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MASTER

TRANSPORT OF SOLID COMMODITIES VIA FREIGHT PIPELINE

COST AND LEVEL OF SERVICE COMPARISON
VOLUME I

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July 1976
FIRST YEAR FINAL REPORT
UNDER CONTRACT: DOT-OS-50119

PREPARED FOR

U.S. DEPARTMENT OF TRANSPORTATION
Office of the Secretary
Office of University Research
Washington, D.C. 20590

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16. Abstract

This report describes findings of research performed during the first year of work under Contract DOT-OS-50119 for the Office of University Research, Office of the Secretary of Transportation. The application of freight pipeline for the movement of solid goods offers a new option in the field of transportation. Thus, the purpose of the first year of research was to evaluate the technical and economic feasibility of the freight pipeline as an intercity transportation. Thus, the purpose of the first year of research was to evaluate the technical and economic feasibility of freight pipeline as intercity transportation mode.

The report for the first year consists of the following five separate volumes:

VOLUME I - Cost and Level of Service Comparison
VOLUME II - Freight Pipeline Technology
VOLUME III - Cost Estimating Methodology
VOLUME IV - Demand Analysis Methodology
VOLUME V - Impact Assessment

The second year of research currently is being devoted to sharpening the concepts, boradening the areas of concern and applying the tools of analysis developed in the first year to a specific origin-destination transportation corridor.

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PREFACE

This report describes findings of research performed during the first year of work under contract DOT-OS-50119 for the Office of University Research, Office of the Secretary of Transportation. The application of freight pipeline for the movement of solid goods offers a new option in the field of transportation. Thus, the purpose of the first year of research was to evaluate the technical and economic feasibility of freight pipeline as an intercity transportation mode.

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I.	Cost and Level of Service Comparison	I. Zandi; B. Allen; E. Morlok, K. Gimm; T. Plaut; J. Warner
II.	Freight Pipeline Technology	I. Zandi and K.K. Gimm
III.	Cost Estimating Methodology	Section A: J. Warner and E. Morlok Section B: K. K. Gimm and I. Zandi
IV.	Demand Analysis Methodology	B. Allen and T. Plaut
V.	Impact Assessment	I. Zandi and K.K. Gimm

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The authors wish to acknowledge gratefully the assistance given by Mr. David C. Ryan Jr. of the Office of R & D Policy, Office of the Secretary of Transportation. His numerous technical and editorial suggestions have been of great help to us.

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Iraj Zandi
Principal Investigator

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Volume I

Cost and Level of Service Comparison

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Cost and Level of Service Comparison

Executive Summary

I. - GOALS OF THE RESEARCH

- To evaluate the potential and limitations of "freight pipeline" as a viable mode of cargo transport.
- Specifically, to explore the feasibility of the "freight pipeline" as an effective mode of transporting commodities over long distances.

II. - WHAT IS A FREIGHT PIPELINE?

- A freight pipeline is defined as a pipeline whose main purpose is to convey agricultural, mining, or industrial products which are in solid form*

III. - HOW DOES THE FREIGHT PIPELINE WORK?

- Generally, a pipeline is a transportation system where loads are moved totally enclosed by their guideway and where motive power is applied via a moving fluid. The fluid (gas or liquid) is employed to entrap, fluidize, and convey solid cargo through the pipeline.

IV. - THERE ARE SEVERAL GENERIC TYPES OF FREIGHT PIPELINE SYSTEMS

- Slurry Pipeline - In this system, the conveying fluid is normally water, but occasionally oil or other liquids. The freight is in bulk** form and is mixed with the conveying liquid. This system can obviously be used only if the conveying liquid enhances or at least does not destroy the properties of the freight.
- Pneumatic Pipeline - In this system, the conveying fluid normally is air. In some applications, to eliminate the possibility of explosion, an inert gas may be used. Freight is in bulk form and may be of uniform size or have a wide particle size distribution.
- Capsule Pipeline - The conveying fluid in this system may be either a liquid or a gas. The size of the freight mass approaches nearly the diameter of the pipe or, if individual particles are small, they are aggregated to form capsules.

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* "Solid form" implies that freight to be moved is in the solid state. It may be powdered, granulated, sintered, manufactured, packaged, etc.

