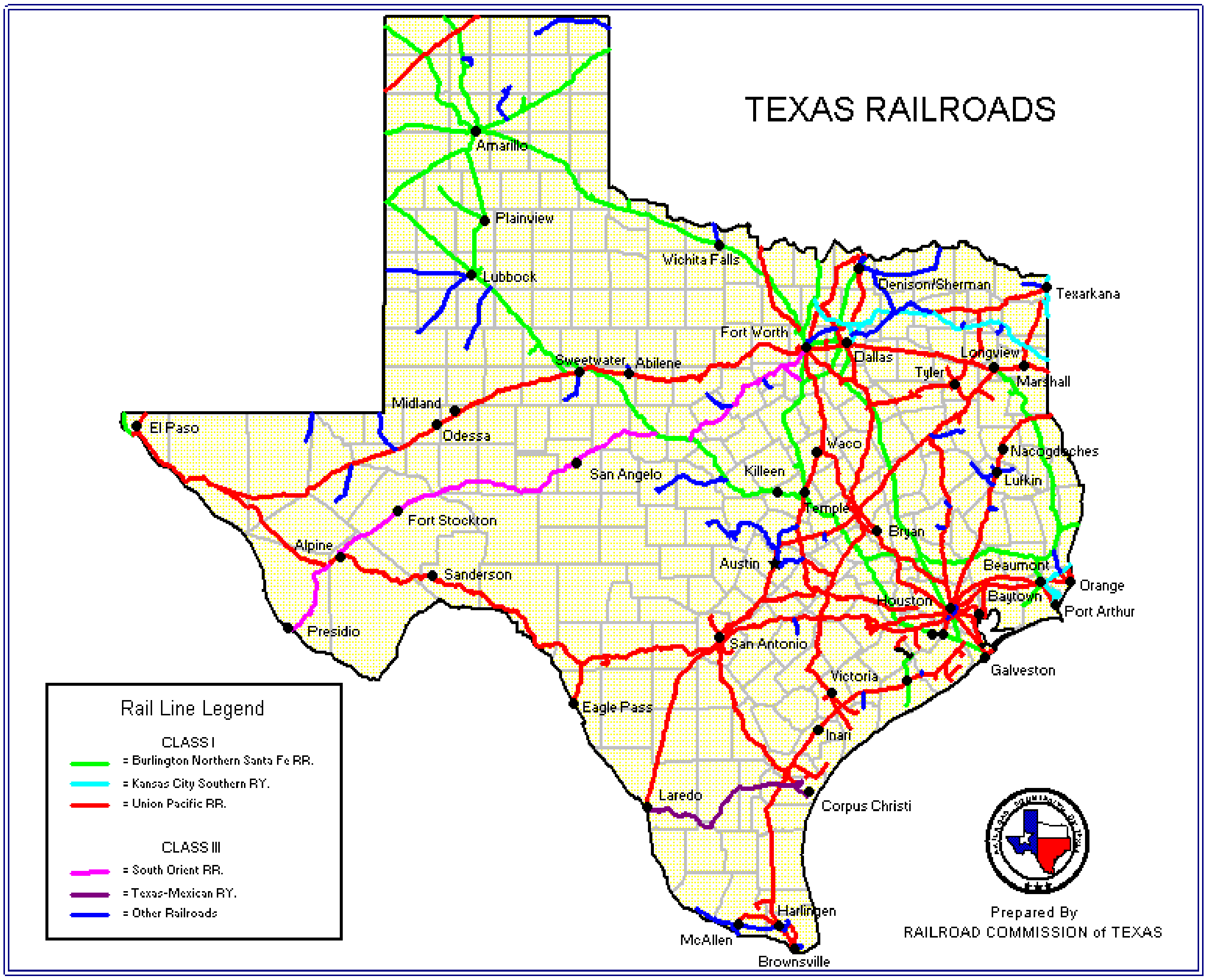

Figure 26. Railroads in Texas (*11*).

Railroad Freight Analysis

Freight Transport Data from the 1998 Surface Transportation Board (STB), Carload Waybill Sample was used to characterize rail freight for the IH-35 corridor area. Because UP is the only railroad that operates on trackage along the corridor, only UP data was used in the analysis. The data was further evaluated for those that typically handle palletized freight and according to state of origin and interchanges. Table 21 shows estimated southbound and northbound rail traffic estimates for total and palletized freight traffic through Laredo, based on analysis of the 1998 STB Waybill sample data.

Table 21. Southbound and Northbound Rail Traffic Through Laredo (tons per year).

Category	Southbound	Northbound
Total Freight	$5*10^6$	$2*10^6$
Palletized Freight	484,544	431,828

Assuming that palletized freight is carried predominantly in intermodal containers, and also assuming an average 40-ft container weight of approximately 15 tons, the traffic levels presented in Table 21 correspond to 32,300 southbound rail containers and 28,800 northbound rail containers per year. Assuming 200 40-ft containers per unit train (100 cars per train, double-stacked), these numbers correspond to 162 southbound unit trains and 144 northbound unit trains per year along the IH-35 corridor.

Rail Freight Transit Time

Based on conversations with railroad industry officials, the travel time for rail freight traffic from Dupo (Illinois) to Dallas is 37 hours and from Dupo to Laredo takes 78 hours. Thus, the travel time from Dallas to Laredo is 41 hours. The average dwell time for a rail terminal in Forth Worth is 33 hours. In addition, the time required for loading or unloading a 100-car container train is approximately two to three hours.

FREIGHT TRANSPORT CONSIDERATIONS FOR TERMINAL DESIGN

To design a terminal that meets the needs of the participants, there is a need to align performance indicators. Some of the performance indicators to be considered in terminal design are identified for the following industry players:

- trucking,
- rail, and
- government authorities.

Trucking Industry Performance Indicators

The performance indicators for the trucking industry will relate, in the most cases, to the cost quality ratio and reliability. The following performance indicators have been identified as important for the trucking industry (*11*).

Back-Haul Availability

If a back-haul is available at a terminal, increased revenue can be gained and need for cargo storage will be reduced. Thus, a trucker must be able to drop his freight at the terminal at the previous specified drop time because the time that the backhaul is available needs to correspond with the drop time of the truck. This allows for more efficient time management for the trucking companies.

Storage Capacity

Storage capacity is used to store freight that arrives before a transport mode can bring it to the destination. Capacity is determined by the size and availability of storage areas for containers, trailers, and chassis. Potentially intense activity over concentrated time periods can also be more easily absorbed with adequate storage capacity.

Accessibility

Good accessibility to a terminal is important to minimize highway congestion. High bridges, wide tunnel clearance, and adequate turning radii are all factors to consider for truck access.

User-Friendliness

Providing quick transfers at the terminal and avoiding long delays. This means coordinating schedules in a highly efficient way and considering back-haul movements. A shortage of equipment will cause time delays and expense and must be eliminated at the terminal. The use of new technologies will contribute to a higher efficient standard. Cargo damage has been a problem with intermodal service because multiple carriers are involved in handling a single cargo. It is difficult to determine where the cargo has been damaged, and therefore, there needs to be some form of liability claim.

Security

In large urban areas, truck hijackings have become increasingly common. This increase as well as other security problems can create significant problems at terminals.

Cargo Tracking and Information Technologies

The factors that impact the effectiveness of intermodal freight transport include reliability and transport costs. Frequently scheduled priority arrivals and departures and fast container and trailer processing can help reduce terminal dwell times, and can be enhanced by cargo tracking technologies. By using sophisticated tracking systems that monitor the movement of the time sensitive cargo during the haul, it is possible to offer reliable arrival times.

Railroad Industry Performance Indicators

The performance indicators for the railroad industry are similar to those described for the trucking industry, with some rail-specific aspects.

Train Length and Terminal Trackage

Two significant factors that must be considered in terminal design are length of the train (up to 1.7 miles) and the fact that mobility is limited because the motive power is generally applied to a train from one end. When the terminal receiving tracks are shorter than the length of a train, railcars must be placed on more than one track or stored at a storage area, which can be time, labor, and equipment intensive. Thus, consideration must be given to adequate storage capacity, with the ideal situation consisting of adequate siding or terminal trackage to store one complete unit train.

Railcar Inspection, Servicing, and Repair

Before a railcar can operate on regular train service it must be inspected for compliance with certain railroad and Federal Railroad Administration (FRA) regulations. For example, railcars must be inspected for proper operation of air brakes, a time-consuming process. Any elements not found in compliance with safety regulations must be repaired immediately. If the repair must be made quickly at the loading area, good access for the equipment should be provided. Also it may be desirable to provide separate repair tracks and facilities for the servicing of railcars that require additional service time.

Governmental Indicators

Economic Factors

A terminal can be generally expected to support business and job growth, and may also attract other industrial developments that may or may not be related to terminal operations. Further, real estate taxes and/or lease revenues might be levied to provide economic return to the host community. Economic developments at a terminal can also increase tax revenues from new and expanding businesses.

Environmental Factors

Efficient terminal operations and a state-of-the-art receiving and delivery gate can be expected to reduce the time that trucks must wait and minimize emissions of air contaminants.

INTERMODAL FREIGHT TRANSPORT ISSUES

Thus far, the Underground Freight Transportation (UFT) system concept includes the transfer of freight from one mode (truck or rail) and transport container (trailer or container) to another (UFT pipeline system and MTM), and vice versa, some similarities can be drawn to intermodal freight transportation, which has grown enormously in past decades. Development of an extensive intermodal freight network has been enhanced in several areas. Trade agreements, environmental (air pollution) and safety (traffic congestion) concerns, technology advancements and service improvements, and public/private infrastructure agreements have all contributed to intermodal development. The market share for intermodal freight varies by corridor, but industry market penetration is greatest for commodities shipped along high-density, long-haul corridors as IH-35.

Factors impacting service selection by shippers include price, transit time, and service reliability. The importance of particular factors may depend on other freight characteristics, such as the commodity value, the costs of stock outs, and inventory management methodology. The importance of reliability and service quality has increased due to Just-In-Time (JIT) approaches to inventory and production, which really is a method of ensuring predictability of shipment arrival and controlling warehouse stock levels. Previous research shows that problems with intermodal service are related to several factors, described as follows (*12*):

Inadequate Service Quality

There are different factors that can be viewed as inadequate intermodal service quality compared with point-to-point trucking or rail. These include slow transit time, on-time performance, cargo damage, fragmented responsibilities, infrequent service schedules, and poor customer service.

Low Profitability

The profit margins are very small in the intermodal industry. In spite of the growth of the volumes, profit margins have remained thin, due to such factors as high drayage costs, terminal costs, low commodity values, low revenues per mile, and high equipment costs.

Low Market Share

In many long-haul markets, and in almost all short-haul markets, the intermodal share is small compared to motor carriers' share. In most long-haul corridors, the market share is between 10 and 35 percent. In short-haul markets the intermodal share is close to zero.

Balancing shipper concerns with profitability and service issues can be a difficult and complicated task for intermodal freight carriers. Quality of service problems can lower the market share, which will reduce the industry profitability. Low profitability results in fewer improvements that may negatively affect service quality. Bad service quality places pressure on profits, leading to reduced market share further deterioration of the service quality. Figure 27 illustrates the challenges faced by the intermodal industry.

Kang concludes that larger companies who ship longer distances and are cost-sensitive are more likely to choose intermodal over truck (*13*). Intermodal also may be selected if there are driver shortages over some or all the trip. For the longest hauls, intermodal can be as fast and reliable as truck service and less expensive. For the shortest hauls, truck service is generally faster, more reliable, and cheaper. For the intermediate hauls, between 500 and 1,500 miles, intermodal is generally cheaper (*11*).

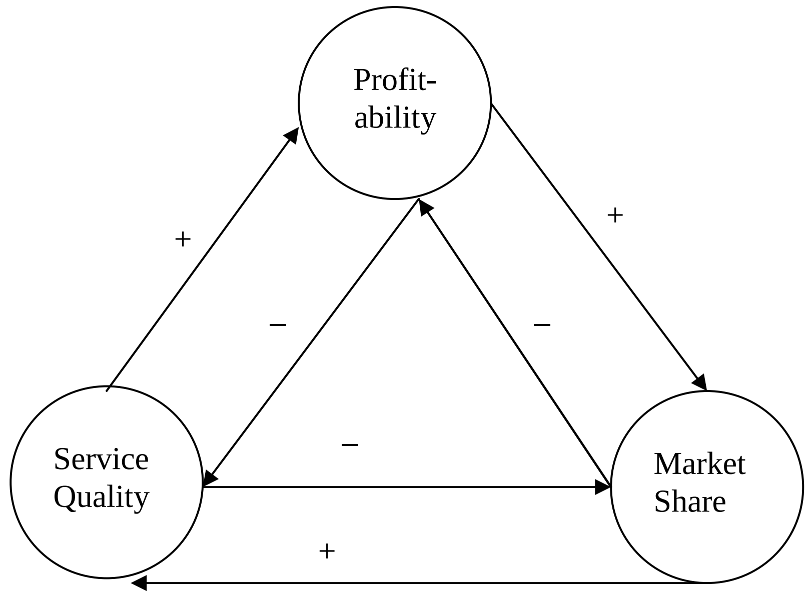

Figure 27. Challenges of the Intermodal Industry.

CHAPTER 9 – CAPACITY SIMULATION MODEL

INTRODUCTION

The viability of a freight pipeline system must be judged by the facility's ability to meet certain criteria, such as transportation time, transport and construction costs, system reliability, and system capacity. The answers to many of these issues must be determined in the initial planning stages so that essential design features (i.e., terminal configurations, number of loading/unloading stations, MTM inventories, etc.) can be incorporated into the study. While much of the pipeline's conceptual design will be based on technological constraints and engineering capabilities, the main goal is to propose a solution that optimizes systems operations.

A computer model of the freight pipeline has been prepared using *Arena* (a simulation software) for the purpose of simulating all freight handling and transport operations within the system. This model simulates the effects that various assumptions, such as pallet arrival or loading rates, have on system performance throughout a 24-hour operations cycle. As the pipeline model is run, the system's performance can be monitored as the simulation produces numerical and graphical information for relevant design considerations (e.g., queue lengths at loading/unloading areas, MTM inventory levels, arrival rates at terminal destinations).

This information can be used to gain a better understanding of the true size and scope of the freight pipeline project. Furthermore, various forms of the pipeline model can be compared to assist in selecting the best design among competing alternatives.

While the simulation of pipeline operations will be of great benefit throughout all phases of conceptual design, current efforts are devoted to creating an initial model capable of performing the tasks previously described. Discussions on the development of the preliminary pipeline computer model, including relevant assumptions, are provided in the sections below.

Structure of the Pipeline Model

The freight pipeline model consists of loading/unloading stations and warehouse/material handling terminals positioned at each end of a main conduit. Figure 28 illustrates how the main conduit is modeled as separate northbound and southbound pathways that link directly to the Dallas and Laredo loading/unloading stations (a distance of 450 miles). This configuration allows the model to simulate a sequence of: 1) loading cargo into an MTM, 2) transporting cargo on the MTM through the conduit, and 3) unloading cargo from the MTM at its point of destination. A second link has been made between the loading/unloading stations and the warehouse/material handling terminals in order to simulate the arrival and departure of freight as it enters or leaves the pipeline system. In addition, the model links loading/unloading stations to separate MTM storage facilities at each end of the pipeline. This configuration allows the model to simulate the transfer of empty MTMs from unloading areas to a storage area where MTMs can be relayed back to loading areas, as needed.

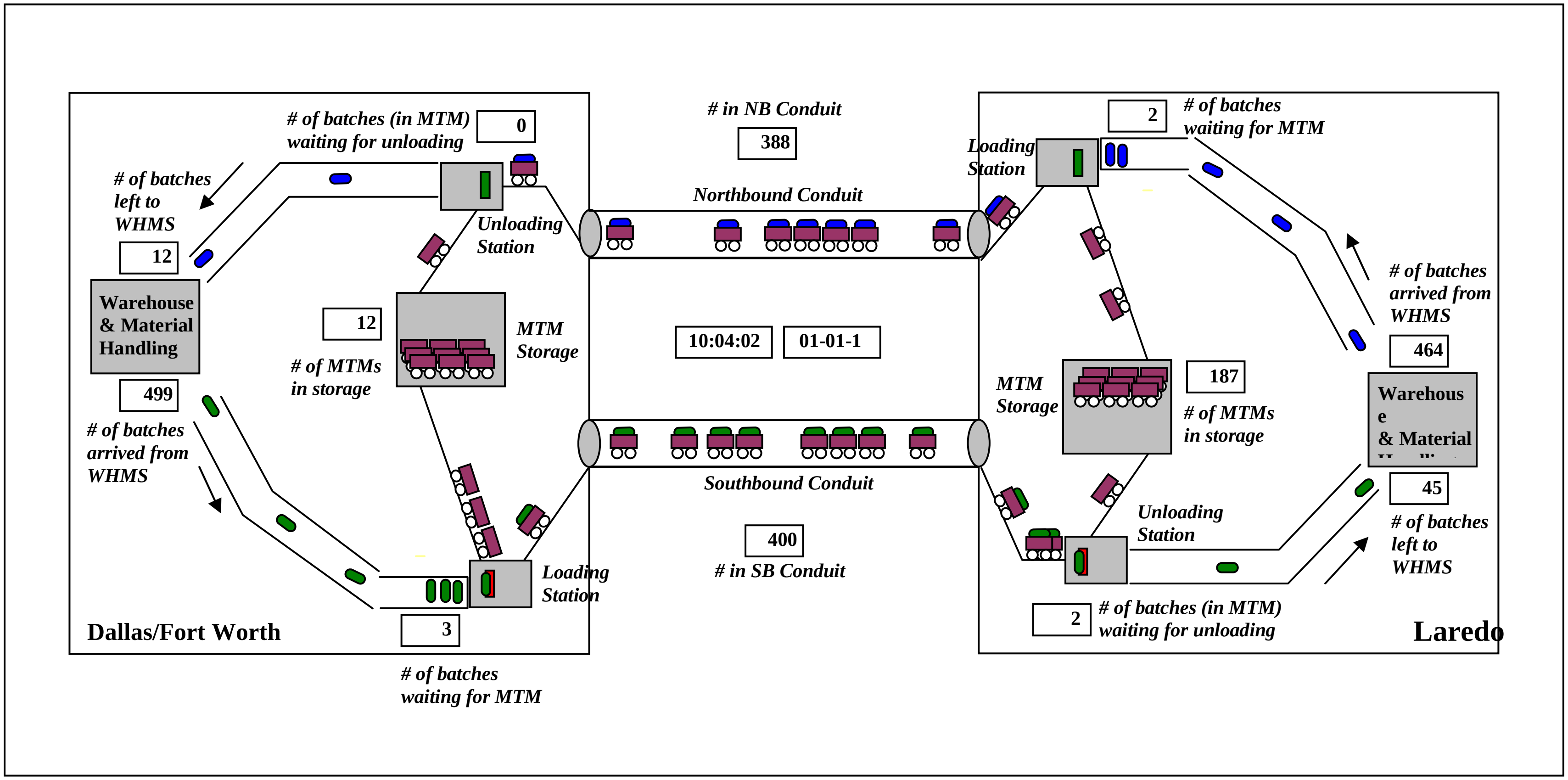

Figure 28. Configuration of Main Components in the Pipeline Model.

Simulation of Pipeline Operations

A time-based evaluation of the freight pipeline's performance is achieved by placing relevant performance parameters on the model that was described in the previous section. The performance parameters in this study are based on a set of initial assumptions, which are:

- Each MTM car can transport six standard pallets.
- MTMs will travel as a set of five linked cars.
- MTMs travel at a speed of 60 mph.
- A set of five linked cars are loaded in 30 seconds.
- All MTMs are initially located in MTM storage.

In addition to the performance parameters of the pipeline system, the rate of freight accepted into the system (at the warehouse/material handling terminals) must be considered. This model incorporates the time-dependent arrival rate functions shown in Figure 29 for the purpose of simulating the anticipated levels of freight arrival at each end of the facility.

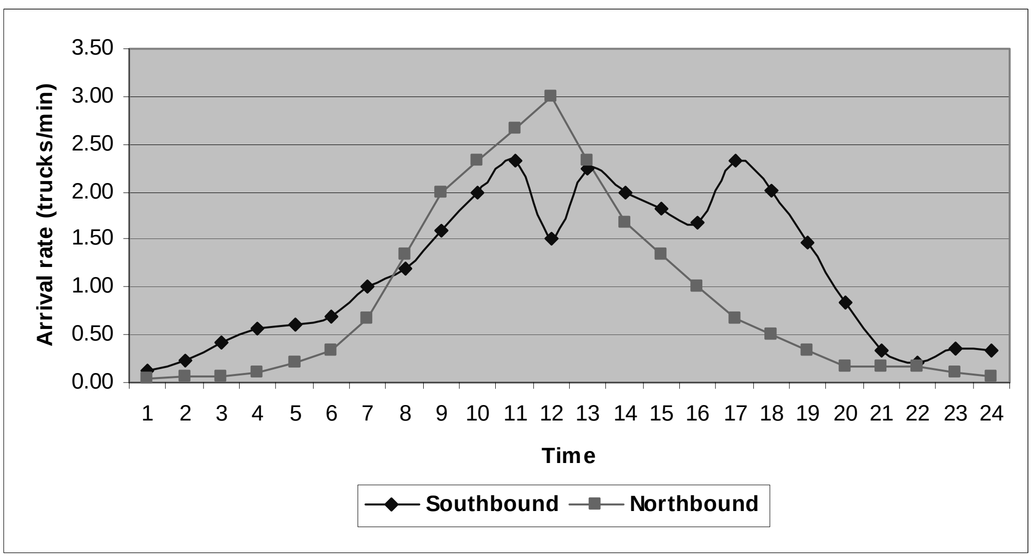

Figure 29. Fluctuations in Freight Arrivals Over a 24-Hour Period.

Temporal Analysis

The freight pipeline model simulates the movement of cargo from the warehouse/material handling terminal to a loading station at which the cargo is placed on an MTM; this sequence is reversed once the cargo arrives at the unloading station of its point of destination. This systematic operation requires the inclusion specific time-based variables that affect the efficiency of the pipeline's performance. The following time-based variables are incorporated into this model:

- forklift loading/unloading times at warehouse/material handling terminals,
- routing time of pallets between the terminal and loading/unloading stations,
- queuing time at loading/unloading stations,
- forklift loading/unloading time of MTMs, and
- transport time through the conduit.

Conceptual design specifications or features, such as forklift speed and capacity, facility geometry, MTM travel speeds, and the initial number of MTMs in inventory, will govern the magnitudes of these variables. With exception to queuing times at the loading/unloading stations, time values for each of these variables are assumed, based on proposed design criteria. Therefore, a simulation of the freight pipeline model for a 24-hour operations cycle can be used to track queuing times over the entire period – information that can be used to modify the design of the pipeline facility.

Spatial Analysis

In addition to the time-based variables discussed in the previous section, the pipeline model includes spatially-based variables that quantify the physical conditions of the facility. The following spatial variables are incorporated into this model:

- queue length,
- MTM inventory volume, and
- number of loading/unloading docks.

The number of loading/unloading docks in this model will be defined as part of the conceptual design. In future work, varying this parameter will help to identify the optimal design of the pipeline facility. *Arena* generates queue lengths and MTM inventory volumes throughout the simulation of a 24-hour operations cycle of the freight pipeline. This will serve as a guide for modifications in the conceptual design.

Sample Output for the Preliminary Model

An initial simulation of the freight pipeline was performed using the following assumptions:

1) MTMs travel at a constant rate of 60 mph,
2) one loading station is in use at each end of the facility,
3) cargo arrivals occur at the rates (described by Figure 29),
4) 500 MTMs are initially in inventory, and
5) a set of five linked cars are loaded in 30 seconds.

To better understand the usefulness of the model, some numerical results from this simulation are shown in Table 22.

Table 22. Results of Initial Simulation Run for Three 24-Hour Cycles.

Parameter	Minimum	Maximum	Average
Average Queue Length (southbound), 5-car MTMs	86	236	150
Average Queue Time (southbound), min.	172.8	748.0	450.8
Average Time in System (southbound), min.	525.5	1077.0	805.9
Average Queue Length (northbound), 5-car MTMs	224	843	527
Average Queue Time (northbound), min.	99.4	254.6	165.6
Average Time in System (northbound), min.	517.9	604.8	562.2

Table 22 lists averages for queue lengths, queue times, and the total handling times for both northbound and southbound directions. These values were obtained by simulating pipeline operations over three continuous 24-hour cycles, whereby averages were calculated from the minimum, maximum, and mean values of each cycle. As expected, the average queue times and five-car MTM lengths are greater for the northbound segment of the pipeline (due to higher traffic rates entering the U.S. at Laredo). The averages from all categories in Table 22 are also exceptionally large, which implies that certain assumptions in the initial model, such as numbers of loading stations, should be modified. Of course, the means by which the pipeline model is incorporated into the conceptual design process is through these adjustments. This approach will be adopted in future phases of the freight pipeline study.

CHAPTER 10 – PRELIMINARY INVESTIGATION OF PHYSICAL CHARACTERISTICS OF DALLAS-LAREDO CORRIDOR

INTRODUCTION

In order to document the physical characteristics and engineering parameters of the predominant formations in the corridor region, and evaluate risks and costs associated with construction and operation of the system, researchers conducted a preliminary evaluation of the corridor area. The suitability with respect to soil, geologic, hydrologic, and topographic factors was evaluated for a corridor between Dallas and Laredo that roughly parallels IH-35, including the counties of Webb, La Salle, McMullen, Frio, Atascosa, Medina, Bexar, Wilson, Guadalupe, Gonzales, Caldwell, Fayette, Bastrop, Travis, Williamson, Bell, Lee, Milam, Falls, Limestone, McLennan, hill, Navarro, Ellis, and Dallas. Figure 30 shows the general study area for which the geology was evaluated.

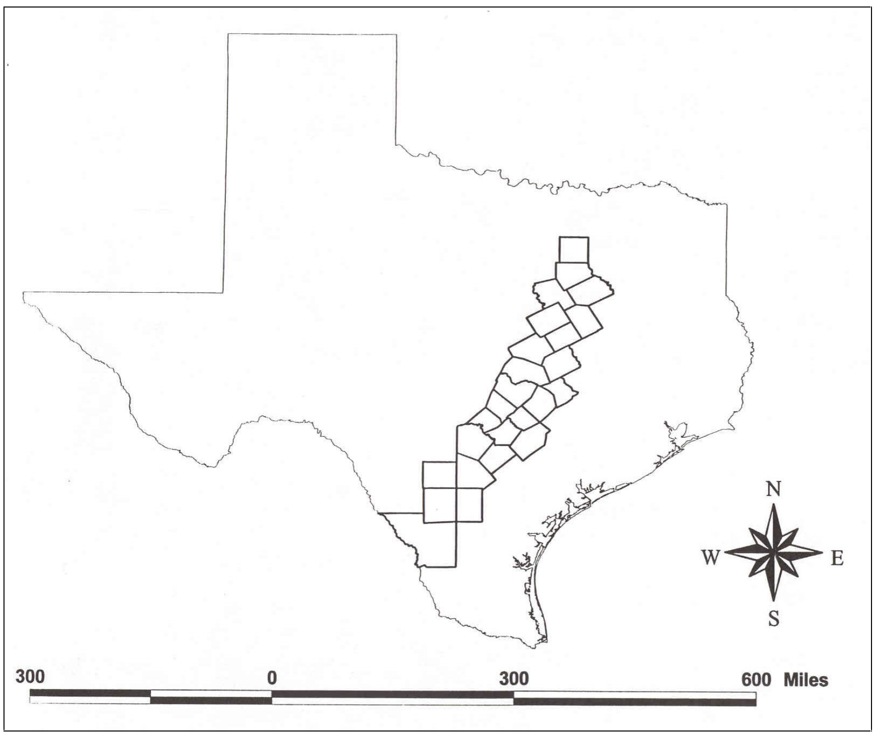

Figure 30. Corridor Evaluation Area.

Because the corridor encompasses a large area, 25 counties, factors, and parameters included in the four categories were broadly generalized for the major formations, which may actually vary to some degree over the total corridor area. As possible, this analysis is based on readily and publicly available information. However, some estimation was required because the pertinent information for some factors was limited. Detailed information regarding the aquifer, geologic, and soil formations may be found in Appendix B.

HYDROLOGIC FACTORS

Water affects the strength, sensitivity, and swelling properties of material. In addition to loadings caused by soil expansion and contraction, a difficult task is to control water seepage into or out of an excavation. The presence of water above the water table is beneficial because capillary forces dissipate, but below the water table, water pressures reduce the angle of friction, making the soil or rock weaker, therefore seepage pressures can cause rapid and complete failure in non-cohesive soils. In addition, buoyant and lateral hydrostatic forces should be considered where applicable. Water may enter a rock or soil through faults, aquifers, or gouge zones, which ultimately affect the way the rock behaves (*14*). The researchers evaluated three hydrologic factors:

- climate, including precipitation and evaporation,
- water table depth, and
- aquifer locations and recharge zones.

The Groundwater Atlas of Texas, U.S. General Soils Map, Groundwater Atlas of the United States, U.S. Geological Survey, National Climate Data, and previous academic studies provided hydrology information.

Climate

Climate, in addition to water table depth, controls initial soil moisture conditions and soil moisture active zones. Climate, though, is the single most important factor contributing to expansive soils. It also ultimately determines the availability of moisture in a hydrological cycle. “The initial soil moisture conditions as well as those of the future will be controlled largely by climate” (*15*). For this project, the Office of the State Climatology provided information on runoff, precipitation, and water table levels. The climatic evaluation was based on Thornthwaite’s 1948 classification, which classifies climate in terms of precipitation vs. potential evaporation (*16*). According to this classification, there are four basic climatic zones: arid, semi-arid, sub-humid, and humid. General climatic zones of Texas are shown in Figure 31.

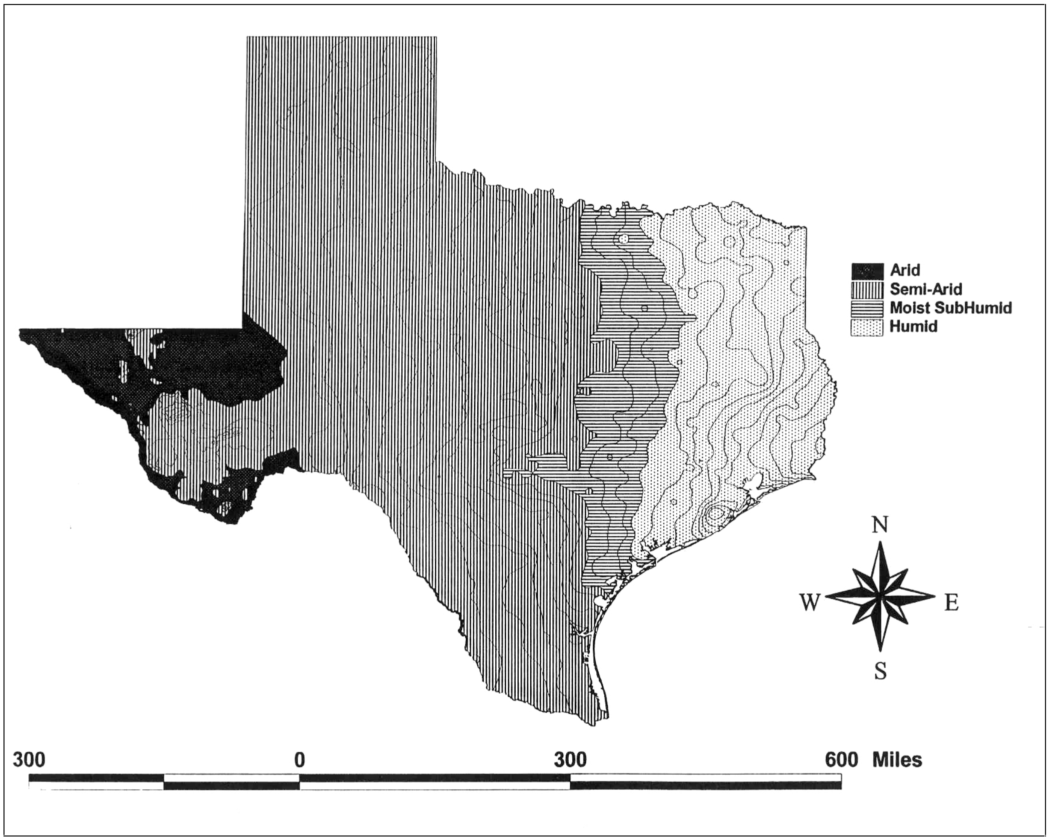

Figure 31. Climatic Zones of Texas.