** "Bulk implies an aggregate that is impressively large, heavy, or numerous", such as grain, coal, mineral ores, etc.

If the conveying fluid is water, the pipeline may be called HYDRO-CAPSULE*; if it is a gas, it may be called PNEUMO-CAPSULE* . It is possible to connect a number of capsules to form a train of capsules. The result will be either a PNEUMO-CAPSULE TRAIN or a HYDRO-CAPSULE TRAIN.

- Each of these generic pipeline systems has distinct characteristics and different potential for commercial application. Together, these systems provide a wide spectrum of technological capabilities allowing almost all materials of suitable dimensions and transport characteristics to be transported via freight pipeline.

V. - WHY FREIGHT PIPELINE?

- A generic freight pipeline system has many features which are attractive from an environmental point of view. Among these features are:

Traffic reduction
Air pollution reduction
Noise reduction
Accident reduction
Less land disturbance (than other modes)
Energy consumption reduction (under proper circumstances)
Lower susceptibility to cost inflation
Potential for complete origin to destination automation
Reduction of freight loss and damage

- A generic freight pipeline also has several limitations:

-Highways and railroads carry traffic other than freight. Pipeline, on the other hand, will be limited--at least in the foreseeable future--to the transport of freight which is of the proper dimensions and which does not otherwise require a special shipping environment.

-Water is usually used in both hydro-capsule pipelines and slurry pipelines as the conveying liquid. When water is scarce at the point of origin of the freight, pipeline can exacerbate the water situation. In this connection, two points need to be made: 1) If water is used, it can be employed beneficially at the destination; and, 2) Sometimes other liquids may be utilized. A very interesting possibility exists, for instance, when the freight is coal. A portion of the coal may be liquified and used to convey the other portion of the coal in slurry form.

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* Some professionals in the field of freight pipeline prefer to use "hydraulic capsule pipeline" instead of "hydro-capsule pipeline" and "pneumatic capsule pipeline" instead of "pneumo-capsule pipeline". An ad hoc committee was formed during the International Symposium on Freight Pipeline which was held in December, 1976, in Washington, D.C., to prepare a recommendation regarding this controversy.

-Freight pipeline may, in some cases, compete with both truck and rail for market shares. Some railroads are particularly dependent on bulk materials such as coal for their revenue. A competing freight pipeline would endanger this revenue and would exacerbate the financial plight of these railroads. However, for freight transportation companies that could choose least cost modal solutions, such a pipeline would be viewed as a way of increasing revenues.

- Freight pipeline is not expected to become the sole mode of freight transport. Whenever it comes into use in the future, it will be in combination with other modes of transport as part of an optimum transportation system.

VI. - METHODOLOGY OF RESEARCH

- In evaluating the feasibility and viability of freight pipeline as a mode of transport, answers to the following questions were sought:

  1 - Is freight pipeline a technologically feasible* transportation mode?

  2 - If technologically feasible, how do its economics compare with those of truck and rail?

  3 - How would freight pipeline service be accepted by shippers?

  4 - What would be the environmental consequences of utilizing freight pipeline?

- The technological feasibility question was answered based on a comprehensive literature review (see Volume II).

- Economic viability was explored by first developing cost and performance models for freight pipeline, truck and rail. These models were used in parametric comparison of freight transport systems. These quantitative comparisons were based on dollar cost of providing service. Other characteristics were discussed qualitatively (see Volumes I, III, and V, respectively).

- The potential demand for freight pipeline was investigated by forming an origin-destination matrix of annual freight flows of products "eligible" (physically) for pipeline. Macro demand models based on these flows were then derived to explain, on an aggregate level, existing modal choice (between truck and rail) for several commodities. Micro demand models were also developed to further investigate modal choice decisions of several specific shippers of pipeline eligible commodities. These micro models used transport rate, transit time, and transit time reliability as explanatory variables, as did the macro models. Potential penetra-

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* For purposes of this report, technological feasibility implies that the current state of the art is determined to be sufficient to produce full scale operational systems, equipment and hardware.

tion of the pneumo-capsule pipeline into an intercity freight transport market was then estimated for several commodity classes by using these models of shippers' past mode choice behavior to evaluate quantitatively their future reaction to a new system having cost and service characteristics of a freight pipeline (see Volume IV).

- A comparison of freight movement economics for pipeline, truck, and rail was made in the framework of the following assumed conditions (see Volumes I and III):

  1 - Cost was calculated differently for pipeline than for truck and rail. The cost of freight pipeline was taken to mean the total cost* of moving any given volume via the pipeline, whereas the cost for truck and rail referred to the marginal cost. This assumption implied that truck and rail facilities already existed, while the pipeline had yet to be constructed.