The climatic zones correspond to the amount of precipitation and evapotranspiration in a given area. In the arid zones, precipitation is far less than evapotranspiration. Humid zones have greater precipitation than evapotranspiration that eventually may cause create greater percolation or runoff throughout the given year, which in the end produces a greater hazard because of the potential for mass wasting in saturated soils. In the semi-arid and sub-humid zones, precipitation is equal or about equal to evapotranspiration depending on the time of year, having less potential for runoff or percolation than humid zones, but more than arid zones.

Figure 32 shows average annual runoff values, in inches, for the state of Texas. Figure 33 shows average annual precipitation values, in inches, for the state of Texas. Precipitation and runoff are important factors when considering tunneling and excavation construction methods. Clays and sands behave differently at various levels of saturation, therefore, the need and design of adequate wall shoring will vary with the geology. High rainfall on clay soils, rather than sands, generally results in less percolation and greater runoff and creating a potential hazard. In arid zones, precipitation is less than evapotranspiration, therefore creating a small hazard to the project. Project hazards due to percolation and runoff correspond to highest (best) rankings for arid environments, moderate rankings for semi-arid and sub-humid environments, and low (worst) rankings for humid environments.

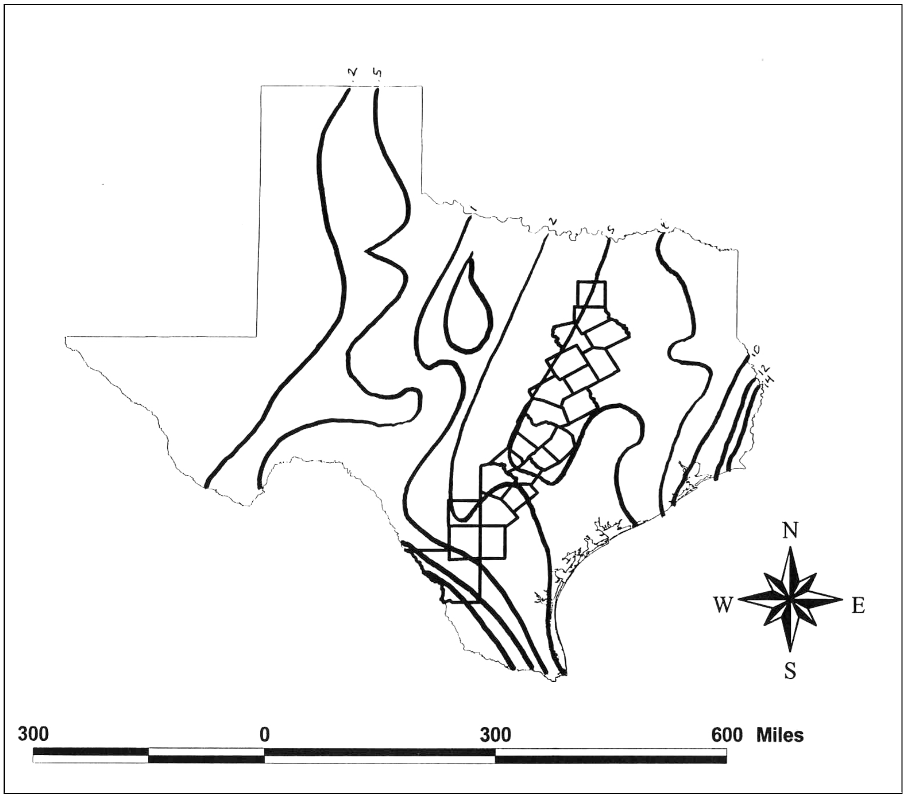

Figure 32. State of Texas Average Annual Runoff Values, in Inches.

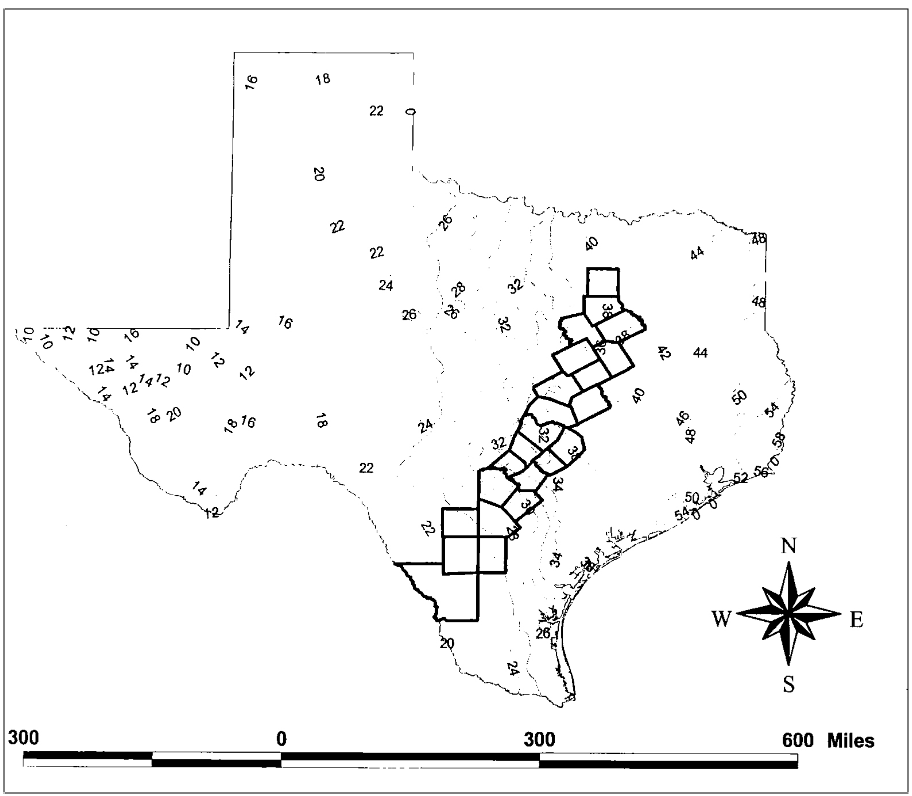

Figure 33. State of Texas Average Annual Precipitation Values, in Inches.

Water Table Depth

Water table depth is another important consideration. Besides the impact of water on occurrence of shrinkage and swelling in clays, another consideration is the control of any water seepage and drainage, for which water table depth is one of the primary influences. The water-bearing capacity of a formation is expressed by its hydraulic conductivity. Factors that affect the hydraulic conductivity are porosity, pore size of the same order, and grain size. Hydraulic conductivity also is dependent on the formation type. For example, water that is confined by shales, e.g., Eagle Ford Shale, will have higher hydraulic conductivities than unconfined formations, such as the Wilcox.

The porosity of a rock depends on the degree of cementation, state of solution, and fracturing of rock. Porosity of unconsolidated materials depends on the packing of the grains, their shape, and the arrangement and size distribution. Unconsolidated materials are sediments that are loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth (*17*). Infiltration occurs through open fractures such as joints, faults, and superficial deposits, which allow infiltration through their pores. For example, gravel and un-cemented sands permit infiltration through their pores without difficulty, whereas clays do not allow infiltration and remain wet after a significant rainfall (*18*). Further information in Appendix B indicates the hydraulic conductivity of the formations studied.

Detailed information on water table levels over the project area was difficult to obtain because of an apparent absence of quality water well construction records, and static water level readings were not publicly available for the area under consideration. However, some general correlations may be made between climatic factors and water table depth. Castleberry documented that in areas having a humid climate; the water table may be very near the surface. On the other extreme, the water table in arid climates may be at a great depth and have no effect on surface soil moisture conditions (*19*).

Thus, some correlation is assumed to exist between climate zones, shown in Figure 31, and water table depth. Shallow water tables are assumed to correspond to humid climates, moderate water tables are assumed to correspond to sub-humid and sub-arid climates, and deep water tables are assumed to correspond to arid climates. Based on these assumptions, water table depths are shown in Figure 34.

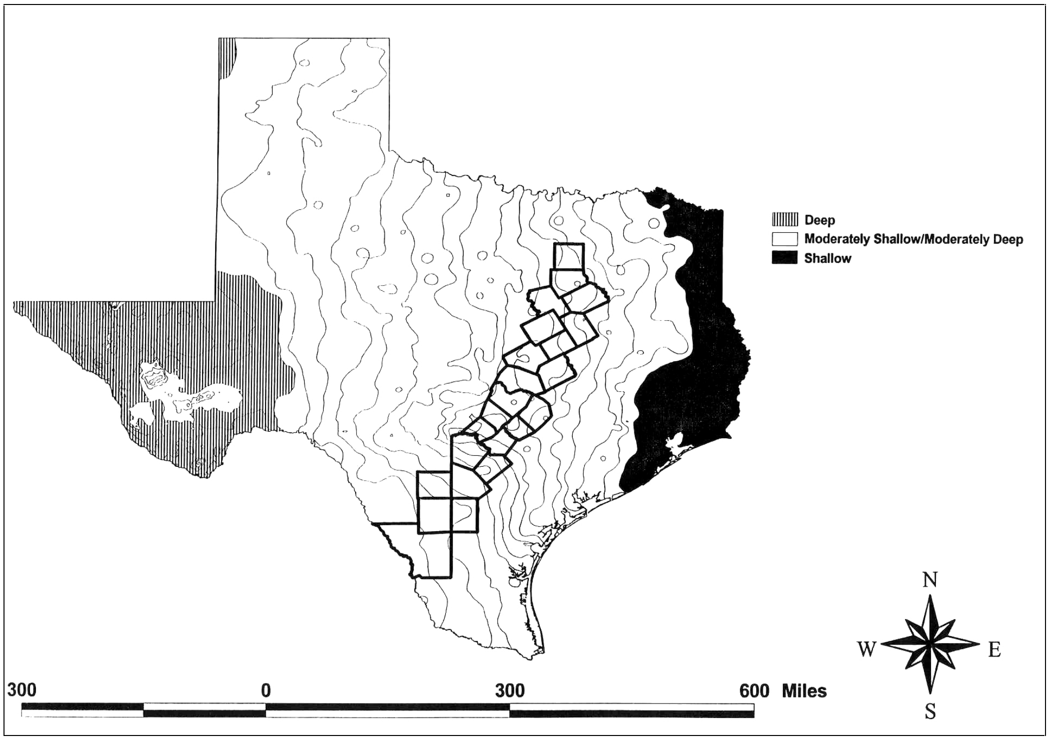

Figure 34. State of Texas Water Table Depths, Assuming Correlation with Climate.

Aquifer Location and Recharge Zones

Two important characteristics of an aquifer are its recharge and discharge areas. Aquifer recharge areas represent high-risk areas because of a potential increase for aquifer contamination at the influx zone. Texas relies heavily on the use of groundwater for irrigation and municipal purposes. Thus, in terms of the corridor, recharge areas are a constraint.

Recharge areas were evaluated by considering the geology and the risk of contamination. Discharge areas have less of a probability for aquifer contamination because discharge areas have a significant amount of water exiting an aquifer system. Figure 35 shows the major aquifers in the corridor area, and Figure 36 shows corresponding aquifer recharge zones. This information was obtained from the Groundwater Atlas of the United States.

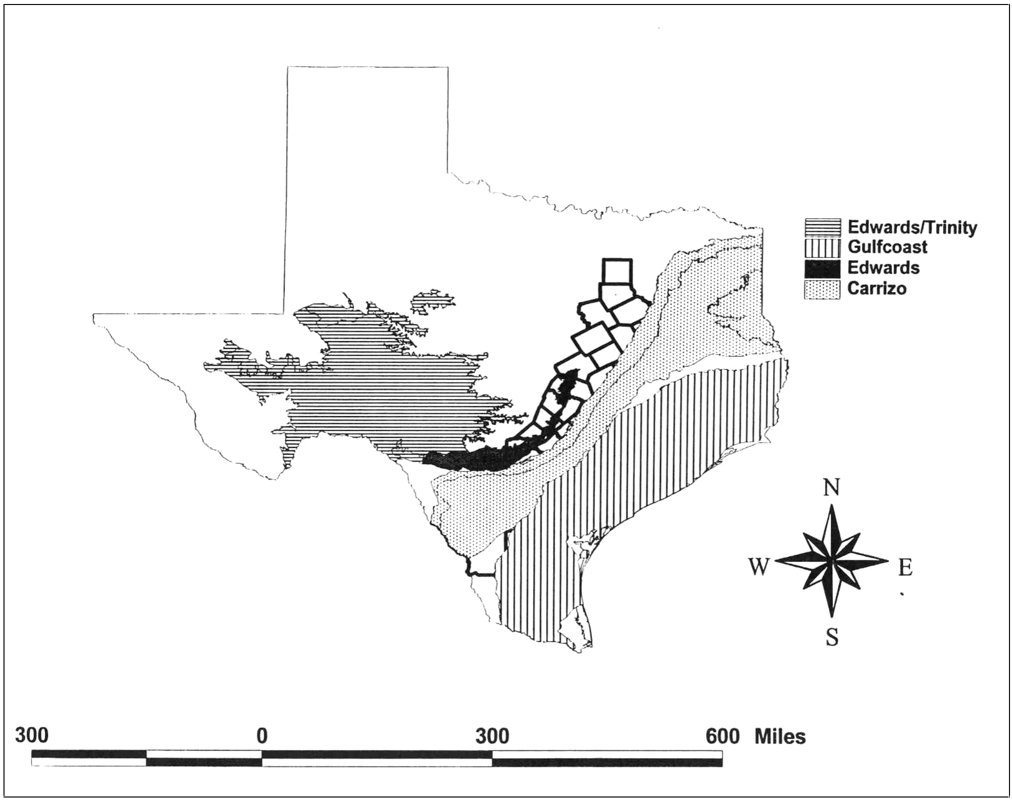

Figure 35. Major Aquifer Locations in Corridor Area.

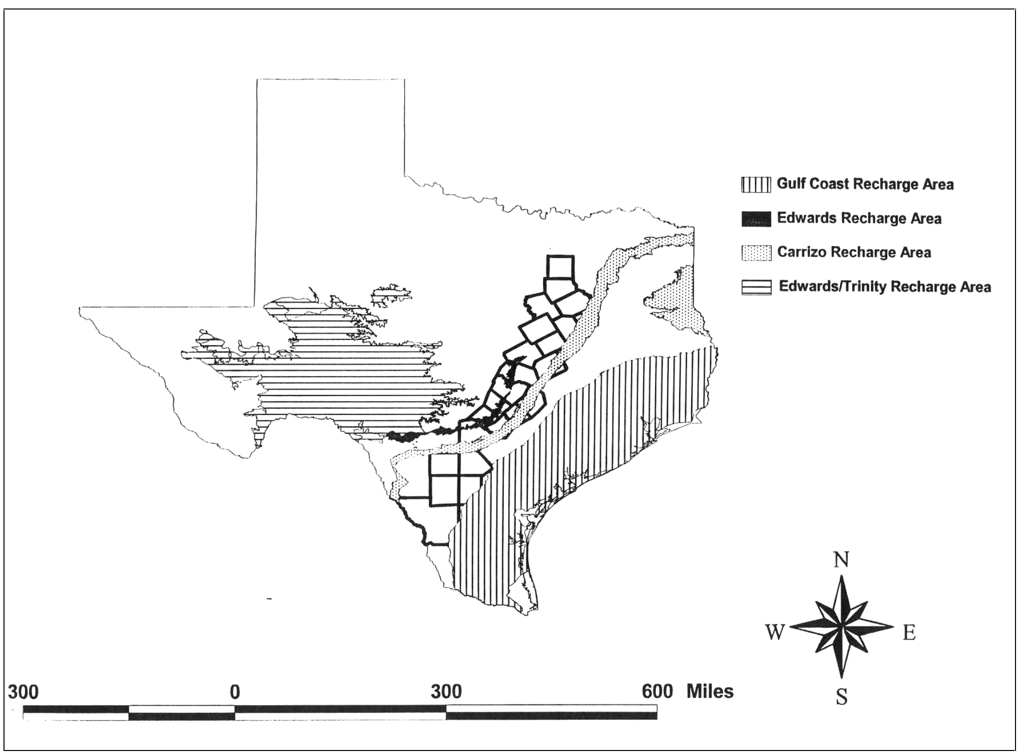

Figure 36. Aquifer Recharge Zones in Corridor Area.

TOPOGRAPHIC FACTORS

Evaluation of topography considered: 1) gradient, 2) continuity of slope, and 3) geomorphic landforms, including landform type, and landform characteristics. "Topographic elements include total relief and elevation differences, slope aspect, slope amount and type, and terrain ruggedness" (*20*). The ranking values for topographic factors of counties in the corridor area are shown in Table 23. Ranking criteria are discussed in sections that follow the table.

Table 23. Topographical Rankings for Counties in Corridor Area.

County	Gradient	Slope Continuity	Geomorphic Landform Type	Geomorphic Landform Characteristic
Atascosa	1	1	1	1
Bastrop	2	2	2	2
Bell	2	2	2	3
Bexar	2	2	2	2
Caldwell	2	3	2	3
Dallas	1	2	2	2
Ellis	1	2	2	2
Falls	2	1	2	3
Frio	1	1	1	1
Guadalupe	1	1	3	2
Hays	1	1	2	2
Hill	2	2	2	3
LaSalle	1	1	1	2
Limestone	1	2	1	2
McLennan	2	2	3	2
Milam	2	1	3	2
Travis	2	2	3	2
Webb	1	1	1	1
Williamson	1	2	3	2
Navarro	2	3	2	1

Topography was evaluated by using a General Soils Map, soil surveys, topographic maps, Geologic Atlas Quadrangle Maps of Texas, and information obtained from the Bureau of Business Research, University of Texas. In addition, a field exercise was conducted to survey the project area to verify surface topography, including site characterization of river valleys throughout the project area in order to observe the effects the rivers had on different geologic formations.

Gradient

Slope, or gradient, is an important indicator for rate of erosion. Steeper slopes show an absence of regolith and a general decrease slope stability. Regolith refers to fragmental and unconsolidated rock material, whether residual or transported, that nearly everywhere forms the surface of the land and overlies the bedrock (*21*). Therefore, gentle slopes that do not suddenly decrease in elevation are more favorable.

Erosion and gradient are greatly influenced by topography and soil or rock type. Erosion is an active process in areas of high slope relief because of wind and runoff, while river erosion is predominant in river valleys. Areas of low topographic slope and relief also have disadvantages because runoff and precipitation infiltrate into the subsurface, but areas of high gradient are unfavorable given that these are unlikely areas to build in; much like a gentle slope and rolling hills should be avoided whereas low topographical slopes are favorable.

Gradient was measured by looking in detail at topographic quadrangle maps of Texas. In order to rank the gradient of the area, 10,000 ft. intervals were measured and then ranked according to the percent gradient listed below. The gradient of the system greatly maximizes costs if exceeded beyond 30 percent; therefore, it was given a Rank 3. Rank 1 and 2 divided 30 percent into two equal parts, 0-15 percent and 15-30 percent. It was decided that Rank 1 would classify a gradient of 0-15 percent because it ranked areas with a low gradient, whereas Rank 2 was given 15-30 percent because it ranked areas with a moderate gradient. It is important to determine the gradient along the corridor to identify areas that may possibly exceed a 30 percent gradient, thereby greatly increasing system operational costs. While evaluating slope gradient, care was taken to review each selected line to ensure that no abrupt slope breaks were encountered.

Rank 1: 0-15 percent
Rank 2: 15-30 percent
Rank 3: > 30 percent

Slope Continuity

Continuity of slope is a measure of slope consistency. Slope characteristics, such as a significant steep cliff, can have a significant effect on topography. For example, a plain may be 90 percent flat, but irregularities of the surface topography might be expected depending on the formation and its environment. The rocks and soils determine what type of relief that slope will have, while rivers affect the way a slope forms depending on the type of geology present. Any landform having a slope greater than 30 ft was considered a steep cliff, and was assumed unfavorable for tunneling because of the increase in problems trying to cross it, whereas anything less than 15 ft was assumed a minimum relief because these are easier to engineer through.

Rank 1: <15 ft
Rank 2: 15-30 ft
Rank 3: >30 ft

Geomorphic Landform Types

Prairies, plains, and bottomlands are all types of landforms. Figure 37 shows landform types for the area under consideration. Flat upland plains are topographical highs indicative of the absence of floodplains. Bottomlands and floodplains are considered to have a high risk for flooding and inconsistencies in stratigraphy. The Brazos, Colorado, Trinity, and San Antonio Rivers, as well as smaller streams that are crossed, could cause potential problems because of their floodplains, which range from a few miles to over 20 miles wide. The potential for flood damage requires analysis of floodplain features. Landforms for which significant levels of tectonics may be expected also require extensive analysis. Flat plains are considered favorable because less wind and river erosion affects this area. The Texas Land Resource Area Map was used to classify landforms into the following:

Rank 1: Flat Plains – Uplands
Rank 2: Rolling Plains – Plains
Rank 3: Flood Plains/Tectonics – Terraces (floodplains)/Tectonics – Bottomlands

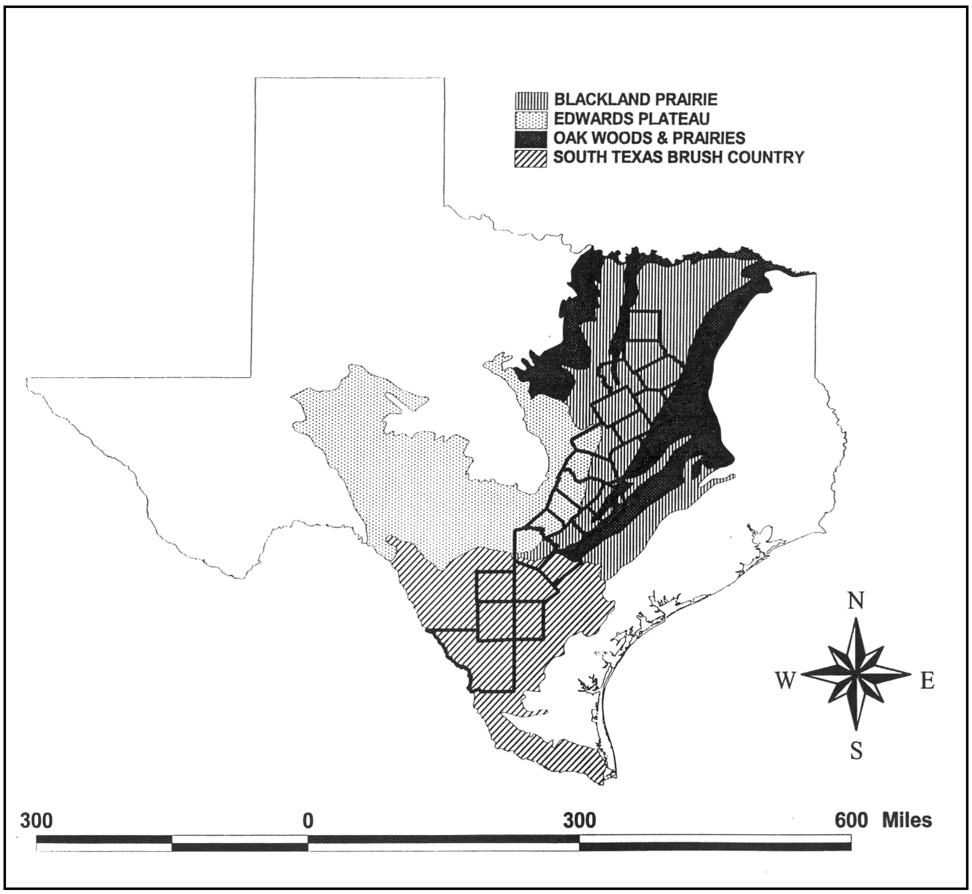

Figure 37. Landform Types in Corridor Area.

Geomorphic Landform Characteristics

An individual landform's characteristics depend on its formations and environmental history. The three common characteristics of landforms that develop are: highly stable landforms, those that erode back, and those that erode down vertically. The profile of the valley depends on the type of rocks which have been eroded. When alternate hard and soft layers are present, erosion in the softer rock is more rapid than in the harder rock and, therefore, terraced slopes develop (*18*). Several different sources were evaluated in order to obtain landform information. Texas topographic and geologic maps of Texas were used as sources to rank landforms. Geology was used because soil and rock type affect slope properties. For example, hard rock such as sandstone and quartzite will produce steep slopes with ridges and cliffs, whereas weak rocks such as shale form shallow slopes and low-lying landforms (*20*).

Topographic maps, the general geology map of Texas, and previous literature provided information on geomorphology. Highly stable landforms have greater slope stability and the slower erosion rates compared to landforms that are eroding back or eroding vertically. "Straight slopes have more uniform weathering conditions, but on concave slopes, weathering increases down-slope, whereas the opposite is true for convex slopes. Thus a slope's character determines both the rate of weathering and the ability of erosional processes to remove its products" (*20*).

Landforms that erode back have a rate of erosion that exceeds the rate of supply, yet not as severe as landforms that erode vertically on which debris is more quickly removed by erosional forces on steep slopes, exposing more material and preventing the development of thick regolith (*18*, *20*). The absence of regolith is one of the factors affecting slope stability. Construction in highly stable landforms would result in fewest impacts on a freight pipeline system, with increasing negative impacts resulting from erosion and slope stability for landforms that are eroding back, and greatest negative impacts for slopes that are eroding down.

The characteristics of a floodplain are also important. River valleys can take on different characteristics depending on the type of soil and geology. River valleys can erode back, causing wide floodplains with broad terraces, or they can incise steeply into the geology, causing a more v-shaped valley. A gently sloping terrain is desirable for tunneling so that adequate runoff occurs to avoid ponding, yet is gentle enough so that erosion is minimal. The following ranking criteria for landform characteristics were used for the counties:

Rank 1: Highly stable landforms or gradual slopes
Rank 2: Eroding back
Rank 3: Eroding down vertically

GEOLOGIC FACTORS

A primary essential to excavations and tunneling is knowledge of the geology of the area. The formation of each type of geologic unit can indicate the stresses that rock can experience over time. Geologic factors that were evaluated for the corridor include uniformity: which includes stratigraphic uniformity, structural uniformity, location of tectonics, and rock type: including slope stability, formation stability, wet weather accessibility, and rock strength. Table 24 is a summary of geologic factors rankings for formations in the corridor area. Ranking criteria are discussed in sections that follow the table. References 15, 16, 19, and references 21 through 56 were used in ranking the geologic formations with respect to the factors presented in Table 24. Figure 38 is a map of the geology of Texas.

Table 24. Geology Rankings Formations in the Corridor Area.

FORMATION	*Stratigraphic Uniformity*	*Slope Stability*	*Stability*	*Accessibility*	*Rock Strength*	*Permeability*	*Shrink/Swell*
Claiborne Group							
Yegua Frm.	3	1	2	2	3	1	1
Wilcox Group							
Carizzo	2	1	1	2	3	2	1
Calvert Bluff	2	1	1	1	2	2	1
Simsboro	2	1	1	1	2	2	1
Midway							
Willis Point	3	1	1	2	1	1	1
Kincaid	3	1	2	2	2	2	1
Navarro							
Escondido	2	1	2	1	2	2	2
Taylor	2	3	1	3	1	1	3
Pecan Gap	3	1	2	3	3	1	3
Wolfe City	2	1	1	1	3	2	3
Austin	3	1	2	1	3	2	1
Eagle Ford	2	3	1	3	1	1	3
South Bosque	2	3	1	3	1	1	3
Lake Waco	2	1	2	2	1	1	3

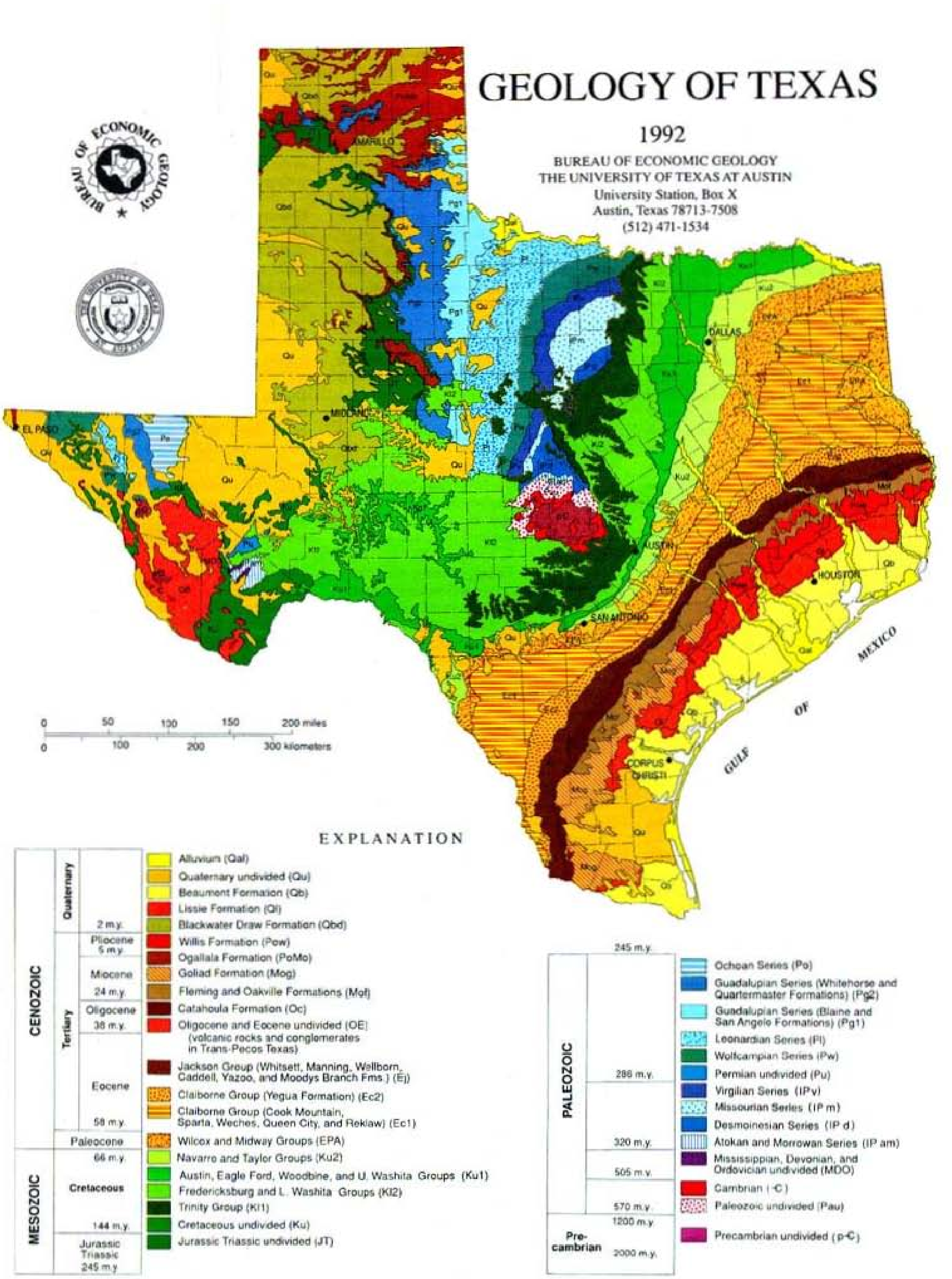

Figure 38. Map of the Geology of Texas (*57*).

Stratigraphic Uniformity

Factors that impact the stratigraphic uniformity of geologic formations include rock type, grain size, and mineralogy. Rock type is a factor of the environment of deposition (EOD) of each formation, from which the vertical and horizontal uniformity can be inferred. There are three main deposition processes. Eolian processes create a continuous lateral and horizontal uniformity in which no significant difference can be assumed. Significant changes in the lateral and horizontal uniformity can be expected in fluvial and deltaic environments, whereas marine environments create continuous lateral and significant vertical changes.

Geologic units were evaluated with respect to homogeneity because variability in lithology generally corresponds in unpredictability in geologic characteristics. Lithology refers to the description of rocks, especially in hand specimens and in outcrops, on the basis of such characteristics as color, mineralogic composition, and grain size (*17*). Geologic groups with a relatively single grain size indicate uniformity throughout the formation, whereas groups with considerable grain size distributions throughout the formations have less predictability. Mineralogy is another indirect measure of stratigraphic uniformity. Formations that have one type of mineral will generally have low variability throughout the geologic group, whereas formations with high variability of minerals may have inconsistencies throughout the geologic group.

Geologic groups, which consist of two or more formations that differ in rock type to some degree, result in vertical and lateral heterogeneity, which thus increases the geologic unpredictability of an area (*58*). A ranking of 1 was given to a group having one lithology vertically and laterally – only one rock type was expected to be encountered – allowing for consistency in design and construction. A ranking of 2 was given to formations with moderate variability in lithology, and a ranking of 3 was given to areas with lithology that varies laterally and vertically. A map of the ranked areas is shown in Figure 39.

Rank 1: Group having one lithology vertically and laterally
Rank 2: Group having changes, but infrequent laterally or vertically
Rank 3: Group varies laterally and vertically

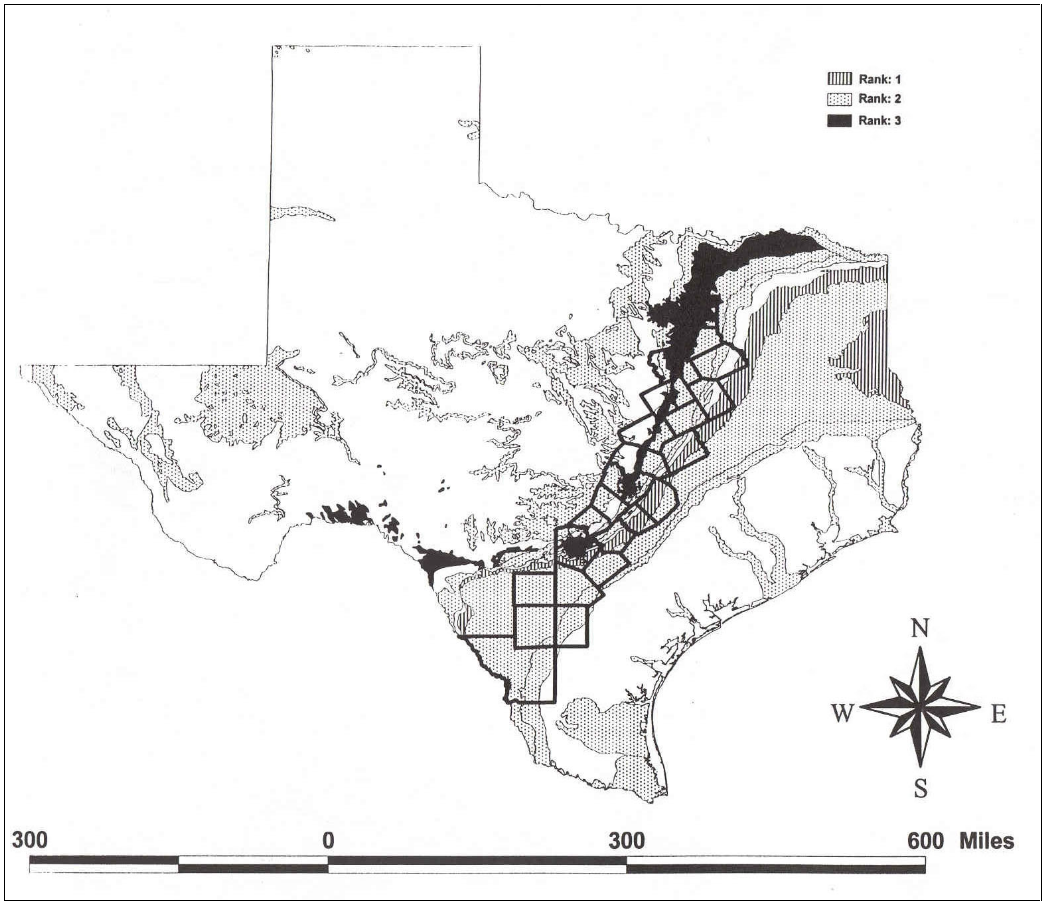

Figure 39. Stratigraphic Uniformity Rankings of Geologic Formations in Corridor Area.

Geologic Formation Slope Stability Estimate

The geology of an area affects the characteristics of excavations made into the formations. For example, cuts in weak sandstone will result in settlement of the ground, utilities and building at the sides of the cut (*59*). Sandstone requires a much flatter slope when making an initial excavation because it has more porosity and permeability and is not as cohesive as shale, therefore, more tieback support systems are necessary to keep the sides of the excavation from failing. Limestone formations are generally suitable for vertical excavation. Although not based on actual tests, geological characteristics of the formations were considered in forming general qualitative estimates of formation slope stabilities. Formations that are expected to have good support (supporting a vertical 90-degree cut to a 45-degree cut) are ranked 1. Formations expected to have less support (supporting between 0 and 45-degree cuts) are ranked 3.

Rank 1: Good expected support: 45° - 90°
Rank 3: Little expected support: 0° - 45°

Geologic Formation Stability

The stabilities of geologic formations are largely dependent on their geologic history of formation. Diagenesis is the change undergone by sediments after their initial deposition, exclusive of weathering and metamorphism. It includes compaction, cementation, and replacement and occurs under conditions of pressure and temperature that are normal in the outer part of the earth's crust. Diagenesis also includes geochemical processes or transformations that affect clay minerals before burial in the marine environment. It increases strength by cementing and thereby decreasing permeability.

Several types of formations are encountered in the corridor area. Limestones, which are formed largely of chalk, are considered to have moderate stability because while chalk is stable when not fractured or faulted, small normal faults are quite common under certain conditions. Consolidated sandstones and shales are considered highly stable rocks because of the amount of cementation and other geologic processes that compact the sediments. Unconsolidated sandstones and siltstone were given a ranking of three because of decreased cementation and increased permeability. Stability was ranked as follows:

Rank 1: Highly stable/consolidated sandstones, consolidated shales
Rank 2: Moderate stability/shale, siltstone, and limestone
Rank 3: Low stability/unconsolidated sandstones, unconsolidated siltstones

Wet Weather Accessibility

Accessibility ranking defines areas that pose a potential threat of delaying construction because of in-climate conditions and the behavior of the rock formation upon wetting. For exposed rock formations, accessibility was predicted based on geological characteristics of formations and ranked as follows:

Rank 1: Easily accessible in wet weather
Rank 2: Moderately accessible in wet weather
Rank 3: Poor accessibility in wet weather

Rock Strength

Rock strength classifies rocks in terms of their predicted rock strength. Low rock strength would be easier to excavate than a rock with high strength. Therefore, a rock with a predicted low strength was given a ranking of 1, whereas those with high-predicted rock strength were given a ranking of 3.

Rank 1: Low predicted strength
Rank 2: Moderate predicted strength
Rank 3: High predicted strength

Permeability

Porosity and permeability are related to diagenetic and compaction factors (*47*). The permeability of a geologic formation will indirectly affect the inflow and outflow of groundwater through a geologic group. Formation permeability was inferred from information sources listed at the start of this section. Formations with low estimated permeability are given a ranking of 1, those with moderate estimated permeability are given a ranking of 2, and those with high permeability are given a ranking of 3.

Rank 1: Low permeability
Rank 2: Moderate permeability
Rank 3: High permeability

Shrink/Swell Potential

Shrink/swell potential was considered for geologic formations encountered in the corridor area. The shrink/swell potential was evaluated from clay mineralogy of the rock formations. Kaolinitic clays have the lowest sorption capacities and shrink/swell potential. "The kaolinites form very stable clays because their tight, inexpandable crystal structure resists the introduction of water into their lattices" (*14*). Therefore, a ranking of one was given to this clay. Montmorillonitic clays have the greatest sorption capacities and shrink/swell potential. "Montmorillonite crystal sheets are bound rather loosely, allowing space for water molecules to insert themselves between the sheet, causing expansion or swelling" (*14*). A mix of montmorillonite and other clays, which may swell to more than 1.5 times their dry volume, which ultimately does not swell as much, was given a ranking of two. Pure montmorillonite, which may swell to over 15 times its dry volume (*14*), was given a ranking of three.

Rank 1: Low shrink/swell potential (kaolinitic clays)
Rank 2: Moderate shrink/swell potential (illitic and mixed clays)
Rank 3: High shrink/swell potential (montmorillonitic clays)

Structural Uniformity and Tectonics

Structural uniformity addresses any form of physical discontinuity in rocks. Faults, fractures, and any abnormal features that would affect a tunnel were noted. In this region, all faults are inactive, but discontinuities within the formations exist because of faulting. Structural predictability is an important feature because a fault can disrupt stratigraphy causing it to change suddenly, adding to problems in construction, thereby increasing costs.

"Massive" is a term used to describe rock formations. It is said of rocks of any origin that are more or less homogeneous in texture or fabric, displaying an absence of flow layering, foliation, cleavage, joints, fissility, or thin bedding. In rock mechanics it refers to a durable rock that is essentially isotropic and homogeneous and is free of fissures, bedding, and other planar discontinuities (*60*). "A tunnel should not be sited in fractured rock or in heavily weathered rock or in regions of faulting and folding. If, as is often the case, such situations must be accepted, then certain steps may be taken to minimize deleterious effects" (*61*). Faults within the stratigraphy might also affect the hydraulic properties of that particular rock, altering the inflow and outflows of water. Figure 40 shows a map of fault locations in Texas. Information on faults was obtained from the Structural Geologic Map of Texas and information sources referenced previously.

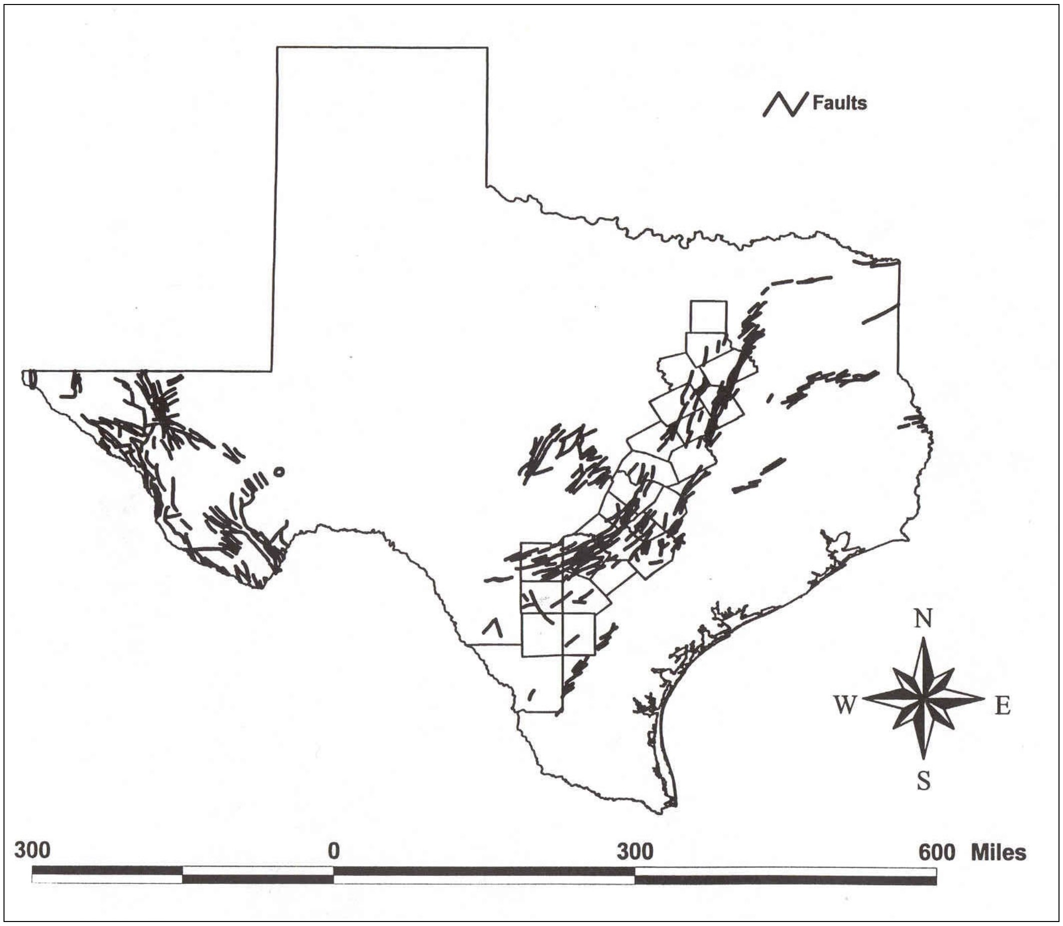

Figure 40. Fault Locations in State of Texas.

SOIL PARAMETERS

In this analysis, the term "soil" includes unconsolidated sediments in the surface and subsurface until more consolidated sediment is reached. Soils in the corridor area generally did not extend beneath 15 ft. Seven parameters were considered to characterize surface formations. Soils were evaluated in respect to: 1) pH, 2) thickness, 3) uniformity, 4) shrink/swell potential, 5) stability, 6) accessibility in wet weather, and 7) permeability. Soil associations, which are groups of individual soils that have similar characteristics, were used as the basic unit. These are found in all counties of the project area. The General Soils Map of Texas, which was prepared jointly by the Soil Conservation Service (SCS) and the Texas Agricultural Extension Service, defined soil associations.

SCS County Soil Surveys were particularly useful in providing information about soil depth to bedrock, unified classification, permeability, liquid limit, plastic index, pH, shrink/swell properties, clay mineralogy, sieve properties, and AASHTO properties. When soils included in the general soil associations on the General Soils Map of Texas were not listed in the soil survey reports, it was assumed that the associations have similar properties as the unmentioned soils because the soil units were grouped in the same soil associations. Groups of soils found in the corridor area are shown in Figure 41. Tables 25 and 26 summarize SCS soil survey information for soils that are found in the corridor area.

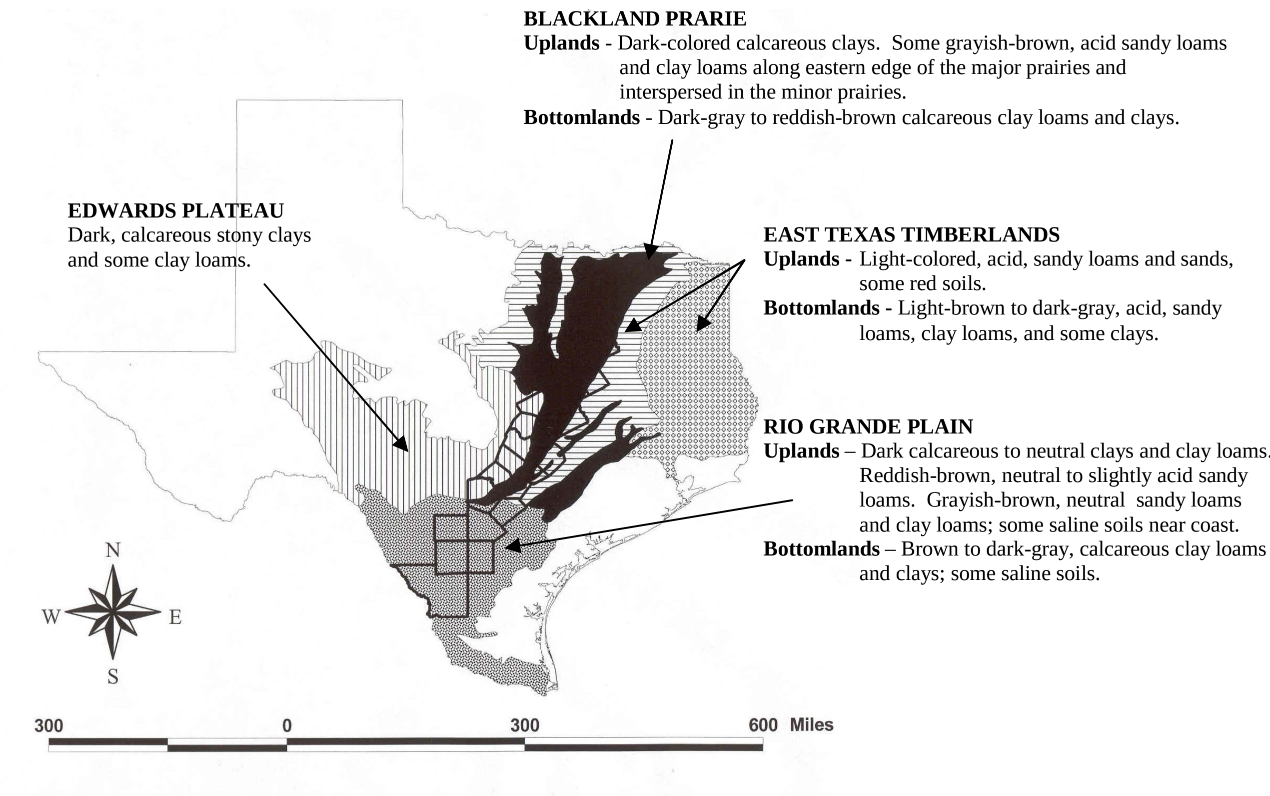

Figure 41. Groups of Soils Found in Corridor Area.

Table 25. SCS Soil Survey Description Summaries for Corridor Area.

Soil Associations	Soil Name	Counties	Soil Description	Soil Order	Bedrock Depth (In.)	Depth from Surface
Houston-Black-Heiden-Austin	Houston Black	Dallas, Hill, Limestone, Navarro, Bell, Bexar, Falls, Guadalupe, Travis, Ellis	Slightly acid soils with loamy surface layers and cracking clayey subsoils; and noncalcareous cracking clayey soils	Vertisol	70-110	
	Heiden	Dallas, Hill, Limestone, Navarro, Bastrop, Bell, Falls, Guadalupe, Travis, Ellis		Vertisol	56-88	
	Austin	Dallas, Hill, Bell, Falls, Guadalupe, Ellis		Vertisol	40-60	Lower 20" weathered bedrock
Wilson-Crockett-Burleson	Wilson	Hill, Limestone, Navarro, Wilson, Dallas, Falls, Travis, Ellis	Noncalcareous and calcareous cracking clayey soils; and slightly acid soils with loamy surface layers and cracking clayey subsoils	Alfisol	60-70	
	Crockett	Hill, Limestone, Navarro, Bastrop, Bexar, Guadalupe, Falls, Wilson, Ellis		Alfisol	55-108	
	Burleson	Navarro, Travis		Alfisol	60-63	
Austin-Stephen-Eddy	Austin	Dallas, Hill, Bell, Travis, Ellis	Very shallow to moderately deep, gently sloping to moderately steep, moderately alkaline loamy and clayey soils over hard limestone	Mollisol	22-40	Lower 10"-20" weathered bedrock
	Stephen	Dallas, Bell, Falls, Ellis		Mollisol	8-40	Lower 20"-40" weathered and unweathered bedrock
	Eddy	Dallas, Falls, Guadalupe, Travis, Ellis		Mollisol	9-40	Lower 20"-30" unweathered to weathered bedrock
Lufkin-Axtell-Tabor	Lufkin		Nearly level to strongly sloping soils that have a loamy surface and very permeable lower layers; on stream terraces and uplands	Alfisol		
	Axtell	Dallas, Limestone, Navarro, Bastrop		Alfisol	76-88	
	Tabor	Limestone, Bastrop, Wilson		Alfisol	62-80	

Table 25. SCS Soil Survey Description Summaries for Corridor Area (continued).

Soil Associations	Soil Name	Counties	Soil Description	Soil Order	Bedrock Depth (In.)	Depth from Surface
Windthorst-Galey-Konawa	Windthorst	Guadalupe	Deep, moderately well drained, gently sloping to sloping, loamy to sandy soils on uplands	Alfisol	72	
	Galey			Alfisol		
	Konawa			Alfisol		
Miguel-San Antonio	Miguel	Frio, Wilson	Poorly drained soils, loamy throughout; and well drained dark soils with loamy surface layers and clayey subsoils: Nearly level to undulating soils of the Rio Grande Plain	Alfisol	60-66	
	San Antonio	Bexar		Alfisol	120	
Duval-Webb-Zapata	Duval	Frio, Webb, Atascosa	Deep soils with loamy surface layers and loamy or clayey subsoils; and loamy soils with indurated caliche at shallow to moderate depths: Nearly level to undulating soils of the Rio Grande Plain	Alfisol	62-72	Lower 20" is weathered bedrock
	Webb	Atascosa, Bexar, LaSalle, Frio		Alfisol	48-80	(72-80" is weathered bedrock)
	Zapata			Alfisol		
Catarina-Montell-Jiminez	Catarina	Webb	Cracking clayey soils; crumbly clayey soils; soils loamy throughout; and shallow to moderately deep soils over indurated caliche: Nearly level to undulating soils of the Rio Grande Plain	Vertisol	60	
	Montell	LaSalle, Montell		Vertisol	65-70	
	Jiminez			Vertisol		
Monteola-Montell-Zaputa	Monteola	Atascosa, LaSalle	Cracking clayey soils; crumbly clayey soils; soils loamy throughout; and shallow to moderately deep soils over indurated caliche: Nearly level to undulating soils of the Rio Grande Plain	Vertisol	62	
	Montell	LaSalle, Montell		Vertisol	65-70	
	Zaputa			Vertisol	n/a	n/a
Sarita-Wilco	Sarita		Soils with sandy surface layers and loamy to clayey subsoils; and soils sandy throughout:	Alfisol	n/a	n/a
	Wilco			Alfisol	n/a	n/a

Table 26. SCS Soil Survey Description Summaries for Corridor Area.

Soil Association	Soil Name	Unified Soil Classification	AASHTO Class.	Sieve Analysis (% Passing)			k	Atterberg Limits		pH
				NO. 4	NO. 10	NO. 200		LL	PI	
Houston-Black-Heiden-Austin	Houston Black	CH	A-7-6	95-100	94-100	85-100	<.06	58-90	34-65	7.4-8.4
	Heiden	CH	A-7-6	95-100	95-100	75-95	<.06	54-65	41-46	7.9-8.4
	Austin	CH, CL	A-7-6	100	95	75-100	.2-.6	45-65	22-46	7.9-8.4
Wilson-Crockett-Burleson	Wilson	CH, CL	A-6, A-7-6	95-100	95-100	60-78	<.06 (.2-.63)	25-36 (U40-57)	21-35	Acidic towards the top (5.6-7.8) 6.6-8.4
	Crockett	(SM, ML, CL, SC) CH, CL,	A-2, A-4, A-6, A-7	85-100	80-100	(30-55), 65-100	(2.0-6.5), <.06	15-60	3-40	Acidic towards the top (5.6-7.3) 7.4-8.4
	Burleson	CH	A-7-6	90-100	85-100	70-95	<.06	n/a	n/a	5.6-8.4
Austin-Stephen-Eddy	Austin	CH, CL	A-7-6	93-100	90-100	75-95	.2-.6	45-65	20-40	
	Stephen	CH, CL	A-7-6, A-6, A-7	85-100	75-100	57-90	.2-.6	45-66	22-42	7.9-8.4
	Eddy	GC, GP-GC, CL	A-2, A-6	20-50 (90 in Ellis)	15-50 (80 in Ellis)	8-40 (70 in Ellis)	.2-.6	30-40	11-40	7.6-8.4
Lufkin-Axtell-Tabor	Lufkin									
	Axtell	(SM, ML, SM-SC, CL-ML) , CL. CH	(A-4, A-2-4) A-7-6	90-100	75-100	(28-60), 36-85	(.6-2.0), <.06	(<31), 42-60	(NP-7), 25-40	4.5-8.4
	Tabor	(0-15 SM-SC, CL-ML, SC), CH	(A-2-4), A-7-6	85-100	75-100	(30-55), 55-90	(.6-2.0), <.06	(<.25), 30-55	(NP-6), 25-45	5.1-7.8
Windthorst-Galey-Konawa	Windthorst	SC, CL, CH	A-4, A-6, A-7-6	90-100	90-100	21-85	.2-.6	30-55	16-35	5.6-8.4
	Galey									
	Konawa									
Miguel-San Antonio	Miguel	CL, SC-SM, SM, CL, CH	A-4, A-6, A-7-6	90-100	90-100	36-70	<.06-.2	30-55	15-32	6.6-8.4
	San Antonio	CL, CH	A-6, A-7	95-100	93-100	80-85	.8-1.0	n/a	n/a	7.4-8.4

Table 26. SCS Soil Survey Description Summaries for Corridor Area (Continued).

Soil Association	Soil Name	Unified Soil Classification	AASHTO Class.	Sieve Analysis (% Passing)			k	Atterberg Limits		pH
				NO. 4	NO. 10	NO. 200		LL	PI	
Duval-Webb-Zapata	Duval	SM, SC-SM, SC, CL-ML	A-2-4, A-4, A-6	80-100	75-100	15-50		20-40	4-19	
	Webb	SM-SC, CL, CL-ML, SM	A-4, A-2, A-6 A-7	75-100	51-100	30-80	.6-1.5	30-50	10-38	6.6-8.4
	Zapata									
Catarina-Montell-Jiminez	Catarina	CH	A-7-6	85-100	82-100	80-98		44-76	23-49	
	Montell	CH	A-7-6	80-100	75-100	75-100	<.06	51-74	29-49	7.4-8.4
	Jiminez									
Monteola-Montell-Zaputa	Monteola	CH	A-7-6	80-100	80-100	75-96	<.06	51-80	30-54	7.4-8.4
	Montell	CH	A-7-6	80-100	75-100	75-100	<.06	51-74	29-49	7.4-8.4
Sarita-Wilco	Zaputa	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Sarita	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Wilco	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 28 shows the soil parameter rankings for soils found in the project area. The soil parameters were ranked for each formation as follows: from the soil survey information, average values were taken for the seven parameters in each county. The average values were defined for each soil association using the lowest and the highest value that was encountered for that association in each county. The average values were then ranked according to the criteria discussed in the sections following sections.

Table 28. Soil Rankings for Corridor Area.

Properties/Soil Associations	pH	Thickness	Uniformity	Shrink/Swell	Stability	Access	Permeability
Houston Black	1	2	1	3	2	3	1
Heiden	1	2	1	3	2	3	1
Austin	1	3	2	3	2	3	1
Wilson	2	2	2	2	2	3	1
Crockett	1	2	2	2	2	3	1
Burleson	3	2	1	2	2	3	1
Austin	1	3	2	1	2	3	1
Stephen	1	3	2	1	2	1	1
Eddy	1	3	3	1	1	3	2
Lufkin	N/A	N/A	N/A	N/A	N/A	3	1
Axtell	3	2	2	1	2	3	1
Tabor	3	2	1	1	2	3	1
Windthorst	3	2	3	1	1	2	2
Galey	N/A	N/A	N/A	N/A	1	N/A	N/A
Konawa	N/A	N/A	N/A	N/A	2	N/A	N/A
Miguel	2	2	3	1	1	1	2
San Antonio	1	1	2	1	2	3	1
Duval	N/A	2	3	1	1	1	2
Webb	2	3	3	1	1	1	2
Zapata	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Catanna	N/A	2	1	3	2	3	1
Montell	1	2	1	3	2	3	1
Jiminez	1	N/A	N/A	N/A	N/A	N/A	N/A
Monteola	1	2	1	3	2	3	1
Montell	1	2	1	3	2	3	1
Zaputa	N/A	N/A	N/A	N/A	N/A	N/A	N/A

pH

Soil reactivity is a measure of acidity and expressed as a range in pH values. These values are important because they can influence the risk of corrosion. “Chemical analysis of groundwater samples at various depths and locations, essential for determining the suitability of construction materials, also makes it possible to detect potential grout unsuitability” (*62*). It is also an important for ease of vegetative reclamation. Information sources for pH evaluation included previous literature and consultations with soil scientists.

A soil having a pH of 6.0-8.0 was given a ranking of one because neutral soils are ideal for vegetation and indicate waters that are not corroded. A buffer zone was given around 7.0 to include those soils ranking somewhat above and below it, but not showing acidity or basic behavior. Basic soils (above a pH of 8.0) were given a ranking of two, because colloids flock to these soils, giving the soils more nutrients. Acidic soils were assigned a ranking of three because of the lack of nutrients and their problems with neutralizing the soil. Rankings for pH were assigned the following order:

Rank 1: Excellent reclamation - pH (6.0-8.0)
Rank 2: Average reclamation - pH (above 8.0)
Rank 3: Difficult reclamation - pH (below 6.0)

Thickness

Because depth of cover and ease of excavation are anticipated to be of critical importance to construction costs of the project, deep soil thickness (>10 ft) was given a ranking of one. Medium thickness (5-10 ft) was given a ranking of two, whereas the least soil thickness (< 5 ft) was given a ranking of three. Various literatures, which discussed the effect thickness had upon soils, were used in order to rank soil thickness. Rankings for soil thickness were assigned as follows:

Rank 1: Heavy thickness (> 10 ft)
Rank 2: Medium thickness (5-10 ft)
Rank 3: Thin soil layers (< 5 ft)

Uniformity

Uniformity is important because the character and properties of the tunnel or excavation must be predictable. Soil uniformity was determined from soil descriptions and soil classification in the county soil surveys. Similar to geology, vertical and lateral discontinuities were evaluated. Soil uniformity was ranked as follows:

Rank 1: Soils having one soil type vertically and laterally
Rank 2: Soils having changes, but infrequent laterally or vertically
Rank 3: Soils vary laterally and vertically

Shrink/Swell Potential

Clay soils present a hazard because of their ability to expand and contract, accompanying soil moisture changes (*14*). Clay minerals retain a film of water that leads to an expansion or contraction of the soil profile as this water film changes. During dry seasons, the water evaporates causing the soil profile to shrink and desiccation cracks to form. Clay type and content of each soil affects its liquid limit (LL), plastic index (PI), and expansiveness.

Information on the LL and PI for each association was compiled and averaged. In general, an increase in depth corresponds to an increase in clay content for the formations considered. The LL and PI indicate the range from the lowest LL and PI found to the highest reached LL and PI for each formation in the counties evaluated. This was done to best estimate the range of values through each of the counties.

Castleberry documented that in areas having a humid climate; the water table may be very near the surface and expansive soil problems become non-existent because of the unlimited access to water. On the other extreme, the water table in arid climates may be at a great depth and have no effect on surface soil moisture conditions (*19*). "Regions which receive a large percentage of their annual rainfall within a relatively short time and experience relatively dry conditions the rest of the year are especially vulnerable to expansive soil problems as opposed to regions receiving the same amount of rain but spaced at more regular intervals throughout the year" (*19* and *44*).