  2 - The freight was assumed to move between two hypothetical urban centers which might be connected by rail, truck, TOFC or freight pipeline. The distance between two cities was taken as 100, 300, 500, or 700 miles.

  3 - Both shipper and consignee were assumed to be located on rail sidings. No local freight or access costs were added to the rail costs.

  4 - For freight pipeline, three alternative access arrangements were assumed: First, 100 percent truck delivery; second, 50 percent truck delivery and 50 percent urban freight pipeline; and third, 100 percent urban freight pipeline. In any case, full access cost has been included.

  5 - For truck and TOFC the access was assumed to be an integral part of the line haul system. No local freight or access costs were added to truck and TOFC costs.

  6 - Shipment size** was assumed to have a negligible effect on pipeline line-haul cost. Instead, it was assumed that shipments smaller than full capsule size would be consolidated; and shipments larger than capsule-size would be divided among several capsules. Estimates of pipeline terminal cost were adjusted upward to reflect this assumption.

- Environmental questions arising from substitution of freight pipeline for either truck or rail were explored semi-quantitatively through literature review (see Volume V).

- Figure E-1 shows the tasks performed in the course of this research.

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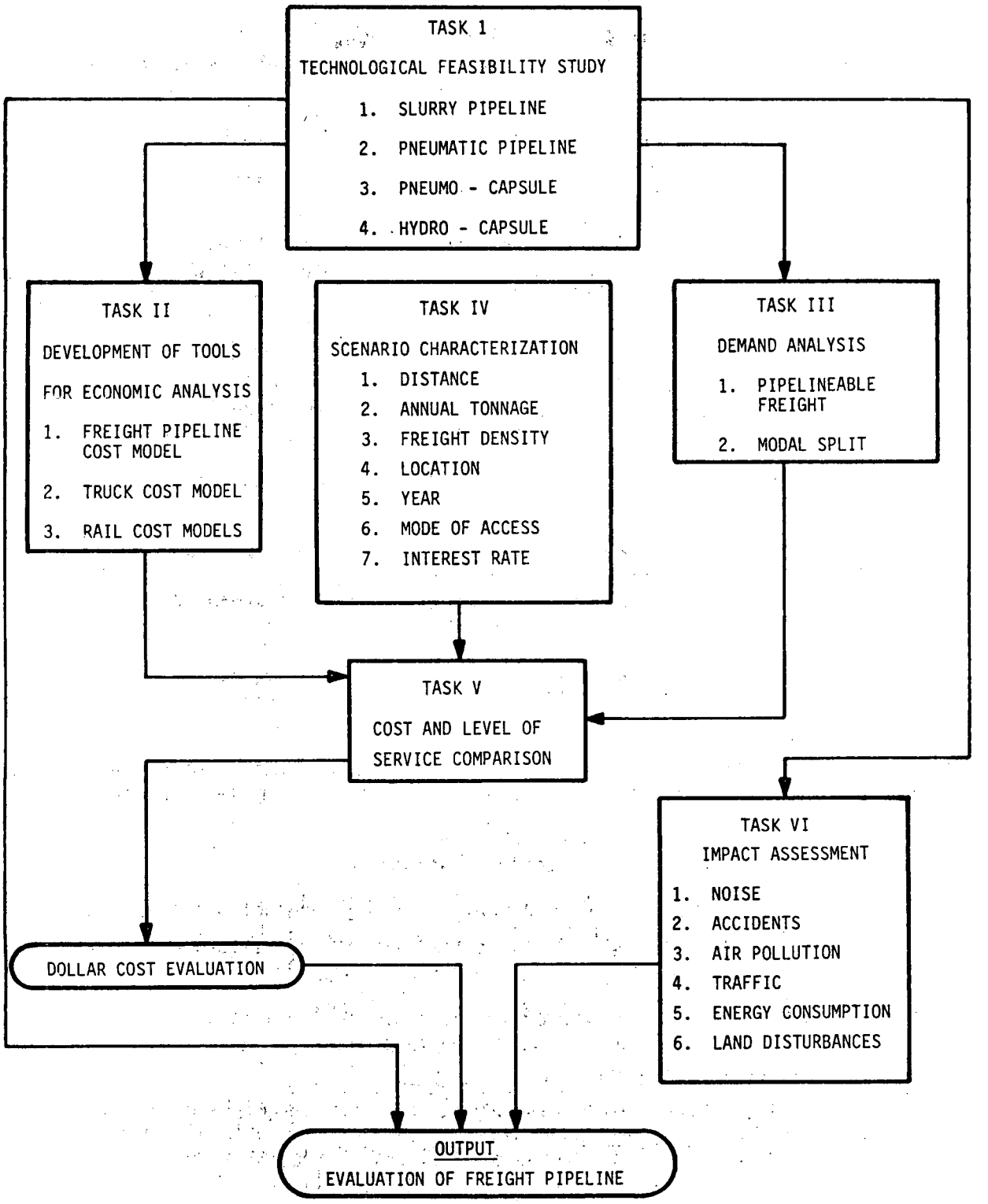
* For purposes of this study, total cost, when referring to freight pipeline, was assumed to include: capital, operating and maintenance costs of the pipeline system including access, terminals, capsules, and accessories.