Kaolinitic clays have the lowest sorption capacities and shrink/swell potential. "The kaolinites form very stable clays because their tight, inexpandable crystal structure resists the introduction of water into their lattices" (*14*). Therefore, a ranking of one was given to this clay. Montmorillonitic clays have the greatest sorption capacities and shrink/swell potential. "Montmorillonite crystal sheets are bound rather loosely, allowing space for water molecules to insert themselves between the sheet, causing expansion or swelling" (*14*). A mix of montmorillonite and other clays, which may swell to more than 1.5 times their dry volume, which ultimately does not swell as much, was given a ranking of two. Pure montmorillonite, which may swell to over 15 times its dry volume, was given a ranking of three (*14*). Soil shrink/swell was evaluated in one of two ways: 1) it was evaluated from clay mineralogy or 2) from qualitative assessments in the county soil surveys. The rankings are shown below:

Rank 1: Low shrink/swell potential (kaolinitic clays)
Rank 2: Moderate shrink/swell potential (illitic and mixed clays)
Rank 3: High shrink/swell potential (montmorillonitic clays)

Stability

Soil characteristics have a significant impact on tunneling or excavations, where the stabilization of clays and sands play an important role in the construction method to be utilized. Soft clays typically have low shear strength, but increases as depth increases. The stability of these soils is dependent on the plasticity. Unconsolidated clays to sandy clays and silty clays would give the greatest amount of stability compared to shales and clays (because of swelling) and sands (because of increased excavation slopes).

Settlement in stiff clays is a result of a decrease in cohesive strength of the soil. In excavations, a clay may yield laterally towards the bottom of the excavation and eventually, sloughing of trench walls occur, which continues until the opening is closed. Lateral movements are much greater with cuts in soft clay than with sand or stiff clay deposits. "When a cut is excavated in soft clay, the clay located at the sides of the cut acts like a surcharge and yielding of the clay near the bottom of the excavation occurs" (*61*). Exposure and rate of excavation are important because undrained shear strength is dependent on pore water pressure; it is desirable to take advantage of the negative pore water pressure which is induced at the time of initial exposure of the freshly cut surface (*61*). Flat side slopes are required for cuts made in very soft soil, making the volume of cut enormous when the center depth is enormous (*63*).

Stabilization of clays and sands play an important role in the construction method and cost estimates. Soft clays typically have low shear strength at the surface that increases as depth increases. Exposure and rate of excavation are important because undrained shear strength is dependent on pore water pressure, which decreases as time increases. It is desirable to take advantage of this negative pore pressure, which is induced at the time of initial excavation (*61*). Exposure and rate of excavation is also important because the stability of these soils is dependent on the plasticity. Overconsolidated clays may present swelling, where linings are required in order to stabilize the overconsolidated clays, that continue until the excavation is closed (*61*). Stability was ranked for soils in a similar manner as was ranked for geological formations.

Rank 1: Unconsolidated clays to sandy clays and silts
Rank 2: Consolidated clays, silts
Rank 3: Unconsolidated sands, unconsolidated silts, sands

Accessibility

Wet weather can play a significant role in construction. Generally, the soil depth in the corridor area does not exceed 15 ft, and the soils can be easily impacted by wet weather. Factors that were considered in ranking the wet weather accessibility of the soils include soil type, topography, and precipitation amounts. Soils were ranked according to the following criteria.

Rank 1: High accessibility in wet weather
Rank 2: Moderate accessibility in wet weather
Rank 3: Poor accessibility

SITE CHARACTERIZATION

Information useful to the selection of systems placement and identification of engineering and construction issues was developed in this report for a corridor between Dallas and Laredo that roughly parallels IH-35. A complete evaluation would require a more extensive, more detailed investigation of the physical characteristics – hydrology, topography, geology, and soils – of the corridor area. Unfavorable conditions with respect to one physical characteristic do not necessarily render a site unsuitable because they may be offset by favorable conditions with respect to other physical characteristics.

Information obtained regarding the hydrology, topography, geology, and soils in the corridor area may be used in an evaluation of costs and benefits for system locations. In addition, some general preliminary conclusions may be drawn regarding formation and regional characteristics of the corridor area, including favorable and unfavorable aspects of the corridor's physical characteristics.

Hydrology

The climatic conditions for the entire corridor area are subhumid/subarid. Within this categorization, there are some differences. The northeastern part of the corridor area is a somewhat more humid climate than the southwestern part, which may have implications to the use of open-cut construction methods. Catastrophic climatic events appear to pose a minimal hazard to the system after construction has taken place, but would likely be the greatest influence during construction. With respect to this parameter, there appears to be no particular location in the corridor area that is immediately apparently better than another location in the corridor area.

Groundwater depth is another physical parameter of consideration. Because specific, detailed information regarding water table depth was not found in the research, some general correlations for this parameter were made with climatic influences. Based on these broad assumptions, the water table may be expected to be encountered in the corridor area between moderately shallow to moderately deep values. Because of the variability in depth, a further investigation of the site and specific criteria on this subject would be necessary to further define water table depths over any specific, selected corridor.

The potential for impacting groundwater aquifers is also considered, and aquifer locations and recharge zones have been identified for the corridor area. As described in Appendix B, the shallowest confined aquifer in the corridor area is at a depth of 300 ft from the surface.

Topography

The corridor area includes four geographic landforms: Blackland Prairies, Rio Grande Plain, Bottomlands, and the Edwards Plateau. Each of these landforms can be characterized by their topographical features: rolling hills, plains, or river valleys. The landforms were ranked for each of the counties in the corridor area with respect to suitability for the underground freight pipeline system with consideration of the general system parameters. Counties that geographically lie in the Rio Grande plain, flat plains with low gradient, and were the highest ranked. The topographic features of the Blackland Marls and the Edwards Plateau, rolling hills and river valleys, were ranked average. Ratings of below average were given in the Bottomlands region, where river valleys dominate the county.

One of the major topographic constraints is crossing the numerous rivers and streams in the corridor area. The Brazos, Colorado, Nueces, and San Antonio rivers have wide, eroding back floodplains. Rivers running through Ellis and Dallas counties have steeper, eroding down floodplains with steep embankments.

The topography indicates that rivers flowing into the Taylor and Eagle Ford Groups have wide floodplains, while rivers flowing through Wilcox and Austin Chalk Groups have flood-plains that are eroding vertically. These areas present potentials for flooding, terraces, eroding valleys, and mass movements. While it is possible to locate the system beneath the rivers via tunneling, appropriate consideration should be given to drainage in this case. Maintenance is another consideration for river valleys due to mass movements and the constant erosion of flood plains. Additional consideration of flooding risks should be given in floodplains.

Topography considerations for rolling hills landforms include impacts on energy usage due to numerous gradient chances, increased probability of erosion and mass wasting, slumping and slope instability and impacts on large-scale excavations due to constant change in gradient. Plains and high-lying areas are generally low risk with respect to flooding. However, risks of wind erosion are higher due to their elevation.

Geology

The soil and geology of the project area appears, overall, to be suitable to the construction of an underground freight transport system. It was found that no unpredictability is expected for the geology and soil characteristics. However, as particular formations have differing characteristics, the selection of optimal formations may vary depending on the particular needs of the system. Each geologic group has favorable and unfavorable characteristics that may outweigh each other.

The corridor area includes several different geologic groups. The geology includes shales, sandstones, siltstones, and limestones. Tectonic faults are found throughout the entire corridor area. Dallas County has minimal faults while Bexar, Caldwell, Falls, Frio, and Medina counties have faults that are found throughout the entire counties. The faults in the project area are inactive, yet they are important to consider because they provide inconsistencies in the lithology when crossed, which may lead to additional design and construction considerations. Permeability is relatively low throughout the entire area for all formations.

Soil

Atterberg limits, grain size distribution, permeability, and depth to bedrock were evaluated for every soil type in selected counties. An additional investigation is necessary to define engineering characteristics of formations in specific selected routes. In particular, the existence of shrink/swell characteristics would have a bearing on the suitability of the site; their existence should be confirmed or denied by additional analysis.

The soils present in the project area belong to the soil associations shown in Table 17. Lean clays are the predominant soils found in the corridor area. The parent materials for these soils are the Taylor Formation, Eagle Ford Shale, Yegua Formation, and the Wilcox Formation.

Fat clays and some sandy soils occur in small areas throughout the areas. These soils are derived from the Austin Chalk, Quaternary deposits, and the floodplain deposits.

Mixed clays, which are also found in much of the project area, have some potential for shrinkage and swelling because mixed clays include montmorillonite, the clay mineral that is most significant for shrinkage and swelling. In particular, soil associations in Dallas, Ellis, and Hill counties have high shrink/swell probabilities and clay contents. Consideration for construction and operation in shrink/swell areas includes prevention of moisture and seepage from reaching these soils. Rapid excavation, adequate moisture control, rapid closure, and adequate capping can help minimize the occurrence of moisture changes.

Soil formations in LaSalle and Frio counties have deep, loamy surface layers with a low shrink/swell probability, variable grain size, low clay content, and basic (pH) soils. Sandy clays, silty clays, and gravely clays that are found in the corridor area can provide stability for excavations and generally have low shrink/swell properties. There are also problems associated with these soils, such as permeability, unpredictability in grain sizes, and weathering aspects. Additional consideration in sandy formations is the maintenance required to remove wind-blown sand or the construction and control mechanisms necessary to either remove or stabilize the sand fields.

Analysis of Routing Alternatives

Four routing alternatives in the corridor area, shown in Figure 42, were selected solely to illustrate advantages and disadvantages of different routes and are discussed below.

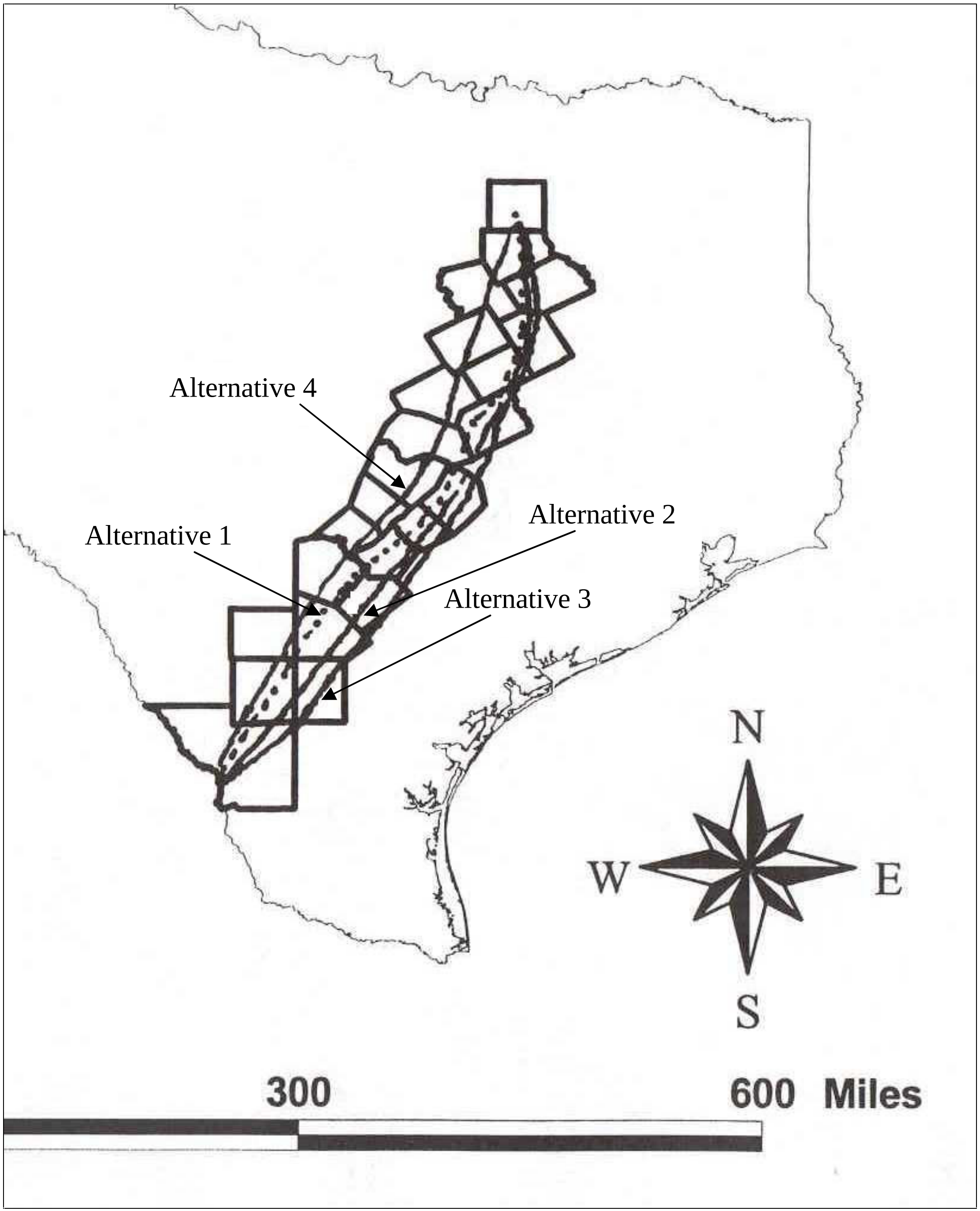

Figure 42. Sketch of Route Alternatives in Corridor Area.

Alternative 1

Advantages to Alternative 1 include ease of construction for soils in LaSalle and Upper Atascosa counties, the avoidance of recharge areas of the Carrizo-Wilcox aquifer system, and avoidance of faults that are not parallel to the route in Bastrop and eastern Guadalupe County. An additional advantage is the avoidance of soils that are poorly suited to system construction in

Ellis and Dallas counties. Because the route is situated more to the east, it also avoids increased and changing gradient that often is seen with rolling hills. Disadvantages of this route include increased risk of flooding due to wider flood plains with wider terraces that are eroding, and an anticipated shallower groundwater table.

Alternative 2

The advantages of this route are that it is anticipated to have a deeper groundwater table than Alternative 1 and is located further away from the Carrizo recharge zone. Known tectonic faults are not found as often in the counties of Williamson, Bell, Milam, and Bastrop counties. Alternative 2 has several disadvantages. It is located near the Gulf Coast recharge zone, populated cities, and the Austin Chalk formations in Ellis and Dallas counties, which also have poorly suited soils. Rolling hills and bottomlands are encountered in the upper portion of the route, creating a potential for mass wasting and erosion.

Alternative 3

Fewer faults are encountered along Alternative 3 than along other routes, as are sandier geologic formations and more plains, resulting in fewer anticipated geologic hazards. The disadvantages are that shallow groundwater, increased fault discontinuities, and wider flood-plains would be found along this route.

Alternative 4

The advantages to Alternative 4 include an anticipated deeper water table, and limited aquifer recharge zones, although this route is located in the Carrizo recharge zone. As this route lies on the eastern part of the Blackland prairies, major floodplains are avoided, and the geologic formations are more calcareous and sand based. Disadvantages to Alternative 4 include the rolling-hill topography and numerous tectonic faults. In addition, there are gradient issues because of the Edwards Plateau providence, and increased maintenance for high shrink/swell soils would be required. This route is also the nearest route to populated cities.

CHAPTER 11 – ECONOMIC EVALUATION FRAMEWORK AND DATA ISSUES

INTRODUCTION

A sound cost/benefit analysis is needed to underpin the political and investment decision making relative to assessing the viability of underground freight transportation compared to more traditional options. In this chapter an investment analysis framework comparing a highway-oriented, truck transport option versus a freight pipeline option for the Dallas-Laredo trade corridor of IH-35 is presented. The benefits, costs, and impacts of each of the investment strategy options are detailed and the pertinent data issues are outlined. The purpose of the economic analysis is to determine if the potential exists to divert enough truck traffic from IH-35 to the underground freight pipeline to reduce the traffic congestion, accidents, air pollution, and noise substantially enough to warrant the investment in an alternative to traditional transportation modes.

Indicators of "Economic Feasibility"

To determine whether a transportation investment is economically feasible, the costs of building and operating a new facility are compared with the economic benefits estimated to be attributable to the improvements. This cost and benefit comparison yields three indicators of "economic feasibility" for the proposed alternatives.

1. *Net Present Value* – All costs and benefits in future years are discounted back to the base year using a 7 percent real (constant dollar) discount rate. The future stream of discounted costs is subtracted from the future stream of discounted benefits. When the sum of the discounted benefits is greater than the sum of the discounted costs, the "net present value" is positive and the investment is deemed to be "economically feasible."
2. *Discounted Benefit/Cost Ratio* – After the future streams of costs and benefits are discounted, the sum of the discounted benefits is divided by the sum of the discounted costs. When the result is 1.0 or greater, the project is considered to be "economically feasible."
3. *Internal Rate of Return* – This calculation determines the discount rate that will result in the net preset value difference between costs and benefits being zero. If the rate of return, expressed as a percentage, is equal to or greater than 7 percent, then the investment is deemed to be "economically feasible."

An investment is considered to be economically feasible if:

- A project is one that has a positive Net Present Value (NPV),
- A project Internal Rate of Return (IRR) is higher than the opportunity cost of money, or
- A project benefit-cost (B/C) ratio is 1.0 or higher.

It is important to note that the higher the NPV, IRR, and B/C ratio, the more feasible the project. In the current study, a benefit-cost analysis performed for the highway scenario will be compared with a benefit-cost analysis performed for the freight pipeline. It should be mentioned that the benefits and costs for each of the projects carry different characteristics and components. For example, the addition of highway capacity increases capacity for passenger transportation as well as for freight. Thus, the effective added capacity for freight must be reduced by an estimate of the passenger-freight mix at the time of project implementation.

Benefits may also be considered as reductions in costs resulting from an improvement and may be measured as the difference in costs between the base case and the improved case. In our case, included in the economic feasibility calculations for travel efficiency will be all quantifiable direct economic costs attributable to the project (cost of planning, designing, building, right-of-way, maintaining, and operating the highway and the freight pipeline) and all quantifiable economic benefits relating to travel efficiency, including user benefits (operating cost savings, value of time savings, and accident cost savings).

One of the general economic implications that result from the development of improved transportation facilities is the increase in transportation efficiency that can be measured in user benefits. User benefits are simply the difference in costs between two predicted future states of the transportation facility under consideration: typically, an improvement will lower user costs, producing benefits. User costs may be normalized by using vehicle miles traveled as the standard against which measures are compared. Total user costs are a product of user costs per vehicle mile times section length times Average Annual Daily Traffic (AADT).

Benefit/Cost Analyses

1. Highway Investment Cost Analysis

There are two cost components included in the cost part of the cost-benefit calculation. These cost components are:

- the net capital costs of implementing the proposed improvements to the Dallas-Laredo section of the IH-35, and
- the net annual administration, operation, and maintenance costs.

The largest single category of highway expenditures for all levels of government is capital outlay, followed by maintenance services. Capital outlays are those costs associated with the planning, engineering, and construction of improvement projects, while maintenance expenditures preserve existing facilities**.**

Capital Costs – Capital costs consist of the cost of implementing the highway project, including right-of-way acquisition, planning, design, and construction.

Annual Operations and Maintenance Cost – Once the highway improvement is completed, it must be operated and maintained. The resulting net change in maintenance and operations cost is estimated. To account for the depreciation, a residual value is calculated as a benefit in the year that follows the year when the construction was completed.

Average generalized cost factors to be applied throughout the Dallas-Laredo section of IH-35 will be developed for the following items to develop project construction costs:

- roadway (earthwork, pavement, and drainage),
- right-of-way (ROW),
- engineering and administration,
- Intelligent Transportation Systems (ITS), and
- operations and maintenance.

The generalized construction costs should permit comparing the research alternatives on the basis of total cost to develop the cross-section under consideration. Generalized ROW costs include: purchase, sale of improvements, appraisal, title insurance, and utility adjustments. Maintenance costs include: route and right-of-way maintenance, highway patrol, engineering and administration, and communications. In addition to the cost of constructing a facility, there is the incremental cost of maintaining the facility. Both the capital costs and the incremental operations and maintenance costs will be analyzed and included in the cost-benefit analysis.

Cost of Trucking

Seven categories of user cost are listed in Table 29 below:

Table 29. Trucking Industry User Costs.

Category	Scope
Fuel	gasoline, diesel fuel, or other fuel consumed by motor vehicles, including taxes
Maintenance	oil, parts, periodic maintenance, unscheduled maintenance, tires, and excise taxes
Accidents and Insurance	cost of accidents (internal), insurance administration, and profit
Vehicle Wear and Ownership	wear and tear, additional depreciation, financing, sales, and excise taxes
Tools and Fees	tolls, registration fees, and license fees
Parking	cost of parking to the user at work, shopping, or other
Travel Time	dollar value of time spent in traveling

These categories can be helpful in providing alternative measures of price, in distinguishing fixed costs from variable costs as a means for defining the relevant costs, and in matching with empirical estimates of costs. Trucking benefits are the difference in costs between two predicted future states of the section under consideration: typically, an improvement will lower user costs, producing a benefit.

Marginal Costs

The marginal costs of highway use are added costs associated with a unit increase in highway use (measured, for example, in cents per vehicle mile). These marginal costs include costs to the highway user (e.g., travel time and fuel), costs imposed on other highway users (principally crash costs and congestion), costs imposed on non-users, and costs borne by public agencies responsible for the highway system (e.g., user-related maintenance costs). Highway users take their own vehicle operating and travel time costs into account when they decide whether or not to make a trip, but they generally do not consider costs they impose on others.

Highway Impact Analysis

The potential effects of shifting traffic from highways to the freight pipeline (the effects of less truck traffic on highway users and the infrastructure) are: capacity-related, safety-related, and pavement-related effects.

Highway user costs are impacted by higher volume-capacity ratios in two major ways. Vehicle operating costs (fuel, oil, tires, maintenance and repair, and use-related depreciation) increase as travel speeds decrease and as the frequency of stop-cycles and idling increase. Slower speeds also result in greater travel-time costs.

Marginal Costs of Automobile and Heavy Truck Travel

The Federal Highway Administration (FHWA) recently published the results of a detailed highway cost allocation study. As part of the study, FHWA developed a set of marginal cost factors for travel by various types of vehicles. Table 30 presents a partial list of marginal cost factors attributable to automobiles and heavy trucks when traveling over interstate highways.

According to FHWA, the marginal pavement cost of an 80,000 lb combination truck traveling on a rural interstate highway is 12.7 cents per mile. In comparison, the marginal pavement cost of the same truck is almost 41 cents per mile on urban interstate highways. Marginal congestion costs are approximately 20 cents per mile for an 80,000 lb truck traveling on urban interstate highways, but only 2.23 cents per mile on rural interstate highways. Finally, marginal crash costs are 1.15 and 0.88 cents per mile for an 80,000 lb truck traveling on urban and rural interstate highways, respectively.

Table 30. Marginal Cost Factors Attributable to Automobiles and Trucks.

2000 Pavement, Congestion, Crash, Air Pollution, and Noise Costs for Illustrative Vehicles Under Specific Conditions						
Vehicle Class/Highway Class	Cents per Mile					
	Pavement	Congestion	Crash	Air Pollution	Noise	Total
Autos/Rural Interstate	0	0.78	0.98	1.14	0.01	2.91
Autos/Urban Interstate	0.1	7.70	1.19	1.33	0.09	10.41
40 kip 4-axle S.U. Truck/Rural Interstate	1.0	2.45	0.47	3.85	0.09	7.86
40 kip 4-axle S.U. Truck/Urban Interstate	3.1	24.48	0.86	4.49	1.50	34.43
60 kip 4-axle S.U. Truck/Rural Interstate	5.6	3.27	0.47	3.85	0.11	13.3
60 kip 4-axle S.U. Truck/Urban Interstate	18.1	32.64	0.86	4.49	1.68	57.77
60 kip 5-axle Comb/Rural Interstate	3.3	1.88	0.88	3.85	0.17	10.08
60 kip 5-axle Comb/Urban Interstate	10.5	18.39	1.15	4.49	2.75	37.28
80 kip 5-axle Comb/Rural Interstate	12.7	2.23	0.88	3.85	0.19	19.85
80 kip 5-axle Comb/Urban Interstate	40.9	20.06	1.15	4.49	3.04	69.64
NOTE: S.U. = Single Unit, Comb. = Combination; Air pollution costs are averages of costs of travel on all rural and urban highway classes, not just Interstate. Available data do not allow differences in air pollution costs for heavy truck classes to be distinguished.						

Based on information given in Table 30 we can calculate the following:

Average Pavement Cost for Trucks 11.90 cents/mile
Average External Cost for Trucks 19.38 cents/mile

Average environmental and safety costs for truck traffic are approximately 7.48 cents/mile (Federal Highway Administration). These costs are 63 percent of costs for pavement damage by trucks (7.48 / 11.90 = 62.86 or 63 percent).

Freight Pipeline Costs

Freight pipeline as a proposed alternative to the current highway system comprises the following cost components:

- Cost of Conduit:
  - cost of box section (does not include labor or other construction charges)
- Cost of Right-of-Way:
  - Right-of-Way, and
  - easement
- Cost of Trenching:
  - earth excavation,
  - earth moving,
  - bedding,
  - conduit burying,
  - compaction,
  - drainage system, and
  - backfill.
- Cost of Terminal:
  - land acquisition, and
  - building.
- Cost of Material Handling System (MHS):
  - automated Storage/Automated Retrieval System,
  - automated Guided Vehicles, Robots,
  - conveyors,
  - automatic Vehicle/Pallet Identification System, and
  - code Scanners, Computers, WMS, Programmable Controllers.
- Cost of Main Transport Mechanism (MTM):
  - tracks (including labor to lay it), and
  - MTM vehicle.
- Cost of Operating Power:
  - power costs.
- Cost of Command, Control and Communication System (CCCS):
  - computers,
  - software, and
  - telecommunication and radio communication system.

This system introduces a completely new infrastructure with advanced equipment and a new labor structure. The benefits of the pipeline system include: labor cost saving (since the system is intended to be highly automated), reduction in environmental impact (noise, air pollution, congestion, and crash), safety cost saving, and travel time saving.

Social Costs

The term “external costs” refers to costs of highway travel that are not borne by individual trip-makers, but that are imposed on other motorists, public agencies, or society as a whole. Social or external costs include damage to the environment, which is the monetized consideration for pollution and property damage in addition to the estimated costs of global climate change; the decline in property value due to noise; and the full cost of accidents, regardless of incidence. While noise and environmental damage costs are pure externalities, in that their incidence falls on those outside the system, accident and congestion costs are inflicted by one system user on another. Time costs reflect the increase in travel time due to congestion (other users).

Highway-related costs are determined based upon average vehicle operating cost rates by class of vehicle and functional class of facility, as reported by *Highway Performance Monitoring Systems* (HPMS) data.

Highway accidents are estimated based upon average incident rates per hundred million vehicle-miles of travel that vary by class of facility. Average rates can be derived from historic motor vehicle traffic accident rates for different functional classes and facilities.

Expenditures by highway agencies do not cover all societal costs of highway construction and use. Use of the highway system can have unintended adverse impacts on other highway users and non-users. Among these adverse impacts are damage to health, vegetation, and materials due to air pollution; noise and vibration effects of traffic; congestion costs to other highway users; fatalities, injuries, and other costs due to crashes; and waste from scrapped vehicles, tires, and oil.

Air Pollution

Motor vehicles produce emissions that damage the quality of the environment and adversely affect the health of human and animal populations. Highway users are a major source of total air pollution in the United States. Air pollution generated from transportation vehicles is an external cost that is not fully absorbed by the transportation user. Environmental legislation requiring improved engine technology and cleaner burning fuels has internalized some of the emission damage caused by motor vehicles; however, the technological advances have not eliminated air quality damage from combustion engines.

Noise

The damages caused by noise include the loss of sleep, lower productivity, psychological discomfort, and annoyance. These impacts are hard to quantify, but because they are associated with a specific location, the quantity of damage can be estimated using information on the reduction in residential property values. A number of studies have been performed over the years to measure the decline in residential property value due to noise and its associated vibration. These studies use a noise depreciation index (NDI) which is the percentage reduction of house price per dB(A) above some base value (dB(A) is an A scale noise measure in decibels). This approach helps determine the amount of noise damage produced by transportation facilities as a direct function of traffic volume and the location of residences near the facility.

Congestion

Costs of highway congestion include:

- added travel time for persons and commercial movements,
- speed-related effects of fuel use and other components of motor vehicle operating costs,

- increased variability of travel time, and
- increased driver stress associated with operating a motor vehicle under stop-and-go conditions.

Congestion cost impacts of changes in traffic levels are extremely sensitive to whether traffic increases occur during peak or off-peak periods. In heavily congested peak period traffic, the addition of a single vehicle to the traffic stream has a much greater effect on delay than the addition of a vehicle during non-peak periods. In general, trucks account for a lower percentage of peak period traffic on congested urban freeways, since commercial vehicles try to avoid peak periods whenever possible.

Crash Costs

The estimated crash costs used in this study will be based on the Urban Institute's 1991 comprehensive crash cost study *The Cost of Highway Crashes* sponsored by the FHWA and the National Highway Traffic Safety Administration (NHTSA). That study examined crash costs associated with property damage; lost earnings; lost household production; medical costs; emergency services; vocational rehabilitation; workplace costs; administrative costs; legal costs; and pain, suffering, and lost quality of life.

CHAPTER 12 – 2002 PROJECT WORK PLAN

INTRODUCTION

The work plan for FY 2002 will continue the approach established in prior years by seeking a design and operational strategy that produces a freight movement system that wins for each stakeholder group – Texas citizens, TxDOT, shippers, and the existing freight transportation industry. The work plan will also move the evaluation toward an economic assessment that established, based on the scenario tested, whether underground freight movement is of sufficient transportation value to warrant the significant investment necessary to see it to fruition.

The FY 2002 work plan will undertake an examination of several policy issues affecting the viability of underground freight movement. Among these will be the potential role of the public sector relative to that of private sector users or beneficiaries. The operational model options for the freight pipeline, which are related to the business model discussed in this report, will be studied with particular attention to management and control issues.

Task 1 – Finalize Technical Specifications

Sub-task 1.1 – Finalize the Technical Parameters for the MTM

The final technical design for the MTM will be undertaken in this task to allow for estimations of performance, weight, and cost. Several design issues remain challenging, among them being the approach taken to fastening the outer skin to the MTM in a manner that allows opening and closing.

Sub-task 1.2 – Finalize the Technical Parameters for the Conduit

The technical design parameters for the conduit relate primarily to final dimensions, reinforcing requirements, prefabrication approaches, weight, and construction techniques. The need for a built-in guideway will be considered, but detailed designs will be left to those charged with building the system.

Sub-task 1.3 – Finalize the Technical Parameters for the Communications, Command, and Control System

The communications, command, and control system will be approached functionally – the specific functions and interactions with other system elements will be defined at a level of detail sufficient to define system scope. The evaluation of the resulting system relative to cost will likely be done by comparing it to an already existing, similar system.

Task 2 – Finalize Business Model Options

Sub-task 2.1 – Finalize Business Relationship with Freight Industry

The interaction of the freight pipeline with existing trucking and rail operations will be detailed in this task with an emphasis on determining the roles, responsibilities, and opportunities for each participating party.

Sub-task 2.2 – Define Terminal Ownership/Leasing Options

The efficient operation of the freight pipeline terminals is key to establishing material throughput sufficient enough to warrant construction of the system. The ownership and operational arrangement for the terminal is central to effective material handling and business coordination. This task will examine options and define the optimal arrangement for terminal ownership.

Task 3 – Finalize Economic Evaluation Framework

Sub-task 3.1 – Finalize the Economic Evaluation Framework

The form of the economic evaluation framework will be defined in this task to allow the comparison of traditional highway options with the freight pipeline system. The prior work in the area has suggested that the analysis should focus on two related elements – capital costs per unit of freight moved and the marginal costs of operation, or user costs. The framework will establish the elements that will be compared between the alternative approaches and the metrics to be employed.

Sub-task 3.2 – Continue Data Collection for Cost Analysis

The economic evaluation of the freight pipeline system requires cost data from a wide variety of sources. These sources range from component and construction costs for the freight pipeline to construction and maintenance costs for highways. Included too, are social costs such as transportation safety, emissions, and land use. The cataloging of these data is essential to a full and accurate appraisal of the economics of transportation alternatives.

Task 4 – Continue Capacity Simulation Modeling

Task 4 will be a continuation of the capacity simulation modeling initiated in Year 2. The model will allow the research team to assess the infrastructure and performance needs of the systems put in place to effect the transfer of goods through the underground system. The model will include a terminal design component to address the parameters determining terminal size, layout, and functionality.

Task 5 – Terminal Design

Sub-task 5.1 – Develop Preliminary Design for Material Handling System

Based in part on inputs from Task 4, this task will work toward a design of the material handling needs and requirements of the terminal. The task may require direct input from firms dedicated to the development of similar systems, and research plans will be adjusted according to the requirements of this circumstance.

Sub-task 5.2 – Develop Preliminary Design for Temporary Storage System

The freight pipeline system is evolving into a first-in-first-out system with little provision for storage of material on-site. The reality of transportation logistics, however, suggests that some provision will have to be made to temporarily hold material. The simulation in Task 4 will assist in defining the quantity of material falling into this category, and terminal layout requirements will guide where temporary storage is best located.

Sub-task 5.3 – Establish Need for Intermediate Terminals

Sub-task 5.3 will establish, based in part on interviews with trucking interests, whether intermediate terminals are required to accomplish the mission of the freight pipeline system.

Sub-task 5.4 – Define Site Requirements

The location of the terminal and the amount of property required at the terminal site will be evaluated in this task based on input from preceding tasks.

Task 6 – Continue Policy Analysis

Sub-task 6.1 – Continue Evaluation of Financing Options and Possible Funding Mechanisms

The process of financing a major capital project is complex at best. The potential magnitude of investment required for this system in conjunction with the innovative nature of the infrastructure may introduce additional considerations that must be fully understood as operational parameters are established. A review of comparable projects will be continued to gain an understanding of the broad requirements and approaches attempted in other efforts. The information gained will help establish the recommended approach to system implementation.

Sub-task 6.2 – Begin an Assessment of the Role for TxDOT in Freight Pipeline Construction, Operations, and Maintenance

This task will initiate an evaluation of the potential role of the department in system design and construction, operations, and maintenance.

Sub-task 6.3 – Initiate an Assessment of the Roles for the USDOT in Future Freight Pipeline Activities

This task will initiate an assessment of the roles that the USDOT could fill in freight pipeline planning, financing, or operations.

Sub-task 6.4 – Begin a Study of the Options Available for Freight Pipeline Management

The freight pipeline will require a managing body or board of directors that will assume responsibility for the operation of the system over time as well as on a day-by-day basis. The possibilities for the form of this managing body range from a port authority model to a corporate model with executive management. This task will evaluate the range of possibilities for an effective management structure and report on the pros and cons of each option.

Sub-task 6.5 – Initiate an Evaluation of Labor Issues Relative to the Freight Pipeline

Sub-task 6.5 will initiate an assessment of the labor issues that may affect facets of the system. The issues range from construction to operation and may impact decisions regarding management structure and ownership decisions.

Sub-task 6.6 – Continue to Evaluate Issues Associated with Right-of-Way Acquisition

The use of existing, publicly owned right of way to construct a freight pipeline could improve the feasibility of the project by reducing cost and contention with private concerns. This task will continue the collection of information concerning the possibility of system placement in publicly owned corridors as well as in new or planned rights of way. The issue of acquisition of property through eminent domain versus obtaining an easement will also be explored.

Sub-task 6.7 – Investigate Issues Associated with Crossing Existing Pipeline System

Texas is home to an extensive pipeline network dedicated to transporting petrochemicals and natural gas. These underground systems will be affected by the need to construct the freight pipeline across pipeline rights of way. The research team has estimated that a Dallas to Laredo underground system may impact approximately 100 gas and petrochemical pipelines. This task will continue the assessment of the policy and cost ramifications of this issue.

TIME LINE

Table 31. 2002 Task Time Lines.

TASKS		FY 2002											
		S	O	N	D	J	F	M	A	M	J	J	A
Task 1	Sub-task 1.1												
	Sub-task 1.2												
	Sub-task 1.3												
Task 2	Sub-task 2.1												
	Sub-task 2.2												
Task 3	Sub-task 3.1												
	Sub-task 3.2												
Task 4													
Task 5	Sub-task 5.1												
	Sub-task 5.2												
	Sub-task 5.3												
	Sub-task 5.4												
Task 6	Sub-task 6.1												
	Sub-task 6.2												
	Sub-task 6.3												
	Sub-task 6.4												
	Sub-task 6.5												
	Sub-task 6.6												
	Sub-task 6.7												*

CHAPTER 13 – SUMMARY AND CONCLUSIONS

SUMMARY

The research undertaken in Year 2 has included a detailed examination of several key technical areas including aerodynamics, energy usage and availability, Texas geology, vehicle design, system capacity, and terminal design issues. In addition, the research team has developed a listing of policy issues that includes right-of-way acquisition, funding, border issues, pricing, and management considerations. The development of a comprehensive implementation plan will require that each of these areas be evaluated for its impact on system viability.

This report also begins to address the economic issues associated with assessing an alternative form of transportation. The economic evaluation framework will include a component that focuses on the capital expenditures required to provide infrastructure to move freight. This element of the evaluation will compare the cost for traditional highway expansion projects to the estimated cost for designing, constructing, and building the freight pipeline to the design team's specifications. A second component of the economic evaluation is the determination of the marginal cost of operation. This assessment is key to the operational viability of the system and central to the system's ability to induce use by the identified user groups – the established freight transportation industry.

The marginal cost of operations will estimate the cost to move 1 ton of freight, 1 mile for the freight pipeline, and compare this cost to the same cost figure for over-the-road shipment by truck. The efficiency with which the freight pipeline can perform this function will determine the level of use by the trucking industry and, through pricing policy, determine the rate at which the system can address capital expenditures.

Operationally, the freight pipeline has been positioned as an extension of the existing freight transportation industry through a business model that passes a portion of the transportation cost savings back to the user. This approach has met with initial approval by the trucking industry, who would be among the principal beneficiaries of this system. This business model formulation is proposed in explicit recognition of the partnership that exists between Texas, TxDOT, the shippers, and the freight transportation industry. The working premise guiding the current research is based on the notion that, to be viable as an alternative to traditional freight transportation approaches, a non-traditional freight system should provide tangible benefits to all stakeholders.

CONCLUSIONS

The principal conclusion emanating from the second year of work on the freight pipeline concept is that the system appears technically feasible. The systems engineering approach employed in the design effort relied on existing, proven technology, and the resulting configuration appears well within feasible limits. Two potentially fatal flaws were investigated, the availability of electrical power in Texas and geological factors limiting trenching, and the findings suggest that neither will preclude the system construction or operations. The technical issues to be addressed in Year 3 will focus on the capacity of the system, terminal design and material handling issues, and on the ability of the freight pipeline to remove freight from highways in sufficient quantities to have the desired, significant impact on truck traffic.

The Year 3 Work Plan, while moving toward a final technical design, will focus on the economic and policy issues that affect system feasibility. Data collection efforts will attempt to establish the costs for traditional (highway) transportation system expansion relative to the estimates for the freight pipeline system. This focus is in response to a preliminary conclusion drawn from the research to date: traditional surface transportation approaches are becoming a casualty of their own success. The development of a quality highway system has spawned economic development and unprecedented levels of commerce, both within the U.S. and more recently with NAFTA, internationally. The diminishing returns associated with continued highway expansion, however, suggest that we, as a society, are nearing the end of a unimodal transportation strategy. The cost of new highway infrastructure coupled with the cost of maintaining existing facilities is daunting enough by itself. When we consider the safety impacts, environmental ramifications, and congestion effects of increasing traffic along with the cost, transportation planning appears in need of creative alternatives. A freight conveying pipeline may be a partial answer to some of the transportation problems we face. Whether it is a partial answer or not, it is significant that we have started looking for new ways to solve our emerging transportation problems.

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APPENDIX A – MTM AERODYNAMICS

MTM AERODYNAMICS

The drag on a MTM is caused by viscous shear and normal pressure loads. These may be itemized as:

- skin friction,
- pressure drag,
- shock-losses, and
- rolling resistance.

In this initial analysis, the MTM is assumed to have a rectangular cross section. The MTM is also assumed to be symmetrically located in the tunnel (also of rectangular dimensions). The front profile of the train is that of a 2:1 ellipse when viewed from the side.

Skin Friction

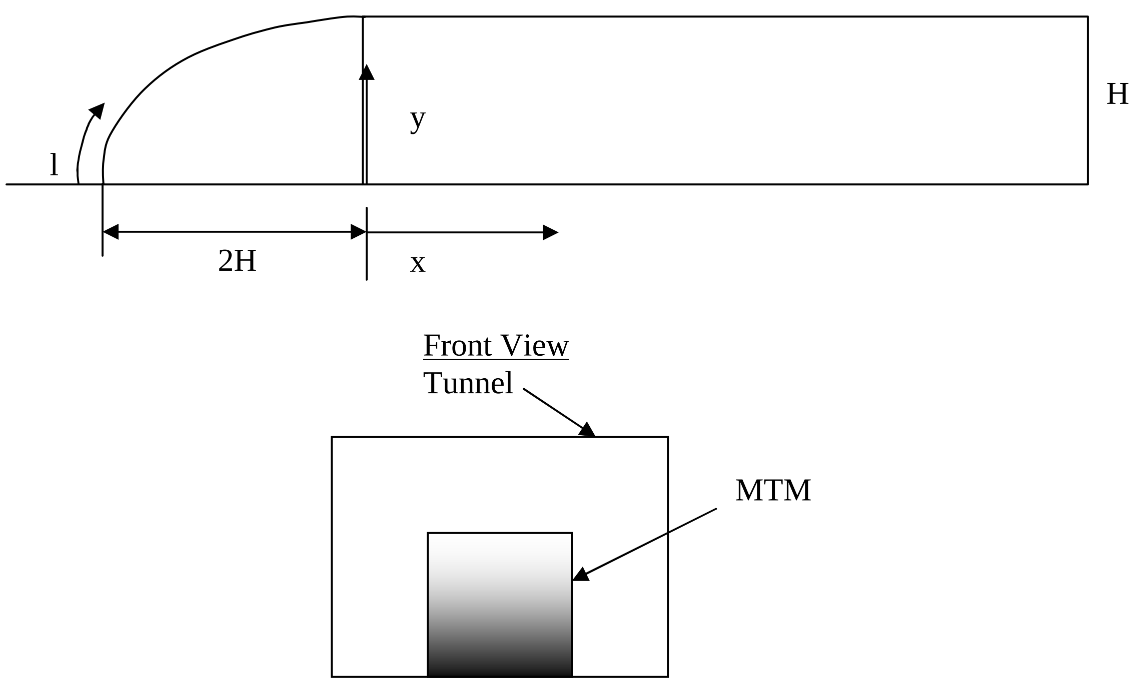

Figure A-1. Skin Friction Model.

Viscosity causes a deceleration of the air flow close to the MTM wall. The resultant shear stresses acting over the MTM surface cause a skin friction drag. The following analysis does not account for the tunnel wall boundary layer development that is induced by flow through the annulus around the train, as this component (relative to the tunnel) is typically small, especially for practical annulus dimensions. The vertical coordinate of the nose section is given by:

$$y = \sqrt{H^2 - \frac{x^2}{4}} \qquad \text{(Eq. A-1)}$$

The arc length of the leading edge surface is given by:

$$l = \int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\, dx \qquad \text{(Eq. A-2)}$$

For a MTM traveling at 60 mph (V_1), the Reynolds number is 1.8×10^6/ m. It may thus be assumed that the boundary layer flow is turbulent. The boundary layer thickness (δ) may be approximated as:

$$\delta = \frac{0.16l}{\mathrm{Re}^{1/7}} \qquad \text{(Eq. A-3)}$$

with the Reynolds number given by:

$$\mathrm{Re} = \frac{\rho V_1 l}{\mu(1-\beta)} \qquad \text{(Eq. A-4)}$$

β is the blockage ratio and is typically defined as A_t/A where A is the tunnel cross sectional area, and A_t the train cross-sectional area. V_1 is the MTM velocity, or the velocity of the free stream if the MTM is considered to be stationary. μ is the air viscosity, and ρ is the air density. Using the equivalent flat plate area, the drag may be assumed to be:

$$D = \frac{\rho V_1^2 W l 0.031}{(1-\beta)^2 \mathrm{Re}^{1/7}} \qquad \text{where W is the MTM width} \qquad \text{(Eq. A-5)}$$

Equation 5 can be used to predict the drag on all three MTM surfaces.

Pressure Drag

This drag component is caused by the acceleration of the flow around the sides of the train. As the flow speeds up, its static pressure drops. If the flow separates from the back of the MTM, this reduced pressure then acts over the rear of the train, i.e., the so-called Borda-Carnot condition. This should be considered as a worst-case scenario and may exist on a MTM with no aft streamlining.

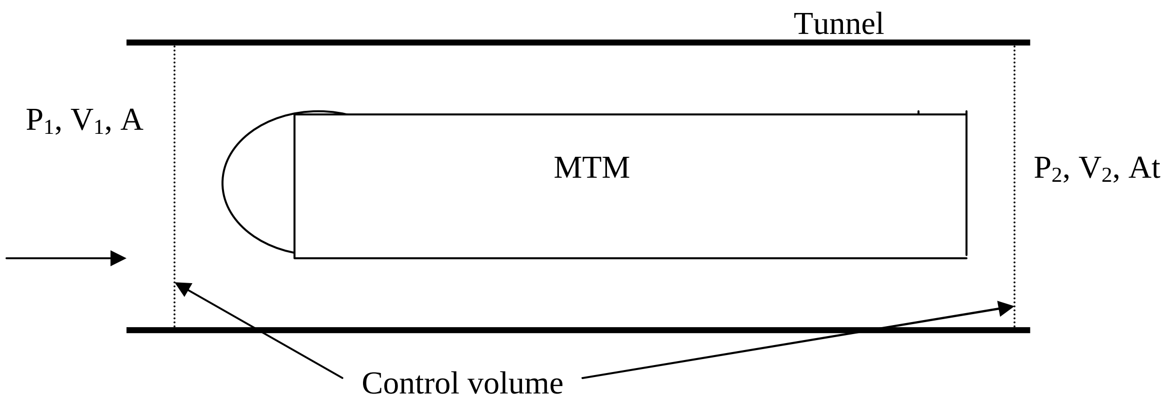

Figure A-2. Tunnel Model with Boundary Limits.

Applying the continuity equation we get (where subscript 1 indicates properties ahead of the train and subscript 2, properties just downstream of the train's annulus):

$V_1A = V_2(A\text{-}At)$
or $V_1 = V_2(1\text{-}\beta)$ with $\beta = At/A$ (Eq. A-6)

Application of Bernoulli's equation gives:

$$P_1 + \frac{1}{2}\rho V_1^{\,2} = P_2 + \frac{1}{2}\rho V_2^{\,2}$$

yielding:

$$P_2 - P_1 = \frac{1}{2}\rho V_2^{\,2}\left[\left(1-\beta\right)^2\right)-1\right] \quad \text{(Eq. A-7)}$$

Application of the x-momentum equation gives:

$$D = P_2A - P_1A + \rho(A - At)V_2^{\,2} - \rho A V_1^{\,2}$$

Substitution of Bernoulli's equation and manipulating gives:

$$D = \frac{\rho A V_1^{\,2}\beta^2}{(1-\beta)^2}$$ where V_1 is the MTM velocity (Eq. A-8)

As mentioned previously, this expression represents the maximum pressure drag. If the rear of the MTM is streamlined, then D in Equation 8 reduces. A pressure recovery factor may be defined as:

Krec = 1 for total separation
and Krec = 0 for no separation

or generally,

$$Krec = \frac{\iint_s p\hat{n}d\vec{s}}{\frac{\rho V_1^{\,2}\beta^2}{(1-\beta)^2}} \qquad \text{(Eq. A-9)}$$

An additional component of pressure drag occurs due to the development of the boundary layer along the MTM, i.e., pressure drag due to boundary layer-induced jetting. The reduced velocity of the fluid in the boundary layer causes an increase in the airspeed outside the boundary layer so as to satisfy the continuity equation. Once again, the boundary layer development on the tunnel wall is neglected, as the velocities *relative* to the wall are small.

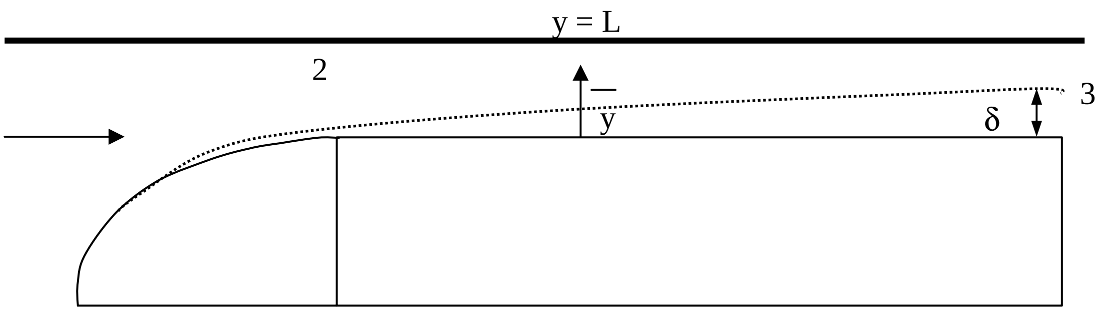

Figure A-3. MTM Pressure Drag Boundary Layer.

Applying the continuity equation between points 2 and 3 gives (per unit depth), where L is the annulus height:

$$\int_0^L V_2 d\bar{y} = \int_0^\delta V_3(\bar{y})d\bar{y} + \int_\delta^L V_3 d\bar{y}$$

with $V_2=V_1/(1-\beta)$ and $V_3=V_3(\tilde{y}/\delta)^{1/7}$ assuming a turbulent boundary layer. Solving for V_3 gives:

$$V_3 = \frac{V_1}{(1-\beta)}\frac{L}{(L-\delta)} - \int_0^\delta \frac{V_3(\bar{y})}{(L-\delta)}d\bar{y} = \frac{V_1 L}{(1-\beta)(L-\delta)} / \left[1+\frac{7\delta}{8(L-\delta)}\right] \qquad \text{(Eq. A-10)}$$

Applying Bernoulli's equation between points 1 and 3 yields:

$$P_1 + \frac{1}{2(1-\beta)^2}\rho V_1^{\,2} = P_3 + \frac{1}{2}\rho V_3^{\,2}$$

and gives:

$$\Delta P = \frac{1}{2}\rho V_1^{\ 2}\left[\frac{1}{(1-\beta)^2} - \left(\frac{L}{(1-\beta)(L-\delta)}\frac{1}{(1+\frac{7\delta}{8(L-\delta)})}\right)^2\right] \quad \text{(Eq. A-11)}$$

The additional drag due to this pressure reduction is then:

$D_{\Delta P} = \Delta P.At$ (Eq. A-12)

Shock-Loss

This loss is incurred due to the abrupt expansions and contractions encountered between MTMs. This type of loss may be expressed in the form:

$$D_{S-L} = \frac{\rho V_1^{\ 2}}{2(1-\beta)^2} At\left(\sum_{i=1}^{N-1} K_{Li}\right) \quad \text{(Eq. A-13)}$$

where K_{Li} gives the loss of pressure, and N is the number of MTMs. This component can be significantly reduced by eliminating gaps between MTMs or having smoothly blended MTMs.

Rolling Resistance

The rolling resistance is dependent on the friction encountered in the wheel bearings, resistance between the rails and the flanges, and rolling resistance between the steel wheels and the rails due to deformation. This drag may be estimated using the following empirical expression:

$$Droll = 3.82x10^3 \frac{capsule\_mass}{424.4} + 0.039\frac{capsule\_mass}{424.4}V_1 \quad \text{(Eq. A-14)}$$

where the MTM mass is measured in metric tons. Droll is measured in Newtons. The rolling resistance is composed of two components, one static and the other dynamic.

Notes

If the boundary layer that forms on the MTM impinges and/or merges with that of the wall, an additional drag results due to a loss of stagnation pressure (viscous dissipation converts mechanical pressure to non-recoverable internal energy and also causes heat transfer). This loss manifests as a reduction in static pressure at the rear of the MTM. Flow in the annulus between the train and the wall also leads to the development of a boundary layer from the tunnel wall out. The shear associated with this boundary layer, however, is small as the annulus velocities relative to the stationary wall are generally low, unless the annulus is of very small extent. Flow separation is also responsible for a loss of pressure at the nose of the train, which increases drag.

However, if the train is streamlined, this effect is generally negligible.

Figure A-4 shows the effect of blockage, β, on the theoretical maximum pressure drag and the skin friction drag. As seen for high blockage, i.e., a small annulus, the pressure drag is significant. For larger annuli, skin friction drag predominates. As clearly seen in the figure, from a drag perspective, a large annulus is preferable. Figure A-5 shows the effect of the length of the MTM on the relative magnitude of the drag components for β = 0.5.

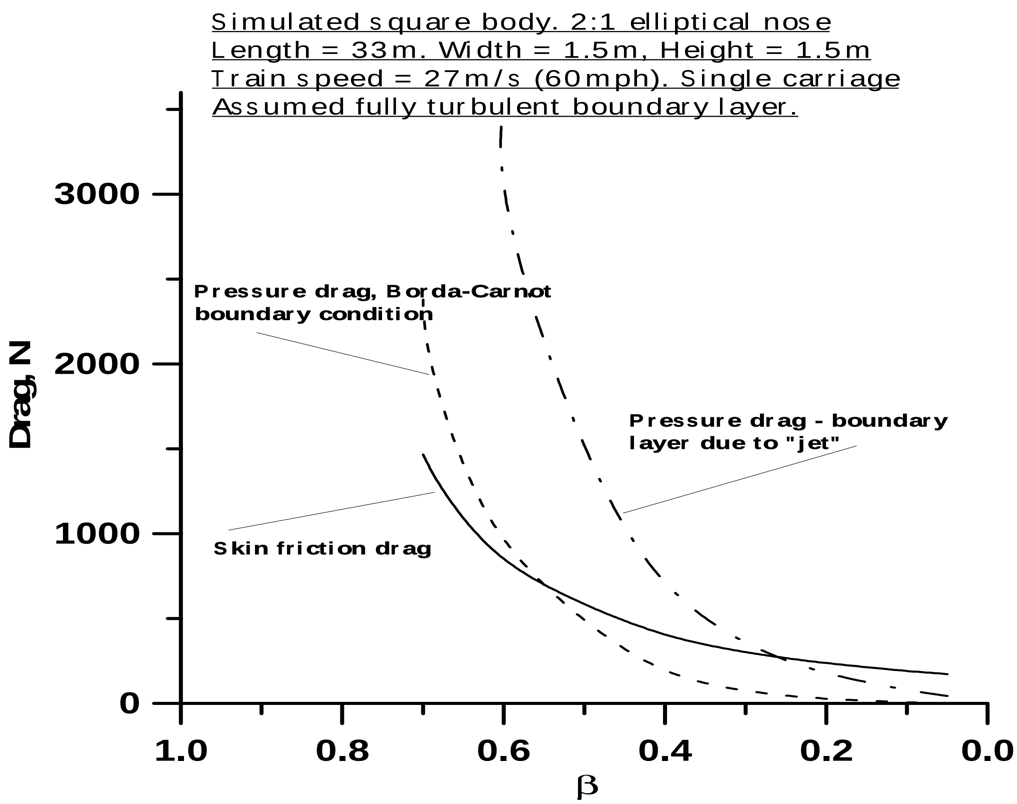

Figure A-4. Effect of Blockage Ratio on Theoretical Drag Components.

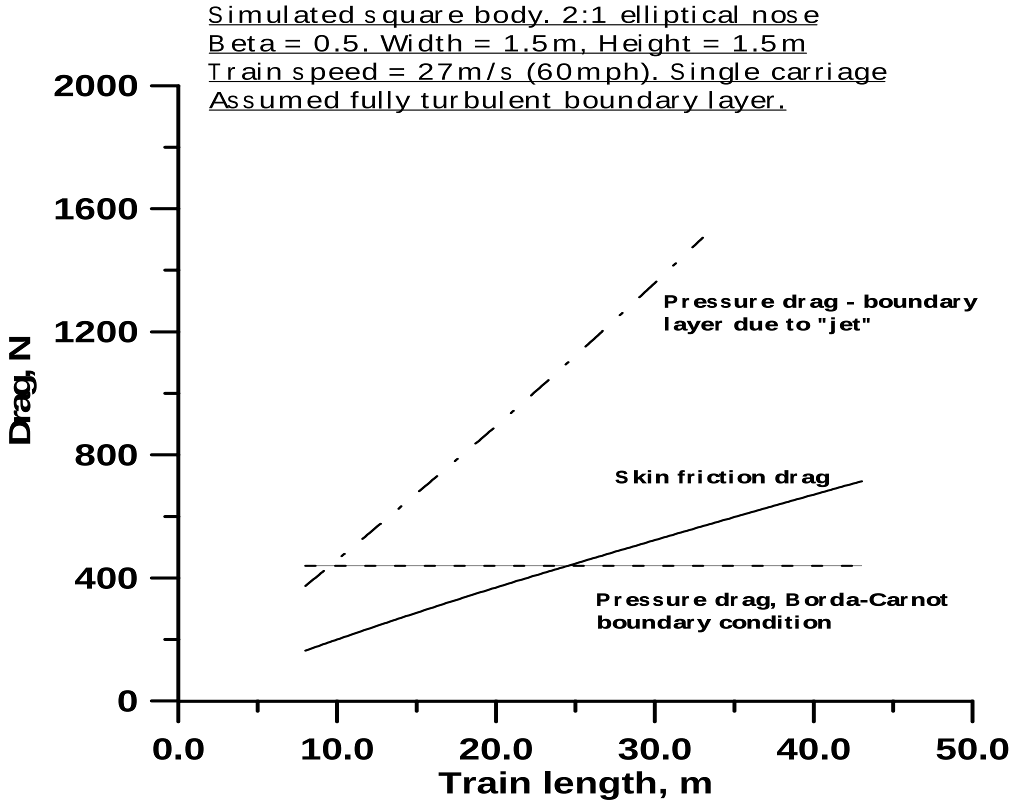

Figure A-5. Effect of Train Length on Drag Components.

Discussion of Preliminary Results

From an aerodynamic perspective, shock losses can be easily reduced by blending the MTMs together so they present a smooth exterior (as is commonly done on high-speed trains). Rolling resistance is not an aerodynamic consideration but is dependent on the mechanics of the MTM. Thus, from an aerodynamic perspective, the components of significance are skin friction and pressure drag.

Basic Considerations in Drag Minimization

Equation 5 shows that skin friction drag is most sensitive to the train speed ($\propto$ train speed^2). However, the speed of the MTMs is also dictated by other factors, and the suggested transit speed of 60 mph is not high. Thus, speed does not present itself as an independent design variable. The drag is also linearly proportional to the width and length of the MTMs. Obviously, reducing the size of the MTMs would reduce this drag component, but the MTM size is dictated by the payload. Reducing the length, or having extremely short "trains," is not viable for a *given length* of train; a continuous vehicle will have lower frictional drag than a train constituted of separate MTMs. As the air flows over the MTMs, it is retarded by viscous effects, and as a result, the viscous shear on each subsequent section is reduced. The skin friction drag is also seen to be proportional to $1/(1-\beta)^2$. As shown previously in Figure A-4, the skin friction drag reduces rapidly as the size of the tunnel relative to the train increases. The dependence of skin friction on β follows from the effect of the tunnel constraint on the air that flows through the annulus around the train. Decreasing this annulus increases the velocity and so increases the shear forces that the train experiences. Figure A-4 also suggests that a β less than about 0.3 is desirable.

Pressure drag is highly dependent on the blockage ratio β, as suggested by Equation 8 and may also be surmised from Figure A-4. This expression for the pressure drag must be interpreted carefully, however. It assumes that the air separates (i.e., no longer conforms to the surface) at the back of the train, the so-called "Borda-Carnot" boundary condition. In this case, the static pressures toward the back of the train are low and cause an additional drag, i.e., "pressure drag." This drag can be reduced in two ways:

- by having a large β, and
- by controlling flow separation from the back of the train (independent of β).

Figure A-4 shows that as β reduces below about 0.3, the pressure drag becomes comparatively small. If the flow was controlled such that it did not separate from the back of the train, then this drag component would be zero, as the annulus flow's dynamic pressure would be reconverted into static pressure (i.e., so-called pressure recovery). Thus the static pressures acting on the front and the back of the train would be equal, and no drag would result. An additional component of drag also exists in a confined tunnel due to the growth of the boundary layer from the train (and potentially the walls – depending on the nature of the annulus flow). As seen in Figure A-4, this component may also be reduced by maintaining β below 0.3. Notice that pressure drag (Borda-Carnot criterion) is independent of the length of the train (see Figure A-5). Please also note that pressure drag does exist for a train in the open if the flow separates from the back of the vehicle; it is just not as large in magnitude as that in a confined system.
The proceeding analysis shows that:

- To minimize both skin friction and pressure drag, a fairly large tunnel is desirable with $\beta < 0.3$.
- The MTMs should be smoothly blended together to form trains, thus reducing shock-losses.

Another important benefit of large β is a reduction of the so-called "piston" effect. When a train moves through a tunnel with a small surrounding annulus, depending upon the train's profile, a certain amount of air is pushed ahead of the train, while a certain amount moves past the train in the opposite direction. The train profile and β dictate the relative quantities. This effect causes additional drag. If, however, β is low, the air is no longer pushed ahead of the train but is displaced laterally (for a dual track configuration), with concomitant drag benefits.

The proceeding discussion does not give any insight into specific details of the train profile; the simple analytic expressions employed are not amenable to yielding this information. It does, however, lay the guidelines of what is required for an efficient system. The following sections of this report will describe the use of CFD methodology to start yielding information as to optimal designs.

Additional Parameters Affecting Drag

In addition to the size of the tunnel, the drag of the MTMs will also depend upon:

- The shape of the tunnel: probably dictated by structural considerations and thus not a variable. This would benefit from CFD analysis.
- MTM eccentricity: the lateral location of the train relative to the walls will influence the drag. As the tunnel will probably be a dual-track system, choices of eccentricity will be constrained by structural requirements such that the tunnel dimensions are minimized. This would also benefit from CFD analysis.
- MTM shaping: the cross-sectional and for/aft shape of the train will influence drag. CFD analysis will be used to reduce this drag.

Potential Drag Reducing Alternatives

A potential drag reduction mechanism may be partial evacuation of the tunnel. The effect on drag would be to reduce the air density. Consequently, drag reductions would be proportional to the reduction in air density. The system could be evacuated in two ways:

- by partially evacuating the whole tunnel, and
- by evacuating sections of the tunnel enclosing the train(s).

Both of the systems have drawbacks: (1) it would require the extraction of a tremendous quantity of air, and (2) it would require continual monitoring of the MTM trains in the tunnel (moving in both directions) so that sections of the tunnel could be sealed/isolated and evacuated. Neither approach is optimal nor likely to be efficient considering the size of the proposed tunnel. Partial evacuation would, however, be beneficial in helping to eliminate heat transfer from the moving components into the environment following from the reduction in air density.

APPLICATION OF COMPUTATIONAL TOOLS

A Navier-Stokes solver, STARCD, was used for computations. As a first step in the optimization, researchers investigated various MTM configurations. For a particular configuration, drag would be minimized by suppressing flow separation. The following configurations were analyzed, (see Figure A-6):

- a circular front and flat tail,
- an elliptical front and flat tail,
- a sharp front and flat tail,
- a circular front and circular tail, and
- an elliptical front and elliptical tail.