** "Shipment size" is interpreted herein to mean the weight or the volume of an individual shipment from a shipper to a consignee.

Figure E-1 - Research Tasks



VII - FINDINGS

● Examination of information available on the state-of-the-technology of freight pipeline reveals that (see Volume II):

1 - Slurry pipeline is technologically feasible. Many successful commercial installations around the globe have demonstrated the service reliability of this mode of transport. Commodities such as coal, iron ore, copper concentrate, cement and many others are already being conveyed via pipeline over distances up to 300 miles. Longer pipelines are being constructed or planned.

2 - Pneumatic pipeline has had a long history of successful use. Until recently, commercial use has been limited to short (less than a mile), in-plant lines. However, pipelines of longer distances (several miles) are gradually being considered and built. Technologically, no limit to pipeline length exists. Materials such as grains, cereals, minerals, and solid waste have been transported via pneumatic pipeline.

3 - Pneumo-capsule pipeline has been utilized in many cities for delivery of mail. It has also been used in department stores. In recent years more ambitious applications have been attempted. Conveyance of coal, gravel, and industrial supplies has been practiced. Extension of its use to the conveyance of manufactured products seems to be a matter of course. No technological impediments for this application are envisioned.

4 - Hydro-capsule pipeline has been found to be a technologically feasible system. However, since no commercial installations yet exist, its reliability under service conditions is yet untested. No conceptual technological road-blocks are foreseen. Its adaptation to commercial use requires knowledge which can only be gained through a full scale demonstration of service capabilities.

● Analysis of existing flows shows that, for a specific transportation corridor (Chicago-New York), a potentially large flow of pipeline eligible products maybe available. For example, on the link of a hypothetical pipeline network connecting Johnstown, Pa. and Harrisburg, Pa., a total (both eastbound and westbound) of 25.7 million tons of pipeline eligible products (exclusive of coal, ores, and oil) was moved in 1971. Of the 18 cities on the Chicago-New York hypothetical network, (if off-network city origins and destinations are included) the Harrisburg to Philadelphia link experienced total flows (both directions) of 50.8 million tons of pipeline eligible products in 1971. The modal split analysis showed that the pipeline could capture as much as 30 percent of this tonnage (see Volume IV).

● Figures E-2 and E-3 show ton-mile cost estimated for rail, truck, TOFC, and pneumo-capsule pipeline for line-haul distances of 100 and 700 miles. These figures and similar ones for line-haul distances of 300 and 500 miles (not included in the report) show that freight pipeline is cost competitive with other modes of transport over a wide range of variables (see Volumes I and III).

● In particular, two important conclusions can be made:

A - When annual tonnage was high (25 MM ton/year) and the shipment size was

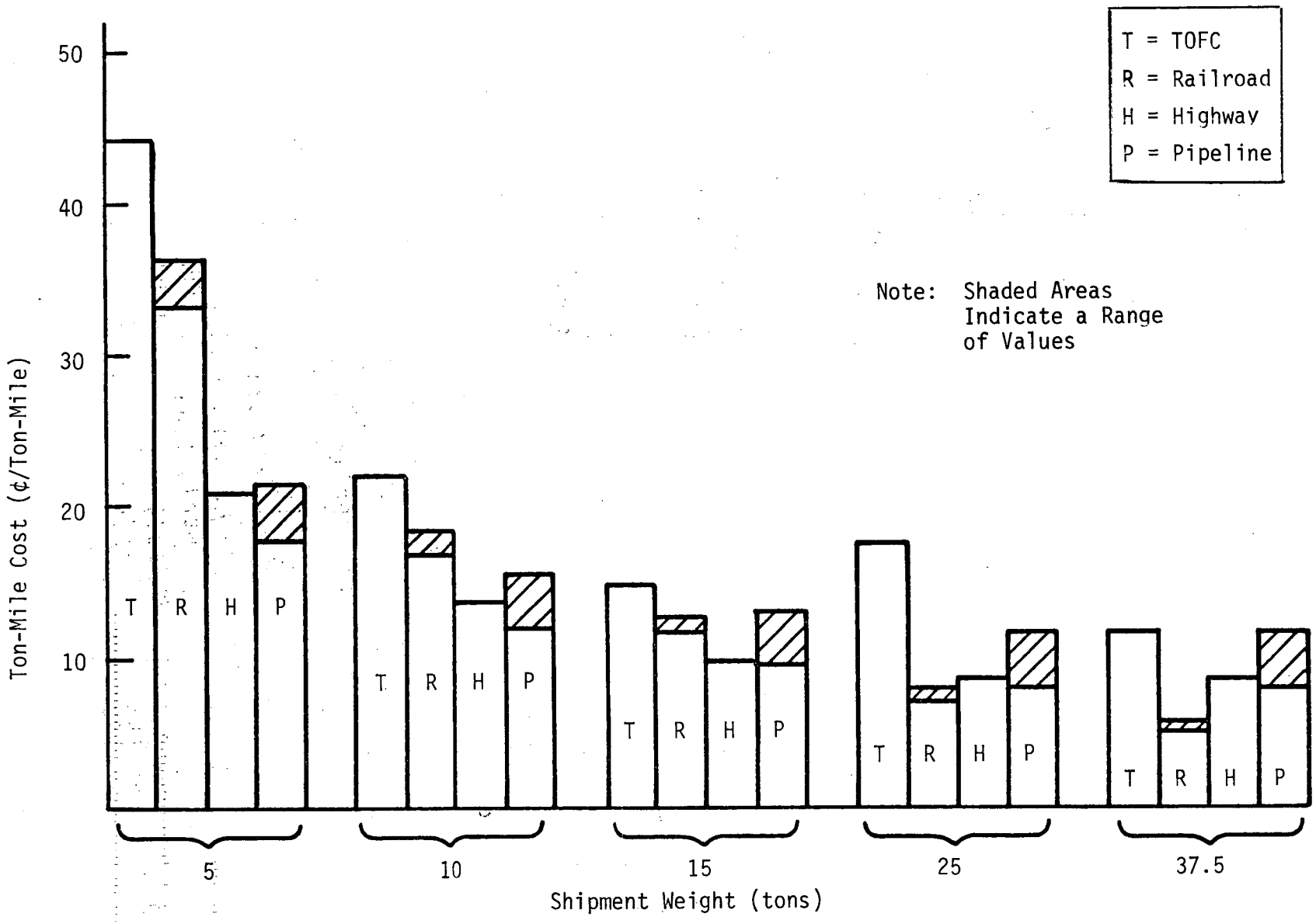


Figure E-2. Ton-Mile Cost at Several Shipment Weights, 100 Miles Distance, 20 lbs. per Cubic Foot Density