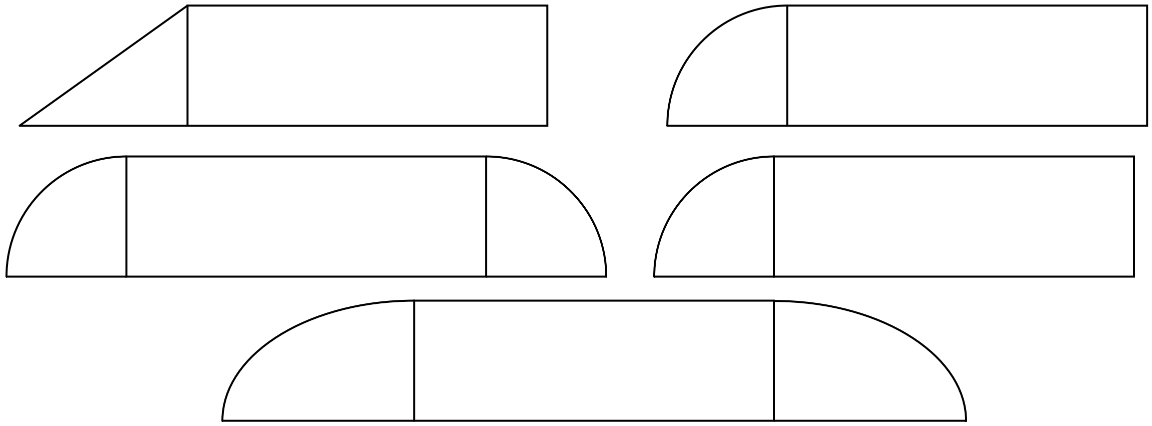

Figure A-6. Tested Configurations.

All the investigated cases were two dimensional. The length of the cylindrical section in all cases was 20 ft. The blockage factor β was 0.49. The radius of the circular section was 7 ft. For the elliptical sections, a 2:1 ellipse was used. The length of the nose section for the various configurations was 7 ft. Each computation used 17,000 cells. The data from this study showed that both the circular and elliptical profiles, applied at the front and rear of the MTM, show the lowest drag, which clearly indicates the significance of suppressing flow separation. The drag is both the pressure and skin friction component. However, the drag of the sharp-edged front section is not appreciably higher than that of the elliptical section and is considerably simpler to construct.

APPENDIX B – ANALYSIS OF FORMATIONS LOCATED IN PIPELINE CORRIDOR AREA

ANALYSIS OF FORMATIONS LOCATED IN PIPELINE CORRIDOR AREA

INTRODUCTION

A detailed review of the aquifer, geologic, and soil formation characteristics was conducted as part of the analysis for the Dallas-Laredo corridor. Information sources for the material presented in this appendix include the General Soil Map of Texas, Texas Water Resources, and Groundwater Atlas of Texas. Core sample information was obtained from the Economic Bureau of Geology and other previous studies, such as theses and reports.

Aquifer Characteristics

Aquifer locations and characteristics are an important consideration in the site selection process. In general, aquifers in the corridor area are found between 300 and 3000 ft deep. Recharge areas are particularly important because of the physical and cultural implications for groundwater use throughout Texas. Texas relies heavily on the use of groundwater for irrigation and municipal purposes. The general description, water-bearing properties, and the amounts of water available for aquifer formations are described below. There are two minor aquifers (Woodbine and Marble Falls Aquifer) and three major aquifers (Carrizo-Wilcox, Edwards, and Gulf Coast Upward Aquifers) in the study area, as shown in Figure 34 of Chapter 10. The properties of each minor and major aquifer are described below.

Minor Aquifers

Woodbine Aquifer

Stratigraphic units included in this aquifer are the Templeton, Lewisville, Red Branch, and Dexter members of the Upper Cretaceous Woodbine Formation. Geographically, this aquifer extends from Northern McLennan County in the south to Red River in the North. It consists of coarse ferruginous sand and sandstone, clay, shale, and sandy shale and some lignite and gypsum. It is hydraulically connected to overlying alluvium along the Red River. Thickness ranges from a few ft in outcrops to more the 700 ft near the downdip limit in Fannin County and to a maximum depth of 2000 ft below sea level. In downdip areas, the aquifer is confined above by the Cretaceous Eagle Ford Group and below by the Cretaceous Buda Formation or Cretaceous Grayson Marl and Cretaceous Mainstreet Limestone. Water generally moves in an east-southeast direction and follows the dips of the beds. There is a large cone of depression in the middle of Grayson County resulting from withdrawals for public supply.

Marble Falls Aquifer

Stratigraphic units include the Marble Falls limestone of Pennsylvanian age. This aquifer crops out primarily in McCulloch, San Saba, Lampasas, and Burnett Counties. Water is contained within joints, fractures, and cavities in limestone, which locally is as much as

600 ft thick. The aquifer is highly permeable in places, as indicated by its wells that yield as much as 2000 gallons per minute and the presence of large springs.

Major Aquifers

Carrizo-Wilcox

Stratigraphic units include the Wilcox Group and Carrizo Formation of Eocene Age. Geographically, this aquifer is a northeast trending band extending from the Rio Grande River into Arkansas and Louisiana. The aquifer dips toward a southeast direction and dips away from the Sabine Uplift. This aquifer ranges in thickness from 150 to 3000 ft, and may yield up to 3000 gallons per minute.

Edwards Aquifer

Stratigraphic units include the Edwards, Georgetown, and Comanche Peak Formations. It consists of massive to thin-bedded, cherty, nodular, argillaceous grayish-white limestone and dolomite. Argillaceous is a term that is applied to rocks or substances composed of clay minerals, or having a notable proportion of clay in their composition, especially such sedimentary materials as marl and shale. Groundwater enters the aquifer in small amounts laterally from the Glen Rose Formation, where it is discharged through natural springs in addition to hundreds of wells. Volume and flow rates respond quickly to precipitation, allowing rapid movements through the aquifer. Thickness ranges from 200-600 ft. It may yield as much as 16,000 gal/min.

Geologic Formations

The proposed system would travel through geology ranging from the Lower Cretaceous units in Dallas to Upper Quaternary units around Laredo. The Cretaceous Edwards Limestone is encountered to the west of IH-35 from Austin to Dallas, whereas high shrink-swell geologic units are encountered to the east. Other geology, such as the Edwards Aquifer and Ouachita Tectonic Belt and the Colorado, Brazos, Trinity, and Nueces Rivers are also crossed. Table B-1 shows the general stratigraphic column for the corridor area.

Table B-1. General Stratigraphic Column of Corridor Area.

Era	System	Series	Formation	Group
Cenozoic	Tertiary	Eocene	Yegua	Claiborne
			Cook Mountain	
			Stone City	
			Sparta	
			Weches	
			Queen City	
			Reklaw	
			Carizzo	Wilcox
			Calvert Bluff	
			Simsboro – Rockdale-Pendletone	
		Paleocene	Willis Point	Midway
			Kincaid	
Mesozoic	Cretaceous	Upper Gulfian	Kemp	Navarro
			Corsicana	
			Nacatoch	
			Marlbrook	Taylor
			Pecan Gap	
			Wolfe City	
			Ozan	
			Gober	Austin
			Brownstown	
			Blossom	
			Bonham	
			South Bosque	Eagle Ford
			Lake Waco	
			Pepper	Woodbine

General Interpretation

The general stratigraphy throughout the entire project site is variable and consists of interbedded, intermixed, silt, sand, clay, and limestone. The sediments in the site were deposited as part of a delta, prodelta, and interdistributary environments of deposition, which were identified within the text. Clays were deposited because of volcanic mudflow deposits in the late Cretaceous. Sand is often present in the Claiborne and Wilcox Groups, whereas clay is dominant in the Taylor and Eagle Ford Groups.

Sediments vary throughout the area; ranging from clays to very coarse-grained sands. This leads to the conclusion that they were deposited in a range of low- to high-energy environments of deposition. In a fluvial-deltaic setting the most likely low flow, regime environment of deposition would be swamps, marshes, and lakes. It is difficult to interpret general environments of depositions for the sediment as a whole because the environments differ greatly throughout the region. Instead, individual specific environments of deposition were interpreted when discussing the stratigraphy.

AUSTIN CHALK GROUP

Stratigraphy

"The Austin Chalk of Central Texas" is basically a chalk unit interbedded primarily with marls and, to a lesser degree with shales, bentonites, fragmental limestones, and glauconite" (*1*). The Austin Chalk is best characterized as a generally very-fine-grained carbonate mud deposit containing coarser skeletal fragments. The Austin Chalk is relatively unstable where exposed to weathering and erosion. Informal stratigraphy recognized an upper massive chalk, middle chalk marl, and a lower massive chalk. Table B-2 shows the stratigraphy of Austin Chalk Group, and Figure B-1 shows a general columnar section of the Austin Chalk.

Table B-2. Stratigraphy of Austin Chalk Group.

Era	System	Series		Formation	Group
Mesozoic	Cretaceous	Upper	Gulfian	Gober	Austin
				Brownstown	
				Blossom	
				Bonham	

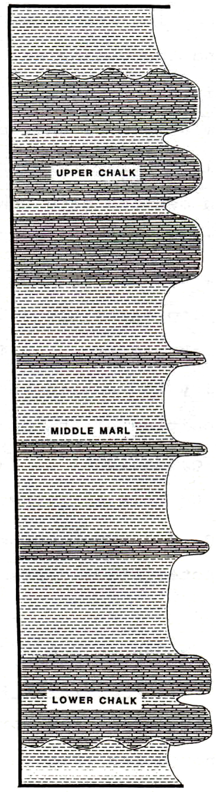

Figure B-1. General Columnar Section of the Austin Chalk (*2*).

Miller analyzed the chemical composition in his thesis and averaged the chemical composition over a period of two years by the Universal Atlas Cement Company in Waco, Texas (*3*). Table B-3 lists the chemical composition of the Austin Chalk.

Table B-3. Chemical Composition of Austin Chalk (*3*).

COMPOUND	PERCENTAGE
$CaCO_3$	85.85
SiO_2	7.90
Al_2O_3	2.85
$MgCO_3$	1.30
Fe_2O_3	1.25
Total	**99.15**

Minor amounts of pyrite, glauconite, aragonite, and phosphate materials and limonite (as seen from the table above) are also present. Samples analyzed show that materials from the middle third of the chalk contain coarse skeletal material greater than 25 percent and usually less than 10 percent. The average carbonate content of outcrop samples is 88 percent and for subsurface samples is 83 percent (*3*).

The Austin Chalk sporadically outcrops from Red River County in northeast Texas, and trends southwest through the cities of Dallas, Waco, Austin, and San Antonio, to southwest Texas. Between Dallas and San Antonio, the outcrop roughly parallels the route of IH-35 and strikes in a north-south direction, dipping to the east. The general Geological Map of Texas shows the outcrop pattern of the Austin Chalk, Taylor Marl, Eagle Ford Shale, Claiborne, Navarro, and Jackson Groups in the project area. Abundance of outcrop along the trend is generally poor, while the best exposures exist in quarries, road cuts, and streambeds.

The Austin Chalk lies unconformably above the Eagle Ford Group and unconformably below the Taylor Group. McNulty found that the upper Austin of Travis County is equivalent to the Lower Taylor Marls of Dallas County on the basis of lithologic and paleontology correlation. Unconformable is a term said of strata that do not succeed the underlying rocks in immediate order of age or in parallel position; especially younger strata that do not have the same dip and strike as the underlying rocks (*4*). Between Dallas and Bell County, the Austin chalk thins to less than 200 ft south of Waco in McLennan County. In the vicinity of Dallas, the Austin Chalk is the most extensive geological formation, which is not a pure limestone, but contains small amounts of other minerals.

Figure B-2 is a sketch based on work by Allen and Flanigan, which shows a geologic cross-section of Dallas, Ellis, and Navarro Counties (*2*). Figure B-3 shows an Isopach Map of Austin Chalk in Dallas County. Figure B-4 is a map of the geology of Dallas County showing outcropping units of the Austin Chalk and the Eagle Ford Shale and Ozan Formation, which will be discussed further. These formations are of the upper Cretaceous Gulfian Age (*2*).

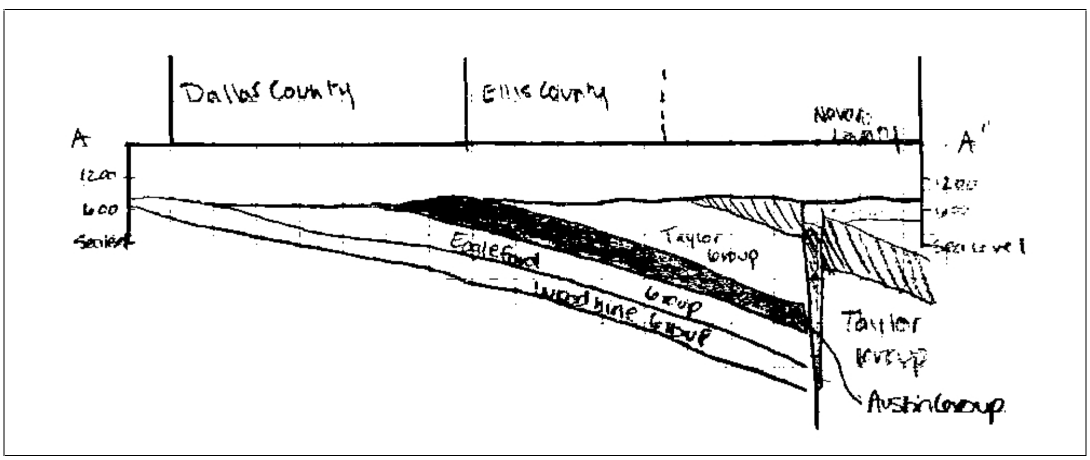

Figure B-2. Cross-Section of Dallas, Ellis, and Navarro Counties (*2*).

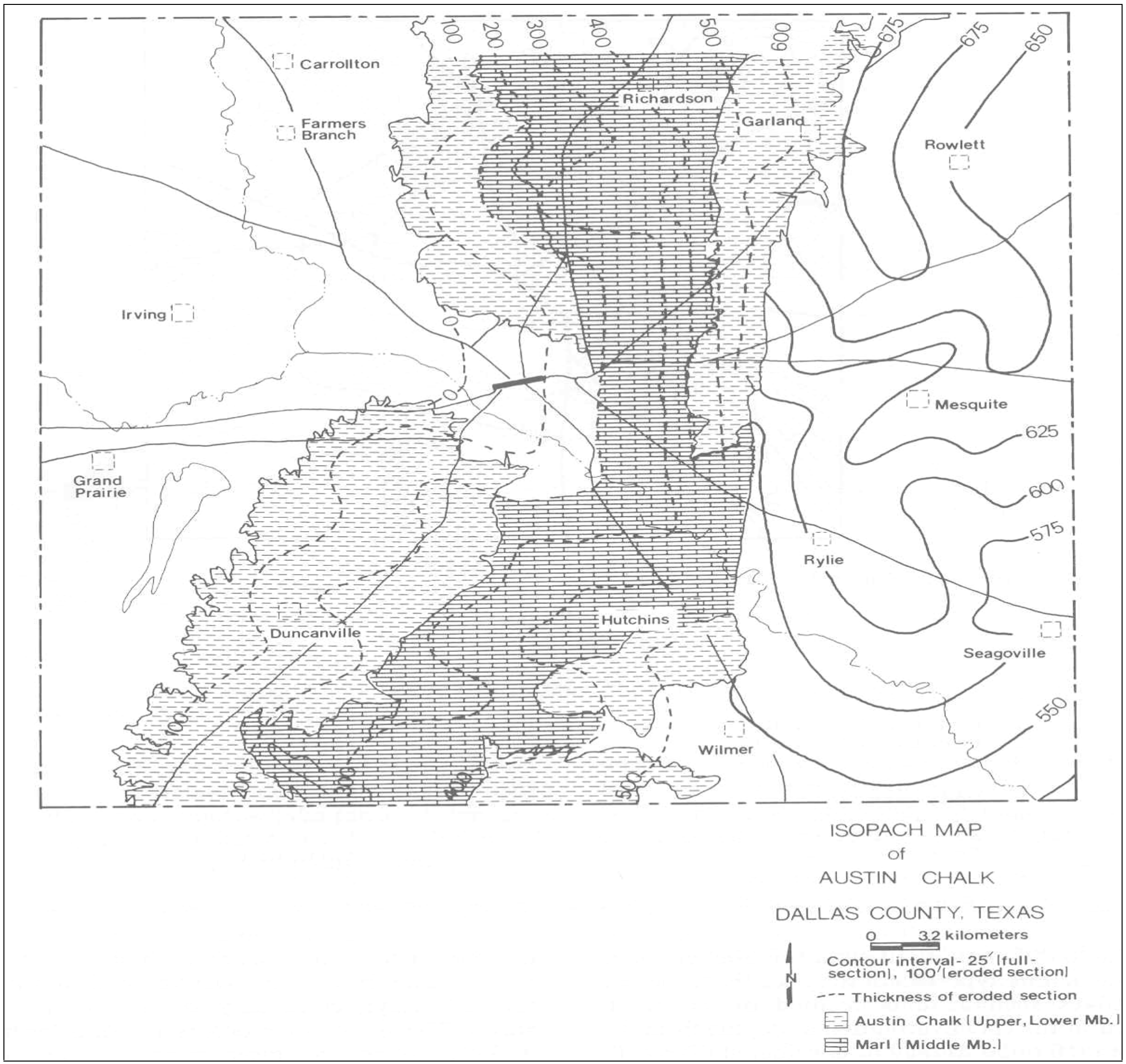

Figure B-3. Isopach Map of the Austin Chalk in Dallas County (2).

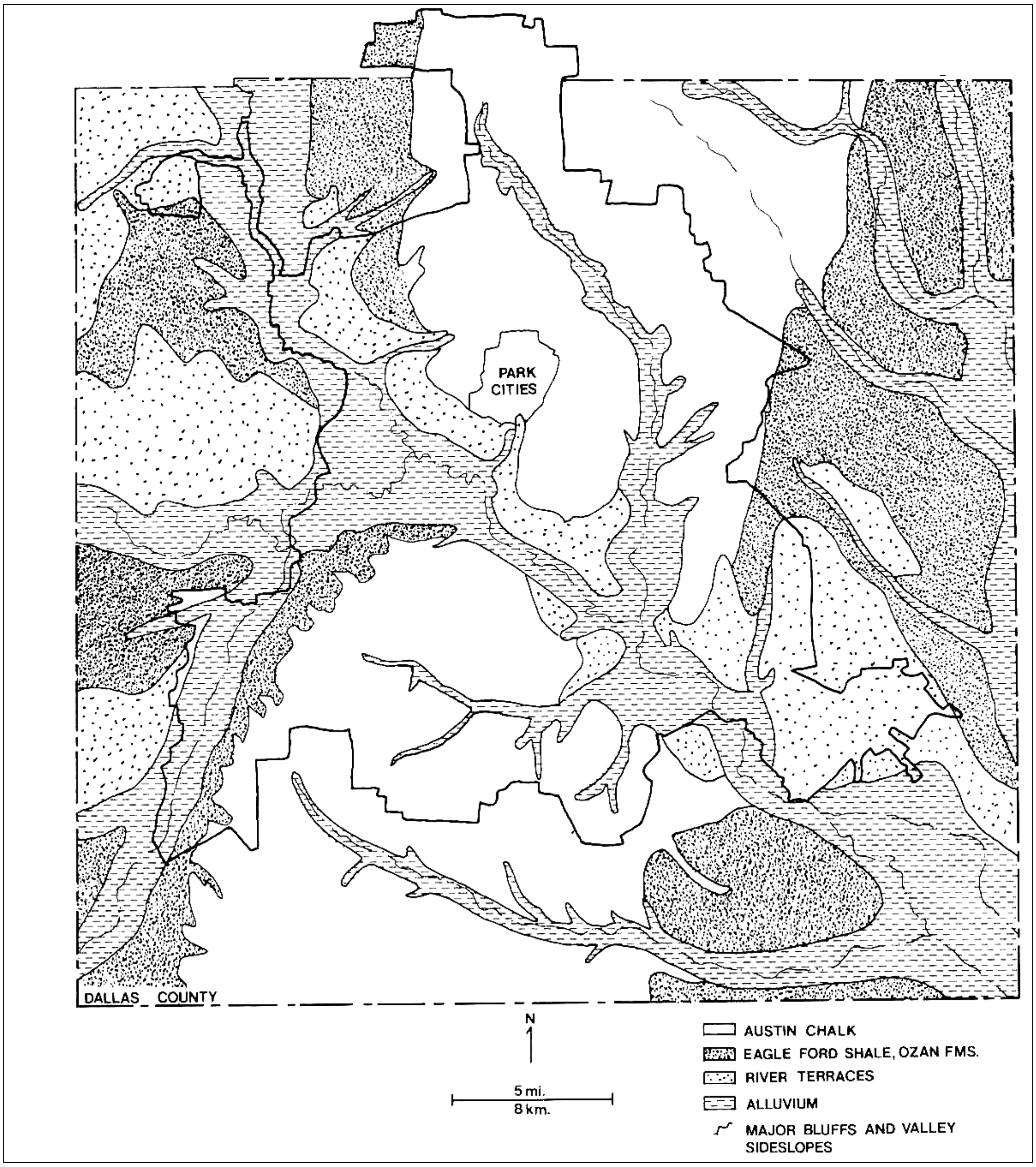

Figure B-4. Geology of Dallas County (*2*).

Figure B-5 is a correlation chart of Dallas County. The lower and upper chalk are of similar lithologies and consists of massive (2-5 ft) beds of light gray to tan-weathering chalk, interbedded with (1-2 ft) beds of marl. The middle member consists of (2-5 ft) beds of marl interbedded with (1-2 ft) beds of chalk. Maximum thickness of the Austin Chalk is 550 ft. The Ozan Formation consists of a soft, laminated, montmorillonitic, calcareous marine shale. Thickness is 50-100 ft in the city, where it displays conchoidial fractures on fresh exposures (2).

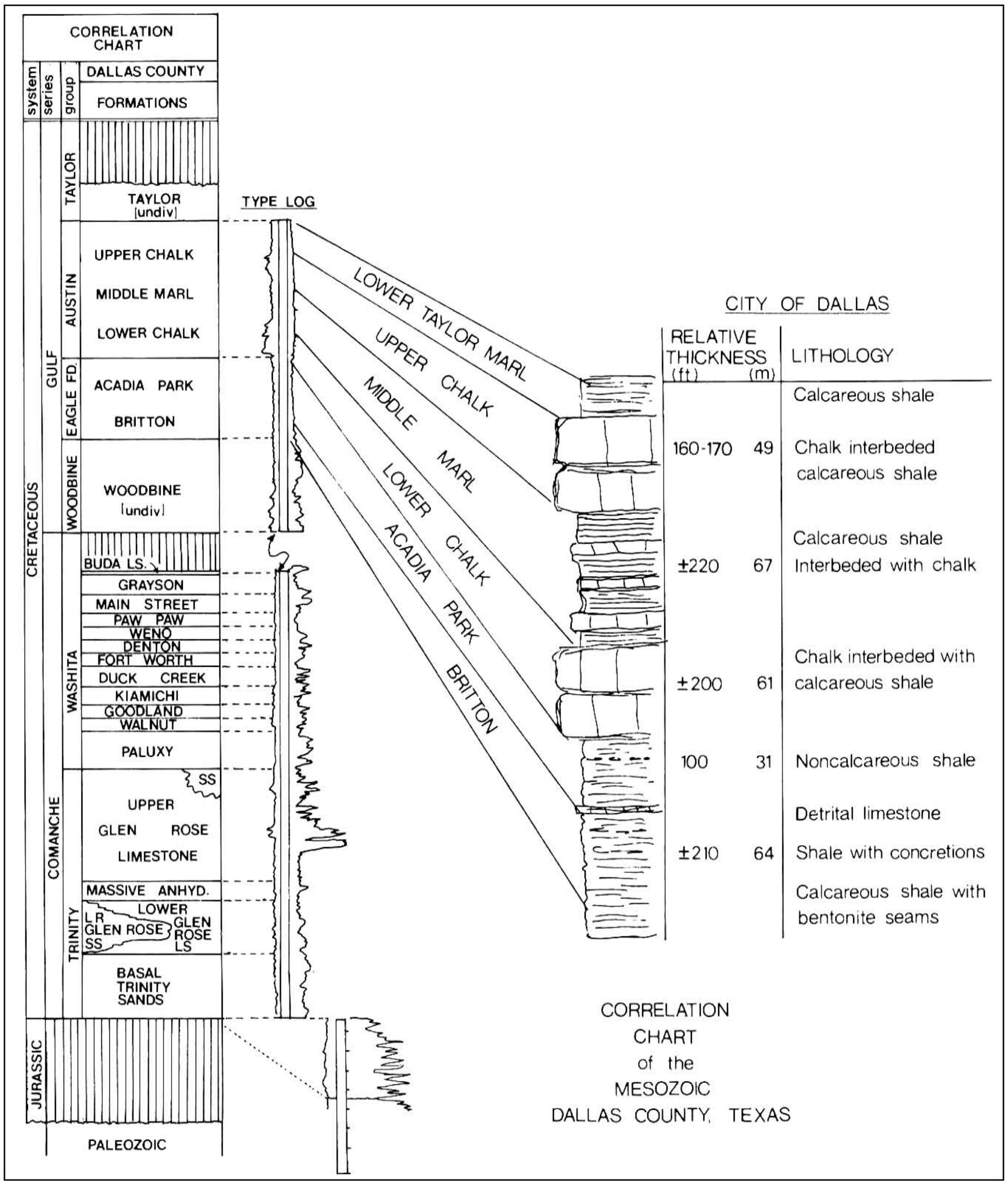

Figure B-5. Correlation Chart of Dallas County (2).

Along the Taylor Marl and Austin Chalk contact, 275 ft of upper Austin is missing in the Waco area and up to 250 ft in Bell County. Figure B-6 is a sketch based on work by Font which shows the regional cross-section and geology through Waco (*5*). Apparently, regional uplift caused a regression that terminated the Austin Chalk deposition and caused water erosion of the upper chalk. Erosional forces in southern McLennan County and northern Bell County removed the upper half of Austin Chalk section, creating what appears to be a large erosion channel. The outcrop trend from northeast of Austin to San Antonio shows a similar wave base that is a shallow-water shelf environment, and indicates rhythmic bedding and reduced macro faunal assemblage. Also noted are the faults in the Waco area, which strike approximately N 5° E and dip eastward 10 to 90 ft per mile. The faults in this area were caused by the Balcones fault system.

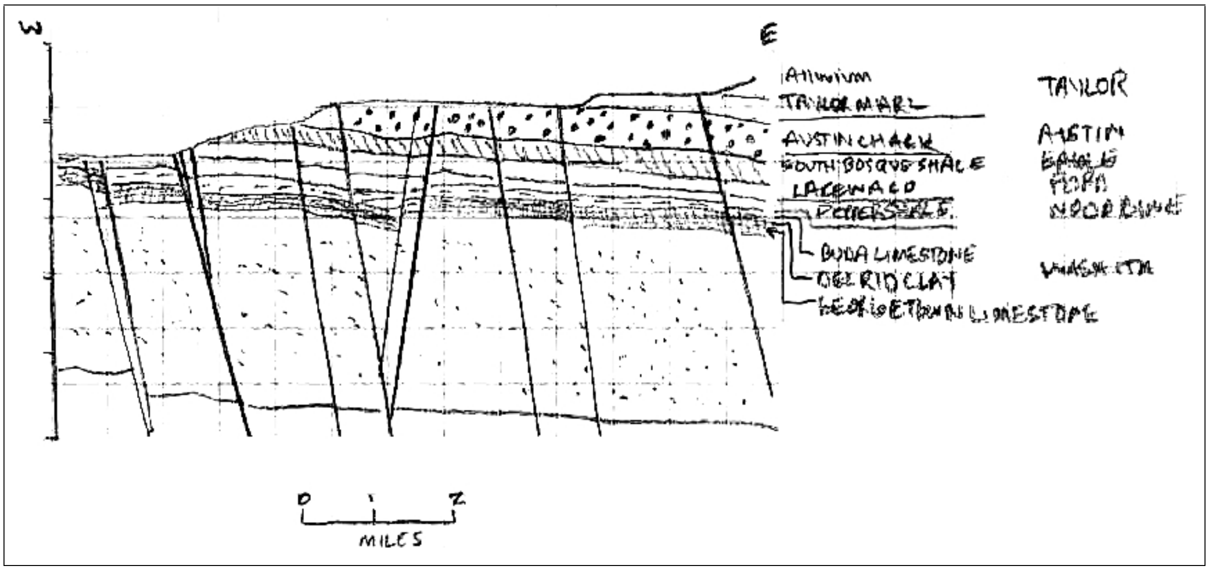

Figure B-6. Sketch of Regional Geologic Cross Section Through Waco (*5*).

In McLennan County, the Austin Chalk crops out in an irregular discontinuous strip, averaging several miles in width and trending in a north-northeast direction. A detailed study of the chalk revealed that composition and texture is the same throughout the entire sequence. Presence of glauconitic and phosphate nodules in the lower few feet are the only variation in composition or texture that might be useful in recognizing individual beds or sequences.

In some areas, the Trinity River has deeply incised its channel through the Austin Chalk into the lower formations. Stephenson attributes this thinning to truncation of the upper Austin chalk beds by the erosion disconformities separating the Austin Chalk and the Lower Taylor Marl (*1*). It keeps thinning gradually southward from 600 ft in Bell County to 420 ft in Travis County. From Travis to Bexar County, the chalk continually thins to a minimum thickness of 110 ft. The marl sections increase in clay content as one moves north of Travis toward Dallas County. Volcanic activity is the source area for these clays. Most of these clays making up the marls are montmorillonite.

Austin Group is a sequence of interstratified chalks and marl deposited during a sea level high stand, and classified as a transgressive unit. The similarity in lithology and fauna of the Austin Chalk in Central Texas suggests similar depositional environments over the entire area. The environment for the Austin Chalk is that of a broad flat shelf area of an epicontinental sea; a southeastward-dipping carbonate ramp exhibits distinctive onshore and offshore chalk lithofacies. Terrigenous input during this time was never sufficient to entirely terminate chalk production, as indicated by the occurrence of coccoliths in marls associated with the chalk. Nevertheless, primary chalk deposition occurred on a shallow-water shelf between San Antonio and Austin and on the pre-existing topographic high of the San Marcos Arch. Deposition occurred above wave base as indicated by massive bedding with virtually indistinct bedding planes. Very shallow water depth at the time of deposition is responsible for the rhythmic bedding of dense chalk beds with thin marl interbeds indicated in the outcrop between San Antonio and Austin (*6*).

Bedding within the chalk is the result of argillaceous sediment interrupting the normal chalk sequence. If it were not for the marl beds, the chalk would be massive in character. Shallower water depth for the Austin Chalk deposition indicates rhythmic bedding of the dense chalk beds and thin marl interbeds found in the outcrop belt southwest of San Antonio and northeast of Austin. These marl beds are composed of a mixture of chalk and clay and appear to be the result of dilution in calcium carbonate by the clay.

Deposition of clay occurred in major cycles with alternating minor cycles. The cyclical variation in climate, producing alternate wet and dry periods, explains the cycles of clay deposition. Periods of wet and stormy climate would 1) increase the rate of erosion causing greater amounts of clastic material to be brought into the sea, 2) create turbid conditions in the shallow near shore areas causing previously deposited muds to be brought into suspension and carried further out, and 3) would decrease the concentration of calcium carbonate in the sea thus reducing the rate of precipitation (*7*).

Diagenesis (mechanical compaction, stylolitization, and calcite cementation) has strongly modified Austin Chalk pore systems. Matrix porosity generally decreases with increasing depth because of progressive burial diagenesis (*8*). Structural features affecting this formation include the San Marcos Arch to the South and the Sabine Uplift to the east of the study area. Effects of burrowing are most notable in the subsurface and the outcrop between San Antonio and Austin.