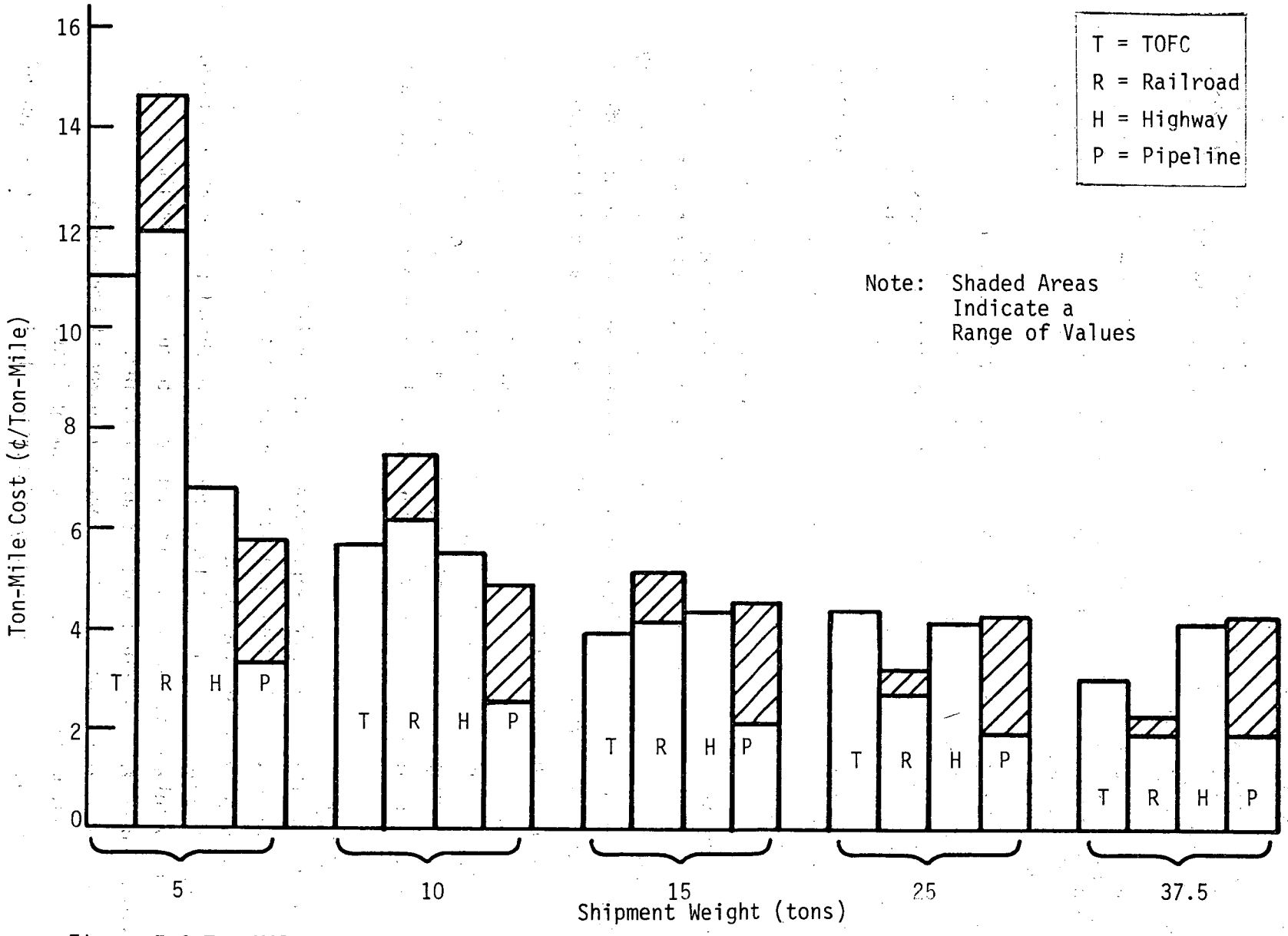


Figure E-3. Ton Mile Cost at Several Shipment Weights, 700 Miles Distance, 20 lbs per Cubic Foot Density

small (5 tons), freight pipeline was cost-wise attractive as compared with other transportation modes for all line-haul distances examined (in the range of 100 to 700 miles). See Figure E-4, where ton-mile cost is plotted as a function of line-haul distance for various modes and a small shipment weight (5 tons). Figure E-5 shows that, even when shipment size was large (35 tons), freight pipeline was still cost competitive, particularly for line-haul distances of over 300 miles.

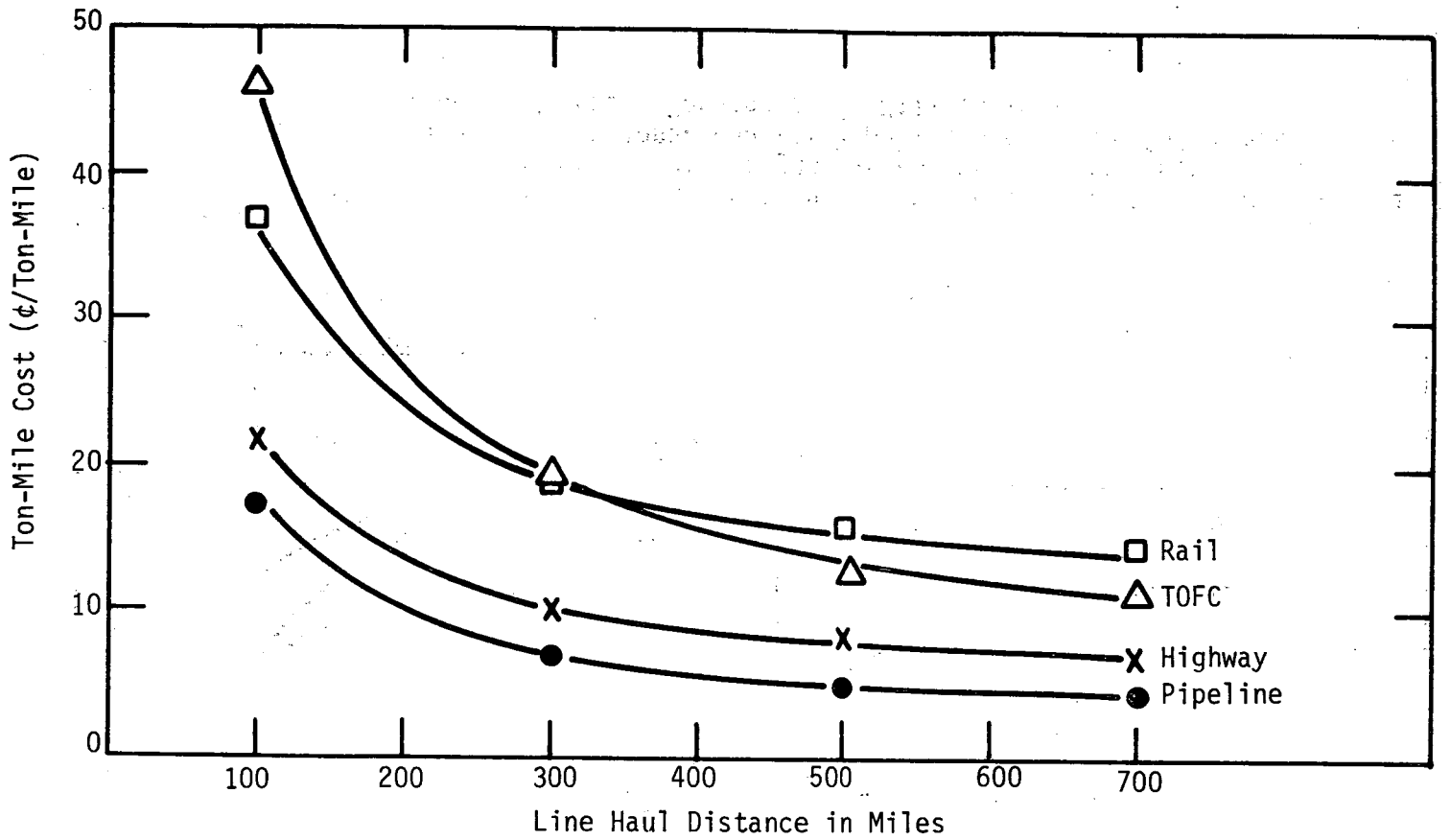
B - When the shipment weight is small (less than 10 tons) trucks are less costly than rail and TOFC (see Volume I). However, the ton-mile cost of freight pipeline was found to be almost identical with truck for all of the line-haul distances (100 to 700 miles) examined even for small annual tonnage (1 MM tons/year). See Figure E-6.

- A large proportion of freight pipeline ton-mile cost for short and medium distances (up to 200 or 300 miles) was due to the access cost. Figure E-7 shows the ton-mile cost variation as a function of annual tonnage for three access assumptions, and a line-haul transport of 200 miles. 100 percent access by truck is noticeably costlier than 100 percent access by urban feeder freight pipeline over a wide range of annual tonnages up to 15 million tons per year, although the superiority is less pronounced as shipment weight increases.
- Because of the methodology of cost estimation, it was not feasible to evaluate the range of variation of cost for truck and rail from their average values given. However, estimation of the range of variation in the ton-mile cost estimate for freight pipeline was possible. Figure E-8 shows the range of ton-mile cost that may be expected under both optimistic (favorable to pipeline) and pessimistic (unfavorable to pipeline) assumptions. It is interesting to note that, as the line-haul distance increases, the estimation range narrows.
- Freight pipeline offers several advantages in terms of environmental impact (see Volume V). Because of the lack of data, it was not possible to quantify these impacts to a high degree. However, sufficient information was developed to support the conclusion that pipeline potentially offers several environmentally significant benefits.