Compaction remains a primary mechanism for porosity reduction but the effect of pore-filling cement to further reduce porosity is significant. Overgrowth cement can be from two sources, alteration of unstable primary aragonite skeletal material to stable low magnesium calcite and pressure solution in the form of interpenetrated grains, microstylolites and stylolites. In the subsurface, pressure solution is relatively important and is responsible in large part for the very low porosities typical of the subsurface. Two environments of diagensis existed: a) the subsurface characterized by pressure solution and ferro-calcite cement, and b) the surface characterized by freshwater conversion of the aragonite and concomitant cementation. Clay minerals are the remaining diagenetic features of interest. The occurrence of kaolinite and chlorite are present, with illite and smectite constituting the remaining clay minerals.

Porosity and permeability of chalk are directly related to two diagenetic factors: maximum depth of burial and pore water chemistry. Under normal conditions, chalk ooze has 70 percent porosity at the water-surface interface. Chalk that is buried to a depth of 1 kilometer, reduces its porosity to 35 percent, at 2 kilometers 15 percent, and at a depth of 3 kilometers, 0 percent. It is therefore apparent that in this formation porosity decreases as a function of depth of burial. Compaction and dewatering may account for 30 percent to 50 percent porosity reduction without significantly altering the original composition or bulk mineralogy. Austin chalk has porosities ranging from 30 percent in Dallas decreasing southwest along the trend to 9 percent at Langtry. The Austin Chalk further reduces its subsurface porosity from 16 percent to less than 5 percent. Samples of the Austin Chalk were analyzed around his study area for the porosities measured, as shown in Table B-4.

Table B-4. Measured Porosities of Austin Chalk (*3*).

Area	Measured Porosity
Dallas-Waco	26.6 %
Austin-San Antonio	18.8 %
Uvalde	15.7 %
Del Rio-Langtry	13.3 %

Geotechnical Properties

Three informal subdivisions of the Austin Chalk exist. The lower and upper chalk members are thick, massive chalk beds that are more resistant to erosion. The unit is made of strongly calcareous clay, CH or CL, with medium-high shrink-swell properties. Building conditions are ideal as foundation settlement of structures within the chalk is generally less than .25 inches (*9*). Highly plastic soils top these areas and may be influenced by bentonite seams in the bedrock. Deposits covering the Austin Chalk have higher dry unit weights and carbonate contents, although problems are most likely to occur where more clay-rich middle marl crops out. The surface and internal drainage is medium to well. Permeability is generally low, although major faults and joints may conduct small amounts of water. Typical rock quality designation (RQD) values range from 85 to 100. Values over 90 are most common (*10*). RQD depends indirectly on the number of fractures and the amount of weathering or alteration that may be present in the rock observed in the rock or soil cores. This method sums the total length of core recovered; the measured pieces must have a length of 10 cm or longer, and must be hard and sound. Poor core recovery (low RQD number) usually means poor quality rock (*11*). Poor recovery, possibly washed away during the coring process, occurs in soft or shaley limestone layers.

Borehole and Core Samples

The analysis of geologic formations included information on geologic borings and cores that was obtained from various sources. The locations of the borehole and cores samples are shown in Figure B-7. The information included core descriptions in terms of composition, texture, color, sorting, primary, and secondary structures. Stratigraphic columns were obtained for each borehole and environments of deposition of distinct sedimentary units were interpreted. Test results for soil and geologic formations were also included in the information for specific gravity, Atterberg Limits, grain size distribution, and various other engineering properties. The core cross-sections are provided in applicable stratigraphic section descriptions below.

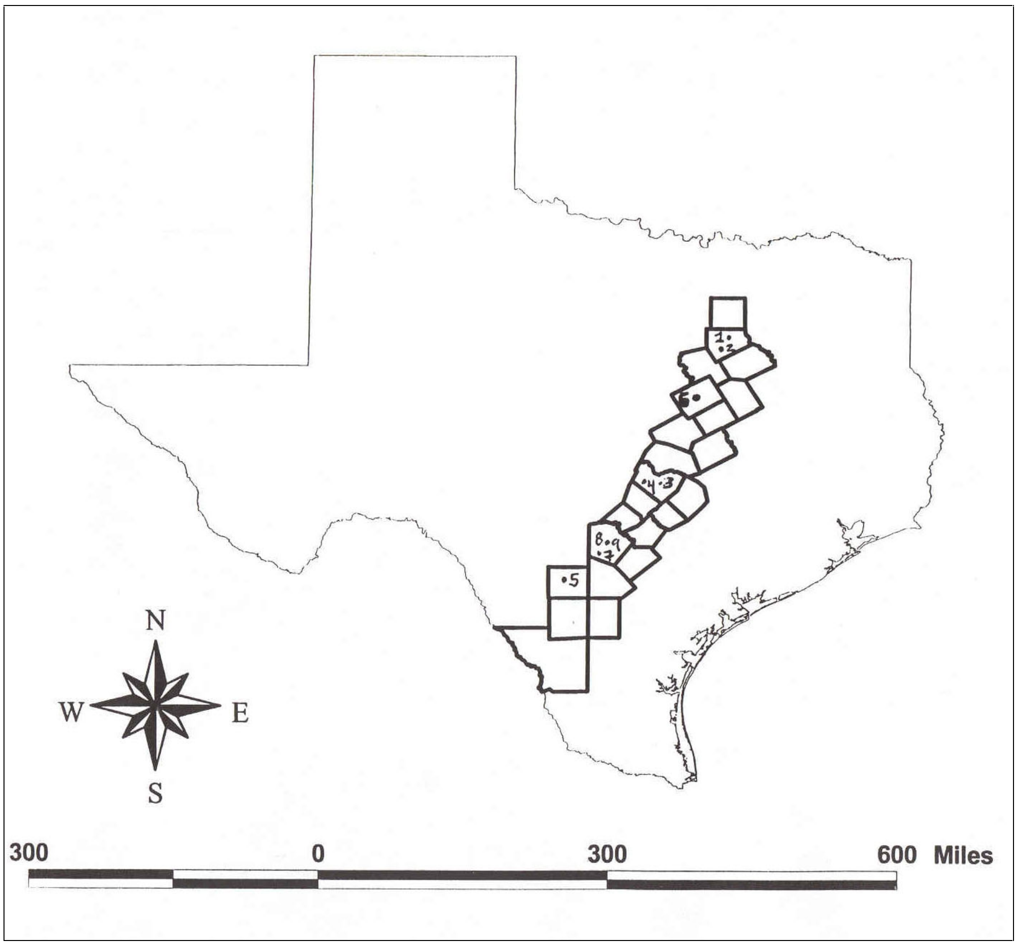

Figure B-7. Borehole and Core Sampling Locations in Corridor Area.

Core Interpretation

The Borehole Number 1 Core, shown in Figure B-8, has been separated into two major soil types and one sedimentary unit. The subdivisions of this core were based on lithology, dominant texture, and/or sedimentary structures. The environment of deposition for the Austin Chalk was interpreted as being a marine setting. The overlying clay units on the Austin Chalk consists of high clay content, high shrink/swell properties, that are found throughout the upper most section, with interbedded gravels found throughout the lower soil formations.

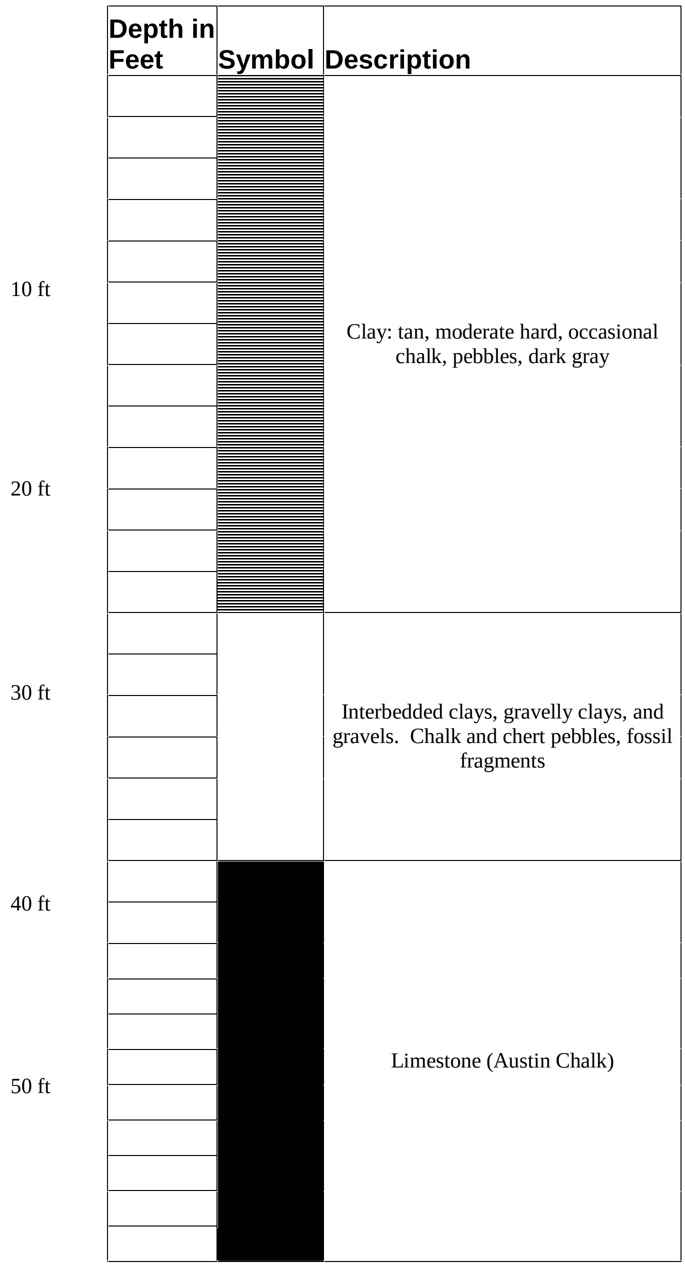

Figure B-8. Borehole Number 1 Core: Ellis County (*12*).

The Borehole Number 2 Core, shown in Figure B-9, has seven major soil types and one sedimentary unit. Geotechnical properties were tested throughout the entire Ellis County survey, and their average engineering properties are found in Table B-5. It was found that soils topping the Austin Chalk are topped by highly plastic soils and may be influenced by bentonite seams. Shrink-swell problems in the Austin Chalk are greatest in these areas.

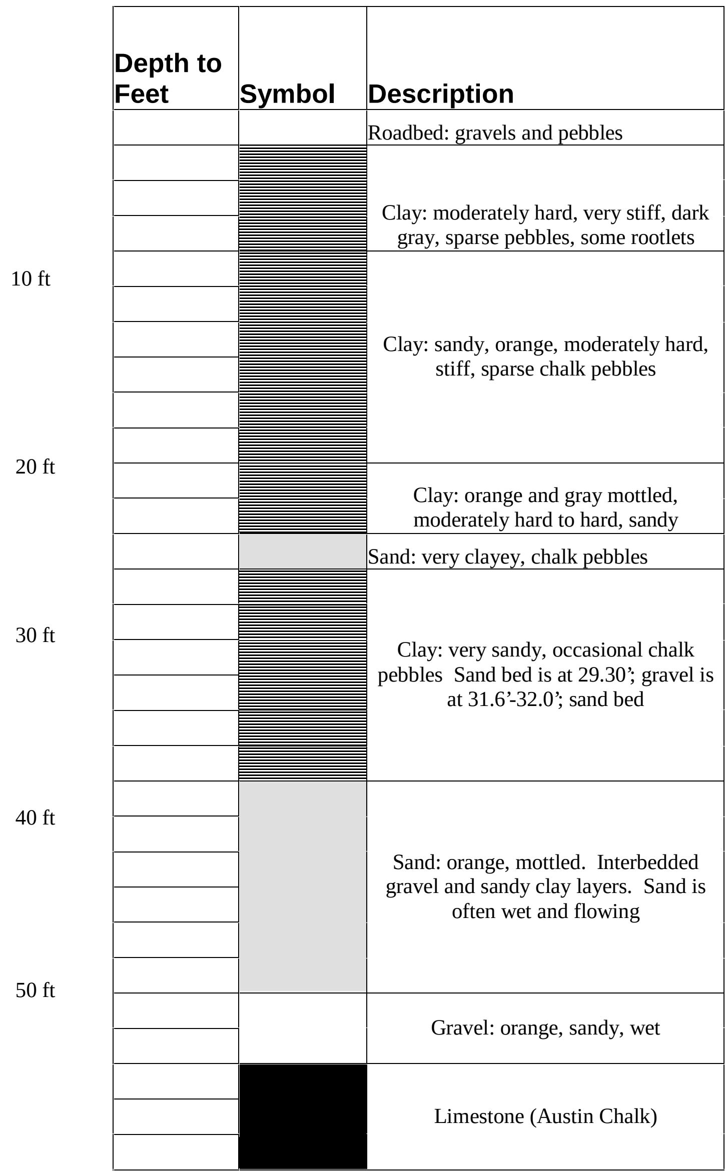

Figure B-9. Borehole Number 2 Core: Ellis County (*12*).

TAYLOR GROUP

Stratigraphy

The Taylor Group extends from Bexar County, northward through Dallas County. There are four informal parts to the Taylor Marl. The oldest formation is the Ozan, followed by the Wolfe City, Pecan Gap, and the youngest formation, which is the Marlbrook. Table B-5 shows the stratigraphy of the Taylor Group.

Table B-5. Stratigraphy of Taylor Group.

Era	System	Series		Formation	Group
Mesozoic	Cretaceous	Upper	Gulfian	Marlbrook	Taylor
				Pecan Gap	
				Wolfe City	
				Ozan/Blackland Marl	

During the course of scientific research on the formation that is referred to as the Taylor Group, there was a discrepancy naming the Ozan Formation. Much debate challenges as to the official name of the Ozan Formation. In this study, the lower Taylor Group (Ozan Formation) is referred to in many texts as the Blackland Marl, taking after the geographical location. This name was adopted after the thesis by Blackstone, who referred to the Ozan Formation the same as this project does (*13*). The Lower Taylor Marl was renamed and referred to as the "Blackland Marl" after the geomorphic province developed on the outcrop belt of this unit.

McFarland's correlations in this study used mainly Pessagno's correlations, which studied the planktonic foraminifera of the Gulf Coast upper Cretaceous strata of Mexico, Texas, and southwestern Arkansas. The Blackland Marl is composed of dark gray to buff, calcareous mudstones containing minor amounts of silt-sized quartz, phosphate, pyrite, and carbonaceous material (*14*).

In Dallas County, the Taylor Marl is most susceptible to erosion. The Ozan Formation consists of clay containing increasing amounts of calcareous silt and sand in its upper portion (*15*). In Dallas and Ellis Counties, the Austin Chalk's maximum thickness is 300-350 ft. The contact marks the beginning of Taylor sediments. The Austin-Taylor contact crops out just east of IH-35 from Dallas and pinches out south of Temple. It is here, along the Austin-Taylor contact, that the 275 ft of upper Austin is missing in the Waco (McLennan County) area and up to 250 ft in Bell County (see Figure B-6). South of Navarro County, the Blackland Marl is relatively calcareous. North into Navarro County it becomes "less calcareous, more quartzose and 200 ft thinner relative to the southern area" (*14*).

Conformably overlying the Blackland Marl, in eastern Falls County extending northward, is the coarser grained clastic unit of the Wolf City sand. The precise boundary is difficult to identify because of the gradational character of the contact. The Blackland Marl thickens from

520 ft in south-central Navarro County to 755 ft in the central of the county, probably because of pre-Taylor erosion of the Austin Chalk and infilling by the Blackland Marl. From Milan and Fall Counties to Dallas County, the Blackland Marl rests unconformable on the resistant Austin Chalk. Erosional truncation of the Austin Chalk is clear evidence of post Austin-pre-Taylor erosion (*14*). Calcareous mudstones dominate the basal Taylor Marls in the upper counties. The Taylor Group on its outcrop in Bexar County consists of 400 ft of marls and calcareous clays. In Medina County, 300 ft of arganaceous, organic, fragmental, asphaltic limestones make up the Anacacho formation.

In naming the Taylor group in Travis County, Hill designated it the “Taylor Marl,” indicating that it contained a considerable amount of calcareous material (*16*). Adkins noted that the Taylor units are made up predominantly of chalks and marls north of the Brazos River. South of the Brazos River, the Anacacho limestone represents the Taylor Group from Kinney County eastward to Bexar County and by the limestone-bearing San Miguel formation in northeastern Mexico (*17*). The Anacacho exists in the subsurface of Frio, Zavalla, and Webb counties. Despite the occurrence of calcareous material on the surface in Texas and Mexico, the examination of the Taylor and Navarro samples from the wells in LaSalle and McMullen counties revealed no zones of predominant, or even of considerable carbonate. The percentage of carbonates average is less than 20 percent (*13*).

The Wolfe City Formation is composed of resistant, brown to gray, argillaceous, calcareous sandstone ledges interbedded with less resistant, dark gray to light gray, sandy shale and shaley sands. In outcrop, the hard sandstones commonly form thin discontinuous lenses and more rarely laterally persistent ledges. Thickness ranges from .25 inch to 1.5 ft. The sandstones exhibit small scale cross bedding and/or laminar bedding, and bioturbation is common throughout the section. The steeply dipping, massively bedded sandstone ledges, which dip at 2 degrees, occur northeast of Dawson, Navarro County, and represent delta forest beds (*14*).

The sandstones found throughout the outcrop belt are consistently composed of moderately- to well-sorted, very fine- to fine-grained, angular to subangular quartz with lesser amounts of feldspar, glauconite, micas, chert, and heavy minerals. Wolfe City becomes more calcareous up section, and grades into overlying Pecan Gap Chalk that varies throughout the outcrop. Phosphate nodules characterize an irregular contact at the type locality. From southeastern Hill County to northern Rockwall County, the typical Pecan Gap is absent in outcrop (*14*).

Pecan Gap chalk is discontinuous in outcrop, thinning northward into Bell County to pinch out in southern Hill County. In outcrop, lower Pecan Gap is composed of white to gray, argillaceous chalk grading up section into less argillaceous chalk. In the southern area it is a hard, silty, fossiliferous chalk overlain by soft, slightly silty, fossiliferous upper chalk, though basinward in the subsurface. As it thickens eastward, chalky marl grades eastward into argillaceous chalk of the Annona Formation (*14*).

Laminated, calcareous claystone with interbedded chalk describes the Taylor Marl geology. Sixty to seventy percent montmorollonite and illite content are attained, producing very low permeabilities. This group is susceptible to swelling upon contact with water because of the amount of clays, rising 8 to 10 inches when exposed to water and atmosphere. Water content decreases with depth, attributed to the decreasing amount of pore space available for water as lithostatic pressure increases. This increased pressure leads to a greater "compactness," and thus an increase in strength and density. Taylor Marl unconformably overlies the Austin Chalk on the western margin of the East Texas basin. Apparently, regional uplift caused a regression that terminated Austin deposition and water related to the erosion of the upper chalk (*18*). Maximum local thickness is 250 ft, whereas maximum probably thickness at one time was 1170 ft (*5*).

Geotechnical Information

The unweathered marl combined with decreasing moisture and increasing lithostatic pressure increases the compressive strength with depth. Deposits covering the Taylor Marl have a higher liquid limit, plasticity index, and water content. RQD values range from 85-100, indicating excellent quality rock. Figure B-10 shows graphs of geotechnical information comparing the Taylor Marl and Austin Chalk group. Very large values of LL (60-120), plasticity index (30-80), and potential volume change (8,000-30,000 psf) characterize these materials. Field strength is usually a function of the residual strength of the clays, or strength along preexisting planes of weakness.

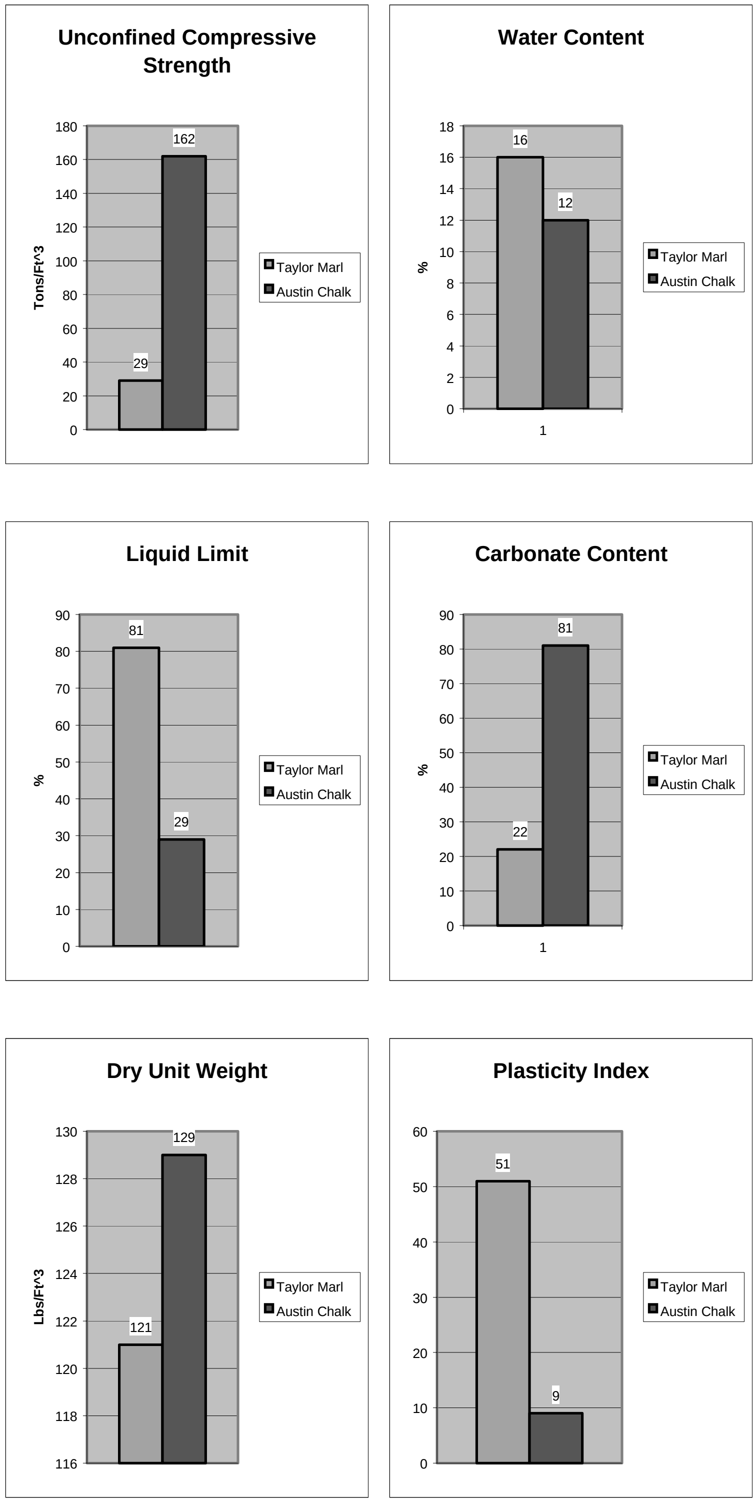

Figure B-10. Average Engineering Properties of the Taylor and Austin Chalk Groups in Ellis County (*12*).

EAGLE FORD GROUP

Stratigraphy

From Dallas to Austin, the Eagle Ford Group thins southward because of non-deposition and truncation of the upper units, possibly because of the Llano Uplift. Near Waco, the Eagle Ford's silt and sand, typical of the northern basin, is absent, taking on more characteristics of carbonate-rich rocks that dominate the lower Eagle Ford. In Austin, the Eagle Ford's thickness is less than 42 ft, which consists of a "thin bedded buff marls and chalks, unconformably resting on Buda Limestone and unconformably overlain by the Austin Chalk" (*18*). Southward beyond Austin, the Eagle Ford Shale thickens to 112 ft in Del Rio where it consists of black shales.

Eagle Ford deposition was "characterized by river-dominated deltas that deposited mostly mud and prograded across the calm marine shelf of east Texas, supplying much of the sediments that comprise Eagle Ford rocks" (*18*). During late Eagle Ford deposition, the Sabine uplift originated a supply of clastic sediments to the east Texas area. A complex delta displaced the Eaglefordian Sea over a sizable area, which terminated the Eagle Ford. Table B-6 shows the stratigraphy of the Eagle Ford Group.

Table B-6. Stratigraphy of Eagle Ford Shale.

Era	System	Series		Formation	Group
Mesozoic	Cretaceous	Upper	Gulfian	South Bosque	Eagle Ford
				Lake Waco	

The Lake Waco Formation consists mostly of montmorillonite clays with a considerable amount of disseminated carbonate calcite. The numerous limestones near the top and base of the Eagle Ford consist of minor amounts of bentonite seams and rare amounts of kaolinite. "Bentonites are concentrated in the Britton where at least 34 bentonite seams have been reported within 70 ft of strata" (*18*). Tables B-7, B-8, B-9, and B-10 show engineering properties of Eagle Ford Group Formations in the Dallas and Waco areas.

"The Waco area lies primarily on the South Bosque shale and partly on the overlying Austin Chalk" (*10*). The upper 30 to 50 ft of the South Bosque, shale is homogeneous, non-calcareous, whereas the lower part contains interbedded calcareous shales, silty limestones, and bentonite seams. Steeper slope areas lie upon the South Bosque shale. The outcrop from Waco to Austin contains shale and sandy shale, while the lower part of the formation contains shaley chalk and chalk.

Table B-7. Engineering Properties of Shales in Dallas County and McMullen County (9).

Index Properties							
	Natural Water Contents Percent			Potential Volume Change			
Formation	Liquid Limit	Plastic Limit	Plasticity Index	Swell Pressure lb/ft^2	Clay Content Percent	$CaCO_3$ Content Percent	Dry Unit Weight lb/ft^3
Taylor Marl	50-70	15-21	35-49	4,000-18,000	70	58	91
Upper Eagle Ford	60-80	26-32	34-48	5,000-25,000	70	2-30	82-96
Betonites Lower Eagle Ford	115-130	40-80	35-90	30,000+	90	5	95
Pepper Shale	60-80	26-35	34-54	6,000-25,000	90	0	71-91
Strength Parameters							
	Cohesive Intercepts (PSI)			Angles of Internal Friction (degrees) and Coefficients of Friction (dimensionless)			
	Consolidated Undrained Ccu	Residual Consolidated Drained Cd	Strength Tests Cr	Consolidated Undrained	Consolidated Drained	Residual Strength Tests	
Taylor Marl	2.1-4.8	1.7-2.8	0	11	25.5	8	
Upper Eagle Ford	1.1-4.2	2.3	0	13.5	18	8-10	
Bentonites Lower Eagle Ford	1.3-4.6	1.1-1.8	0	13.5	21.5	-	
Pepper Shale	1.1-3.1	.2-2.3	0	14.5	20	5	

Table B-8. Geological and Engineering Properties of Formations around the Waco Area (*9*).

Formation	Lithology	Thickness	Engineering Properties	Excavation Properties
Taylor Marl	Dark gray to brown, dominantly montmorollinite clay with varying amounts of silt-sized quartz, calcite fragments.	250 ft	Highly bentonitic, calcareous clay, High shrink/swell.	Excavation should be closed promptly to avoid swelling of bentonitic clays, Normally stable slope of 10° will fail under its own weight.
Austin Chalk	Described in text.	120 ft	Soils derived have high shrink/swell ratio, bearing capacity is 20-35 tons/ft^2	Provides more difficult excavation, supports steep cuts.
South Bosque Shale	Dark gray to black homogeneous shale, upper 40 ft is non-calcareous, lower 120 ft essentially calcareous.	160 ft	Bearing capacity is 3.5-18 tons/ft^2, slope stability directly related to composition of material and amount of water present. Higher shearing strength, greater slope angle will be.	Low slope stability, supports slopes less than 10 degrees under its own weight, low infiltration.
Lake Waco	Has a thin limestone bed in upper and lower part.	80 ft	Greater range of support strengths.	Supports steep facies and heavier foundation loads, excavation is easier in the middle shale member and harder in limestone members.
Buda Limestone	Hard to chalky, fossiliferous limestone.	0-20	N/A	N/A
Pepper Shale	Blue-gray, highly plastic, noncalcareous clay.	60-70 ft	Highly plastic.	Yields under minimum loads and shale slumps under gentle slopes.
Del Rio	Gray, calcareous, plastic clays with occasional discontinuous limestone stringers	85 ft	Highly plastic when wet, forms corrosive soils and impermeable to drainage and infiltration	Clay fails by slumping on gentle slopes, easily excavated.

Table B-9. Engineering Properties of Waco Geology (*19*).

Index Properties							
	Natural Water contents Percent			Potential Volume Change			
Formation	Liquid Limit	Plastic Limit	Plasticity Index	Swell Pressure lb/ft[2]	Clay Content Percent	$CaCO_3$ Content Percent	Dry Unit Weight lb/ft[3]
South Bosque Shale	60-67	26	34-41		7		82
Strength Parameters							
	Cohesive Intercepts (PSI)			Angles of Internal Friction (degrees) and Coefficients of Friction (dimensionless)			
	Consolidated Undrained Ccu	Residual Consolidated Drained Cd	Strength Tests Cr	Consolidated Undrained	Consolidated Drained	Residual Strength Tests	
South Bosque Shale	2	4	0-1.5	2	4	0-1.5	

Table B-10. Geologic Characteristics of South Bosque Shale and Del Rio Clay in the Waco Area (*9*).

	Description	Approximate Composition Based On X-Ray Diffraction Data	Topographic Expression	Related Urban Engineering Problems
South Bosque Shale	Dark gray to black blocky to fissile-fissured shale that weathers-blue-gray to tan. The upper 30 to 50 ft are noncalcareous and give rise to most problems.	34 % Montmorillonite 7 % Illite 5 % Kaolinite 2-8 % Calcite 11 % Quartz 35 % other	Exposed along face of slopes of Bosque Escarpment, but capped by a few ft of Austin Chalk	Slope Instability High Shrink-Swell Inadequate for septic sewage disposal

Geotechnical Properties

The bentonites of the lower Eagle Ford Group, as indicated by the LL and PI, are assumed to cause the most problems with shrink/swell. Table 13 shows geotechnical information comparing the Taylor Marl, Eagle Ford, and Woodbine Groups. As indicated, large values of LL (115-130), PI (35-90), and potential volume change (30,000+ lb/ft^2) characterize these materials (*9*). Generally, the Lake Waco Formation supports steep facies and heavier foundation loads, where the middle shale member allows easier excavation.

The upper Eagle Ford is predicted to have fewer problems associated with shrink/swell because of their lower LL (60-80) and PI (34-48). Table 6 shows some geological and engineering properties of formations around the Waco area. The South Bosque shale stability is directly related to composition of the material and the amount of water present. It is characterized to have a low slope stability, supporting slopes less than 10 degrees under its own weight. Tables 14 and 15 also show geologic characteristics of the South Bosque Shale of the Eagle Ford Group.

Core Interpretation

No information regarding cores for the Eagle Ford Group was found.

NAVARRO GROUP

Stratigraphy

The Navarro Group extends in north and central Texas, where there are four informal parts. The oldest formation is the Neylandville, followed by the Nacatoch, Corsicana, Kemp, Upson, Anacacho, and the youngest formation, which is the Escondido.

The Navarro Group in Bexar County is made up of glauconitic clays and marls, 450 ft thickening to 720 ft in Medina County, which is comprised of glauconitic, arenaceous marls and clays that contain approximately 70 percent limestone in the upper 100 ft (*13*). Sandstones comprise only 20 percent of the Taylor-Navarro Group sections that were studied. The Navarro Group is recognized north and east of San Antonio and consists of poorly bedded clay and subordinate amounts of sandy and chalky beds (*20*). In San Antonio, the Navarro Group consists of soft, gray to dark-gray massive-bedded clay shales. In this study, the Escondido Formation crops out throughout the corridor area.

Escondido Formations are found throughout the Rio Grande Embayment. It is recognized westward from San Antonio into Mexico and is over 500 ft thick. It consists of soft yellowish-gray clay, thin brownish-gray limestone beds, silty and sandy clay, and sandy limestone.

Figure B-11 is a sketch of the generalized cross-section through San Antonio. This geologic section shows where the Navarro is in structural contact with the underlying Taylor

Formation. The rock is fractured and interbedded with thin, 1.6 mm to 25 mm, layers of silty sand. The major faults have more than 150 ft of downward displacement to the southeast (*21*).

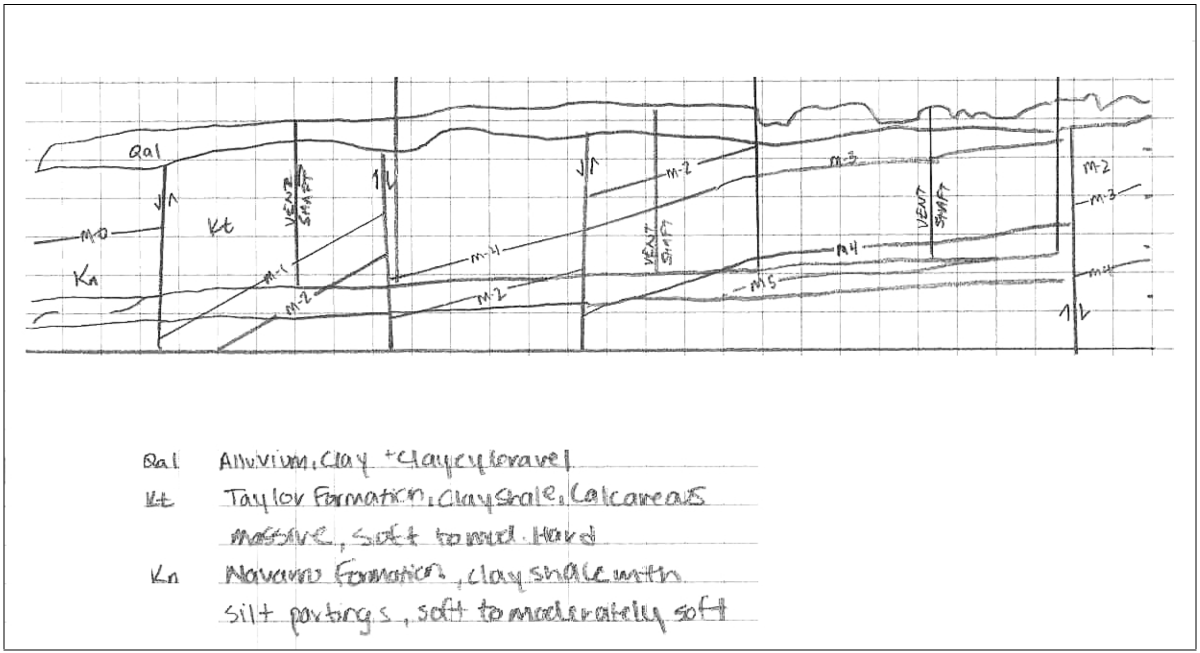

Figure B-11. Sketch of Generalized Cross-Section through San Antonio (*21*).

Geotechnical Properties

The Navarro Group is expected to have similar properties to the Taylor Marl. For the San Antonio Tunnel, engineering properties were tested on both the Navarro Group and Taylor Group. Results found that the unconfined strengths within the upper Taylor and the Navarro Groups were very similar, averaging about 1,914 kPa. A more bentonitic Navarro was distinguishable from the upper Taylor by its much higher LL (107), PI (76), natural water content (22 percent), and much lower dry density (1554 kg/m^3) (*21*).

Core Interpretation

Figure B-12 shows Borehole Number 3, which is taken from Travis County and shows the Navarro Group as the principle formation for the boring. The lower parts of these contain montmorillonite clays and bentonite seams, which can greatly impact the shrink/swell potential if exposed to sufficient moisture. Borehole numbers four through seven contain information on Travis County and Waco City. In addition, engineering properties were tested around Waco City and included in this report. Extending southward, the Navarro Group becomes increasingly clayey with interbedded sands. The northern Navarro Group consists of dominantly massive, high amounts of clay.

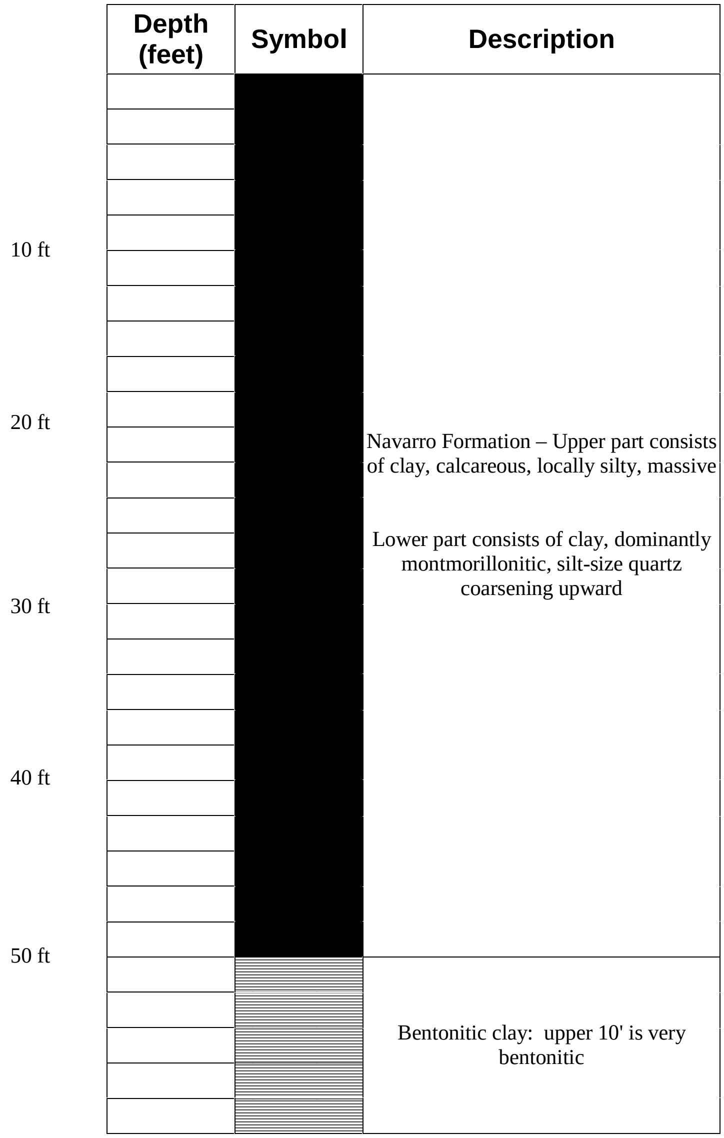

Figure B-12. Borehole Number 3: Travis County (*22*).

MIDWAY GROUP

Stratigraphy

This group is made up of marine mud composed highly of glauconitic sands and sandy clays. The upper midway consists of interbedded marls and glauconitic limestone. The lower part of this group consists of glauconitic sandstone, shales with phosphatic modules, and very glauconitic, fossiliferous limestone. The environment of deposition is interpreted to be low energy depositional environment, marine conditions. Two formations make up the Midway Group, the upper Willis Point Formation, and the lower Kincaid Formation. Table B-11 shows the two informal sections of the Midway Group.

Table B-11. Stratigraphy of the Midway Group.

Era	System	Series		Formation	Group
Mesozoic	Cretaceous	Upper	Gulfian	Willis Point	Midway
				Kincaid	

Marine processes formed the Midway Group. Willis Point Formation is composed highly of glauconitic sand and sandy clays, interbedded marls, and glauconitic limestone. It represents a slow sediment accumulation on an open marine shelf. Kincaid Formation is composed of sandstone in the upper part which is glauconitic, poorly sorted, and argillaceous. The lower part is composed of glauconitic sandstones, shales with phosphatic modules, and fossiliferous limestone. The lower energy depositional environment indicates marine conditions.

Geotechnical Properties

There was no data on engineering properties of the Midway Group. Assumptions can be made though that this group is expected to have low shrink/swell potential because of the low content of clay and is able to support moderate stability support because of the variations in grain sizes.

Core Interpretation

Figure B-13 shows Borehole Number 4, which was taken in Travis County. Figure B-14 shows Borehole Number 5, which was taken in Falls County. These records confirm the Midway Group's and underlying Navarro Group's lithologies. Figure B-15 shows Borehole Number 9, which was taken in Bexar County and shows the soil type that generally forms on top of the Midway Group.

Depth in Feet	Symbol	Description
		Midway Group: Kincaid Formation glauconite, calcareous clay, clay
10 ft – 20 ft		Navarro Group: Kemp Clay Formation; clay with interbedded beds of sand and fossiliferous sand

Figure B-13. Borehole Number 4: Travis County (*23*).

Depth in Feet	Symbol	Description
		Midway Group: Kincaid Formation; calcareous clay
10 ft		Fossiliferous sand
20 ft		Navarro Group: Kemp Clay Formation; glauconite, fossiliferous clay

Figure B-14. Borehole Number 5: Falls County (*23*).

Depth in Feet	Symbol	Description
8 ft		Dark brown clay with pebbles; Turning to light brown shale silty clay at 5.5'; calcareous

Low moisture content prevented penetration below 7'

Figure B-15. Borehole Number 9: Bexar County (*10*).

WILCOX GROUP

Stratigraphy

The Wilcox Group consists of fine to coarse-grained sand with interbedded clay of varying proportions. Maximum thickness reaches 3000 ft. Different units are similar south of the Colorado River and North of the Trinity River, although south of the Colorado River, near-shore marine processes influence sediments, in which interbedded limestone lenses and marine clays were deposited. North of Trinity River, the Wilcox Group was dominantly fluvial in nature and the sediments are generally fine to medium grained, cross-stratified sand interbedded with clay, sandy clay, and thin beds of lignite. The Wilcox Group includes three formations: the Simsboro Formation, the Hooper Formation, and the Calvert Bluff Formation (*24*). Table B-12 summarizes the stratigraphy of the Wilcox Group.

Table B-12. Stratigraphy of the Wilcox Group.

Wilcox Group	**Calvert Bluff Formation**	Consists of fine to coarse-grained, light gray to pale brown sand and sandstone interbedded with various amounts of mudstone, ironstone concretions, and discontinuous beds of lignite. Maximum thickness is 2000 ft. Deposits from extensive fluvial deltaic channel complexes.
	Simsboro Formation	Primarily fine to coarse-grained, light gray kaolinitic sand with small amounts of clay, mudstone, and mudstone comglomerate. Formed in fluvial environment and are discontinuous river channel deposits with interchannel deposits composed of finer grained sands and muds in the northern part, while thick, multilateral sand bodies are found in the southern part.
	Hooper Formation	Predominantly mudstone with various amounts of light gray to medium brown, fine- to medium-grained sandstone. Maximum thickness can exceed 1300 ft in deep subsurface in Central Texas, generally less than 500 ft in shallower areas where groundwater development occurs.

The Simsboro Formation outcrops just east of Waco to the east of Austin. The thickness ranges from 60 to 240 m in East-central Texas (*25*). The Simsboro Formation is a medium to coarse-grained sand deposited by bed to mixed load fluvial systems. It is massive and highly resistive sand, although its strength is weak. Its environment of deposition was interpreted to show excellent dendritic channel geometry. The Simsboro Formation is associated laterally with point bars and vertically with abandoned channel facies. The lower Simsboro Formation consists of persistent beds of fine-grained homogeneous clay and silty clay, kaolinitic sand, thinly laminated sand/silt, clay conglomerates, homogeneous clay, and silty clay (*25*).

The Hooper Formation is an upward coarsening sequence that records a prodelta through a distributary's channel fill. It consists of mud and sand. Calvert Bluff Formation consists of dark gray to greenish clays, carbonaceous clay and lignite, silty clays, calcite, and silica cements are locally present. Its environment of deposition was positioned between the lower delta plain and dendritic fluvial channel. It was a medium- to fine-grained channel deposit, consisting of fine-grained sand and mud (*26*).

CLAIBORNE GROUP

Stratigraphy

The Claiborne Group was formed by a cyclic depositional pattern of near shore marine and non-marine sediments consisting primarily of sandstones, conglomerates, clays and shales (*25*). Much of the Claiborne Group that was deposited in Webb County is known for their cannel-like character (*27*). Outcrops in the project area include the Yegua Formation and the Laredo Formation.

Within the Rio Grande Embayment, the Claiborne Group consists of marine mudstones in the east and northeast, and sandstones and mudstones in the south and southwest. The marine mudstones coarsen upward into the fluvial deltaic Queen City Sand. To the west, it gradually forms the Jackson Group. The Jackson Group overlies the sandy Yegua Formation (*27*). The Carizzo Formation is made of fine to medium sand, which is consolidated by ferruginous cement, and shale is absent from this formation. It has a fining upward sequence, indicating a fluvial environment of deposition.

Geotechnical Properties

There were no engineering properties that were found for the Claiborne Group in Webb County. Based on stratigraphic and core information, it is expected that the shrink/swell potential is low, and rock strength is low as well.

Core Interpreatation

Figure B-16 shows Claiborne and Jackson Group formations from a boring in Brazos County. Figure B-17 shows a stratigraphic column through the Yegua Formation in Burleson County (*27*). Although there may be changes in stratigraphy between these locations and the formations in Webb County, the cores show sequences typically found in these groups.

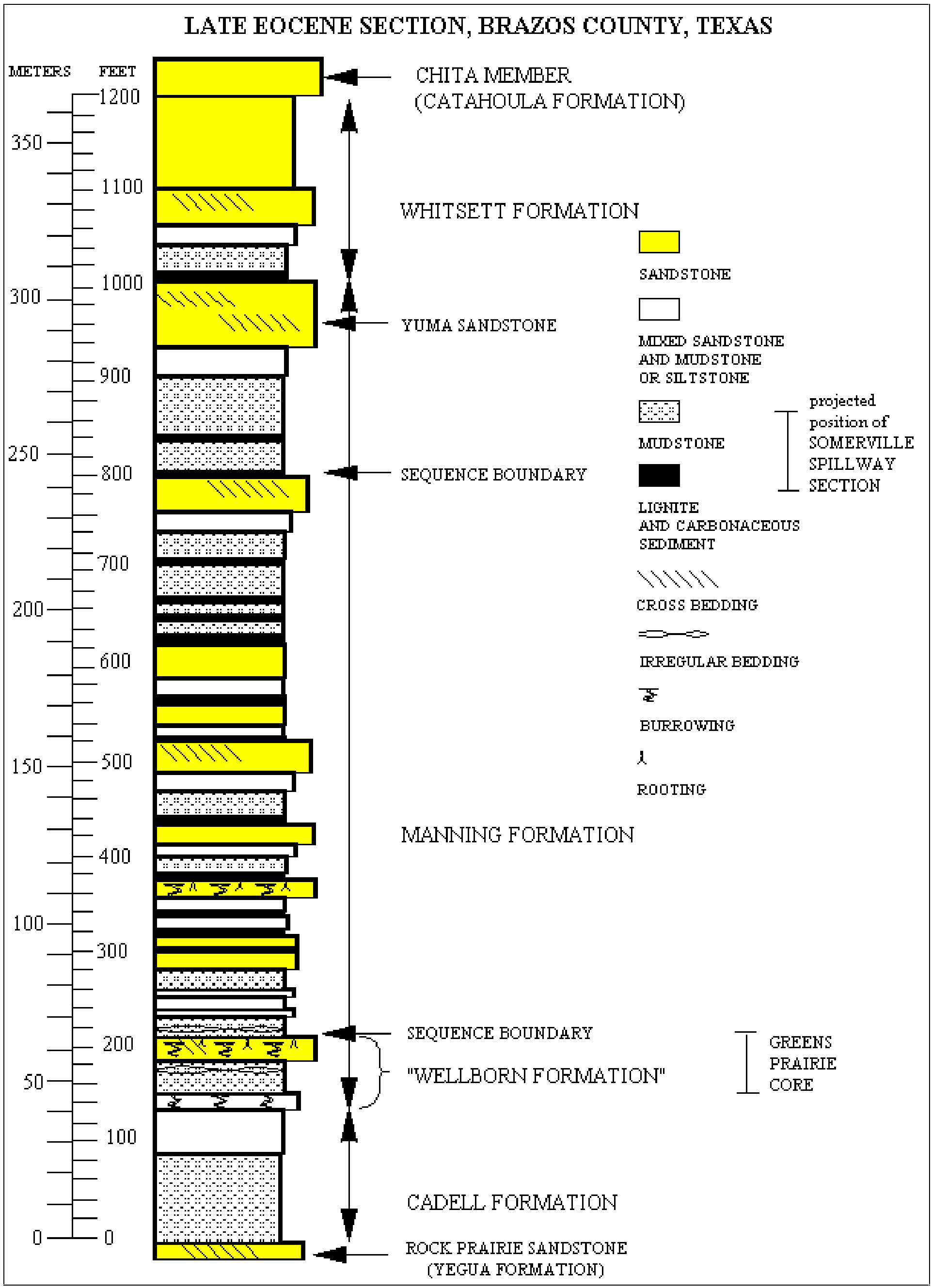

Figure B-16. Stratigraphic Section of Brazos County, Texas (*28*).

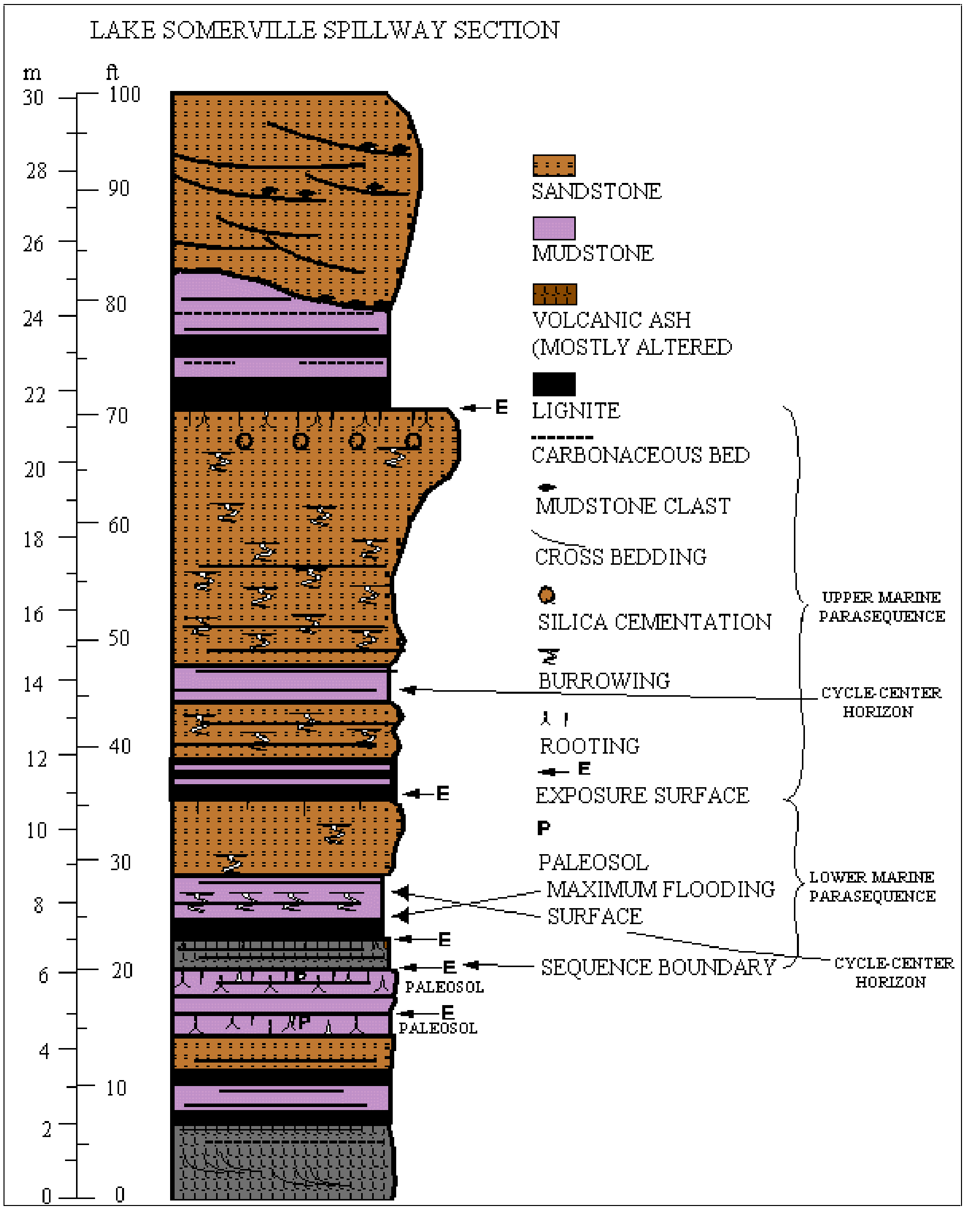

Figure B-17. Stratigraphic Column through the Yegua Formation (*27*).

Soil Formations

Lean clays are the predominant soils in the project area. The parent materials for these soils are the Taylor Formation, Eagle Ford Shale, Yegua Formation, and the Wilcox Formation. Fat clays and some sandy soils occur in small areas throughout. These soils are derived from the Austin Chalk, Quaternary deposits, and the floodplain deposits. The term "soil" pertaining to this project is used loosely and includes unconsolidated sediments in the surface and subsurface until more consolidated sediment is reached. Soils in the corridor area generally did not extend beneath 15 ft.

Geotechnical Properties

Information on geotechnical properties of soil formations was obtained from Soil Conservations Service County Surveys, including: 1) Atterberg Limits, 2) permeability, 3) grain size distribution, and 4) depth to bedrock.

Atterberg Limits can be defined as the water content of a soil at the threshold of distinct behavioral states; the point which a soil behaves plastically instead of elastically. There are three Atterberg Limits: LL, PL, and the shrinkage limit. The liquid and plastic limits and the difference between the values, the plasticity index was also evaluated. Specific values for shrinkage limits were not presented in the county surveys.

LL is defined as the boundary between plastic and viscous fluid states. It is the moisture content as which soil begins to behave as a liquid material and "flow." Moisture content is the percentage by weight of water present in the pore space of rock or soil with respect to the weight of the solid material and is defined as the moisture content (*11*). It is determined in the lab as the moisture content at which two sides of a ½" - groove formed in a soil come together and close after 25 blows. The procedure for liquid limit tests is given in the ASTM Test Designation D-4318.

PL defines the boundary between non-plastic and plastic states. The method to determine the plastic limit is to adjust the moisture content of a soil until it breaks when rolled to a 1/8" diameter roll. The procedure for PL tests is given in ASTM Test Designation D-4318.

PI is the range of water content over which a soil behaves plastically. Liquid limits and plastic limits are often referred to as the Atterberg Limits. LL, PL, and PI are important, along with other soil properties, such as identification of sediments, to correlate with engineering behavior such as compressibility, permeability, compatibility, shrink-swell, and shear strength.

Figure B-18 shows typical engineering properties of soil formed on top of the Taylor Marl and Austin Chalk. The soils on top of the Austin Chalk have higher LL and PI values than those of the Taylor Marl, indicating that the Austin Chalk soils are "fatter" and have greater potential for shrink-swell activity. Figure B-19 for the coring from Borehole Number 6 shows the silty, calcareous clays that form in Waco City. Figure B-20 for the coring from Borehole Number 8 in Bexar County shows typical soils of the Houston Black Formation.

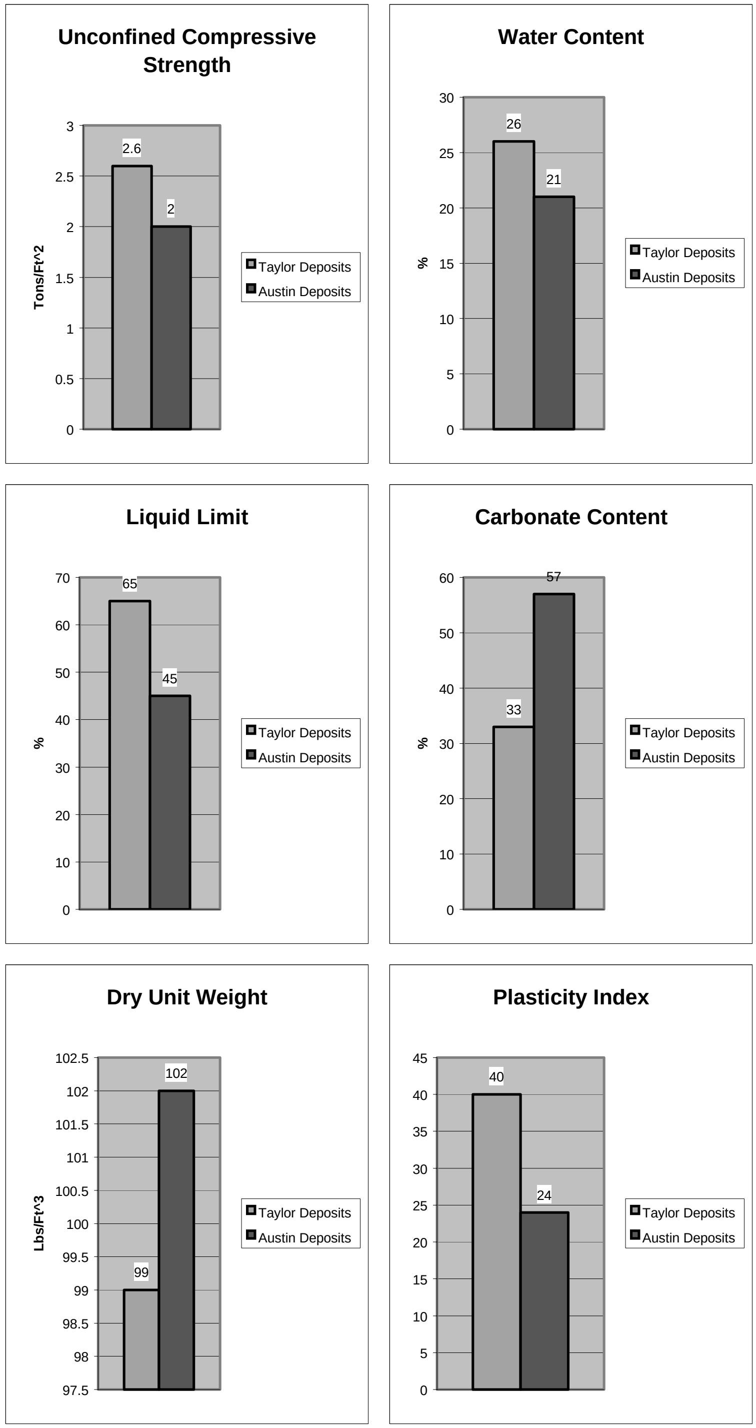

Figure B-18. Comparison of Average Engineering Properties of Deposits Formed on Top of the Taylor Marl and Austin Chalk (*12*).

Depth in Feet	Symbol	Description
		Silty clay, calcareous
10 ft		

Cannot penetrate below 9'

Figure B-19. Borehole Number 6: Waco City (*10*).

Depth in Feet	Symbol	Description
		Dark, black, silty, shaley clay Turning to medium brown silty clay, calcareous, with certy pebbles
6 ft		

Could not penetrate cobbles

Typical boring log in the Houston Black Clay, San Antonio

Figure B-20. Borehole Number 8: Bexar County (*29*).

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APPENDIX C – FREIGHT PIPELINE POLICY ISSUES

FREIGHT PIPELINE POLICY ISSUES

PROJECT FUNDING

- ***Public Funding* –** This policy issue deals with direct funding by the public sector and subsequent arrangements with private users, including leasing terminal space to private firms.
- ***Public/Private Funding* –** One of the alternative funding arrangements to be explored is the partnering of public sector entities, federal or state, and private concerns that participate based on expected return on investment. This approach would impact service pricing.
- ***Private* –** Strictly private financing would be a funding option only under specific conditions.

RIGHT-OF-WAY ACQUISITION/OWNERSHIP

- ***Easement vs. Right-of-Way Acquisition* –** The subterranean nature of the freight pipeline concept may make acquisition of a right of way easier by virtue of the land use features of easements.
- ***Joint-Use Corridors* –** The recent adoption by the Texas Department of Transportation (TxDOT) of the concept of joint-use corridors may facilitate the inclusion of a freight pipeline in a corridor designed with several transportation or communications-related facilities.
- ***Greenfield Right-of-Way or Easement* –** A Greenfield facility refers to new infrastructure located in rural or as yet undeveloped locations. The policy issues associated with this approach include eminent domain and condemnation.
- ***Railroad Rights of Way and Gaining Easements to Cross* –** The ownership by the railroads of their rights of way make crossings subject to negotiation and compensation.

LABOR ISSUES

- ***Labor* –** The use of organized labor at the terminals or for maintenance or operations will be a matter of policy.

SYSTEM OPERATIONS

- ***Ownership of Terminals* –** Closely related to the funding issues are the policy issues concerning ownership of the terminals and company-designated space.
- ***Ownership of Main Transport Mechanisms (MTMs)* –** The determination of who owns and cares for the maintenance of MTMs will be a matter of policy affecting operations.
- ***Insurance* –** The freight pipeline's role as a carrier may require assumption of loss and liability for lost or damaged merchandise. The policy issues associated with this role include insurance and claim adjustments.

- ***Common Carrier Status* –** A determination of the common carrier status of the freight pipeline will have ramifications for the business model, terminal design, labor, and pricing structure.
- ***Designation of Free Trade Zone Status* –** The concentration of North American Free Trade Agreement (NAFTA) related trade intended for the freight pipeline may suggest that Free Trade Zone status may have advantages for the system in terms of business generation.

BORDER ISSUES

- ***Drug Enforcement Administration (DEA)* –** The policy of the freight pipeline's cooperative position relative to the DEA must be evaluated to facilitate both the role of drug interdiction efforts and system throughput.
- ***Customs* –** The policy of the freight pipeline's cooperative position relative to customs must be evaluated to facilitate the mission of both entities.
- ***Brokers* –** The broker community plays a large role in NAFTA trade. The freight pipeline's operations regarding this sector of the trade community will require communication and coordination.
- ***U.S. Department of Agriculture (USDA)* –** The policy of the freight pipeline's cooperative position relative to the USDA must be evaluated to facilitate the mission of both entities.
- ***Facility Location* –** The location of a freight pipeline terminal adjacent to the border will require careful consideration of the needs of the local community.
- ***Mexican Participation* –** The extension of the freight pipeline into Mexico should be considered based on the nature of international trade and market-to-market transactions.

SUPPORTING INFRASTRUCTURE

- ***Connecting Roadways* –** The state's policy relative to constructing and maintaining connecting roadways requires examination prior to facility location.
- ***Physical Location in North Texas* –** The needs of communities in North Texas relative to the traffic generating potential of a freight pipeline require close evaluation.

SYSTEM MANAGEMENT

- ***Designation of a Pipeline Authority* –** The form of the managing body overseeing freight pipeline operations will be a matter of policy based on the business model adopted, the economics, and the funding approach.
- ***Integration with TxDOT* –** The transportation role of the freight pipeline suggests a central role for TxDOT in the location, role, and operation of the system. The specific nature of the department's role must be carefully considered.
- ***Service Pricing* –** The pricing of the freight pipeline's transportation services depends on the funding source, the system's mission, and the level of use. The pricing policy will determine in large measure its success in inducing voluntary use.