VIII - CONCLUSIONS

- Based on experimental data and experience with commercial installations around the world, it can be concluded that most varieties of freight pipeline are technologically feasible modes of transport.
- Based on preliminary economic analysis performed in this first year's research, pneumo-capsule pipelines appear to have the potential to compete successfully with other freight modes when certain conditions are satisfied.
- In addition, freight pipelines offer many environmental advantages.
- These conclusions are qualified by the following facts:

  1 - The economic analysis was based on historical (1973) costs. The effect of



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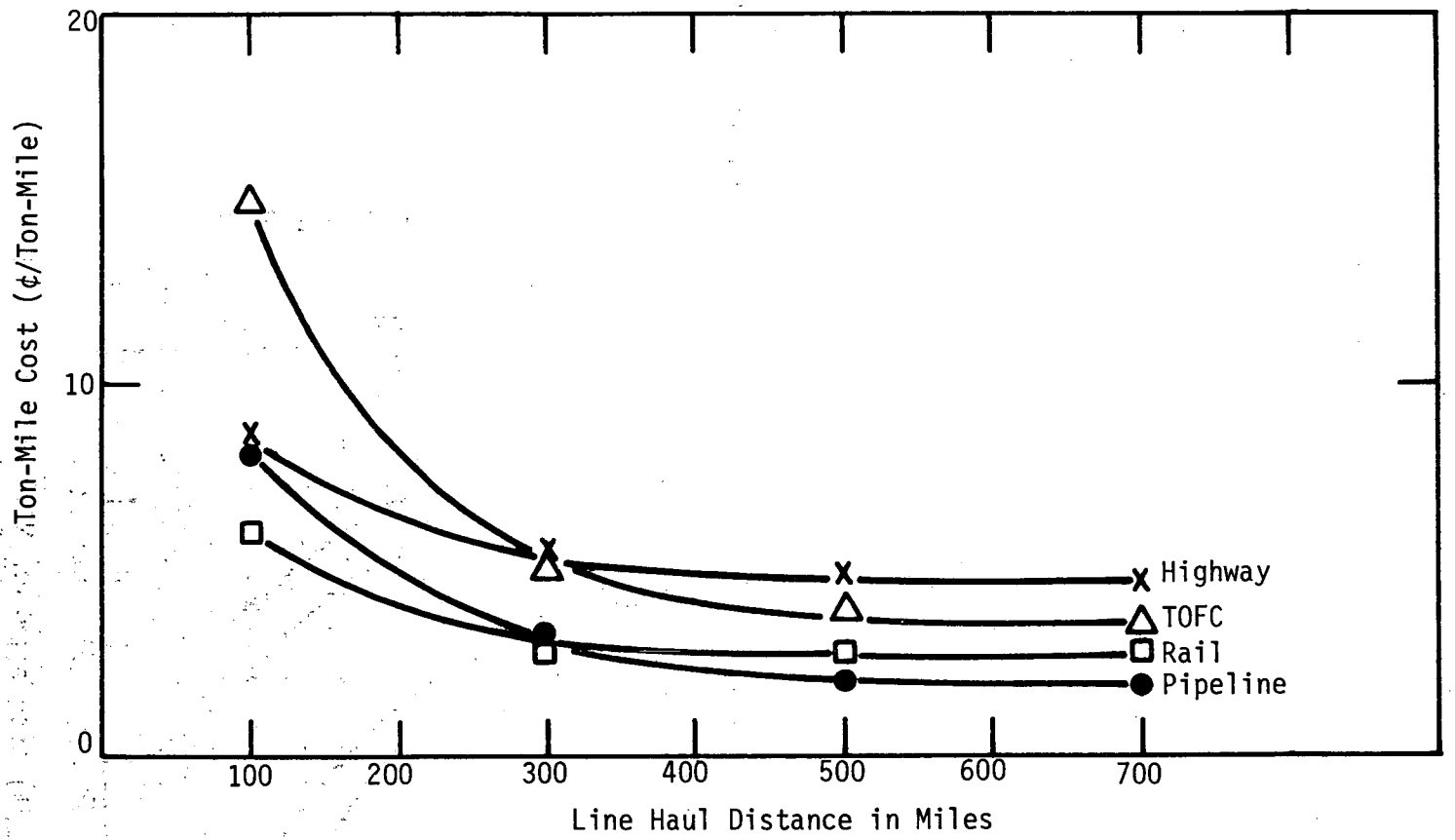

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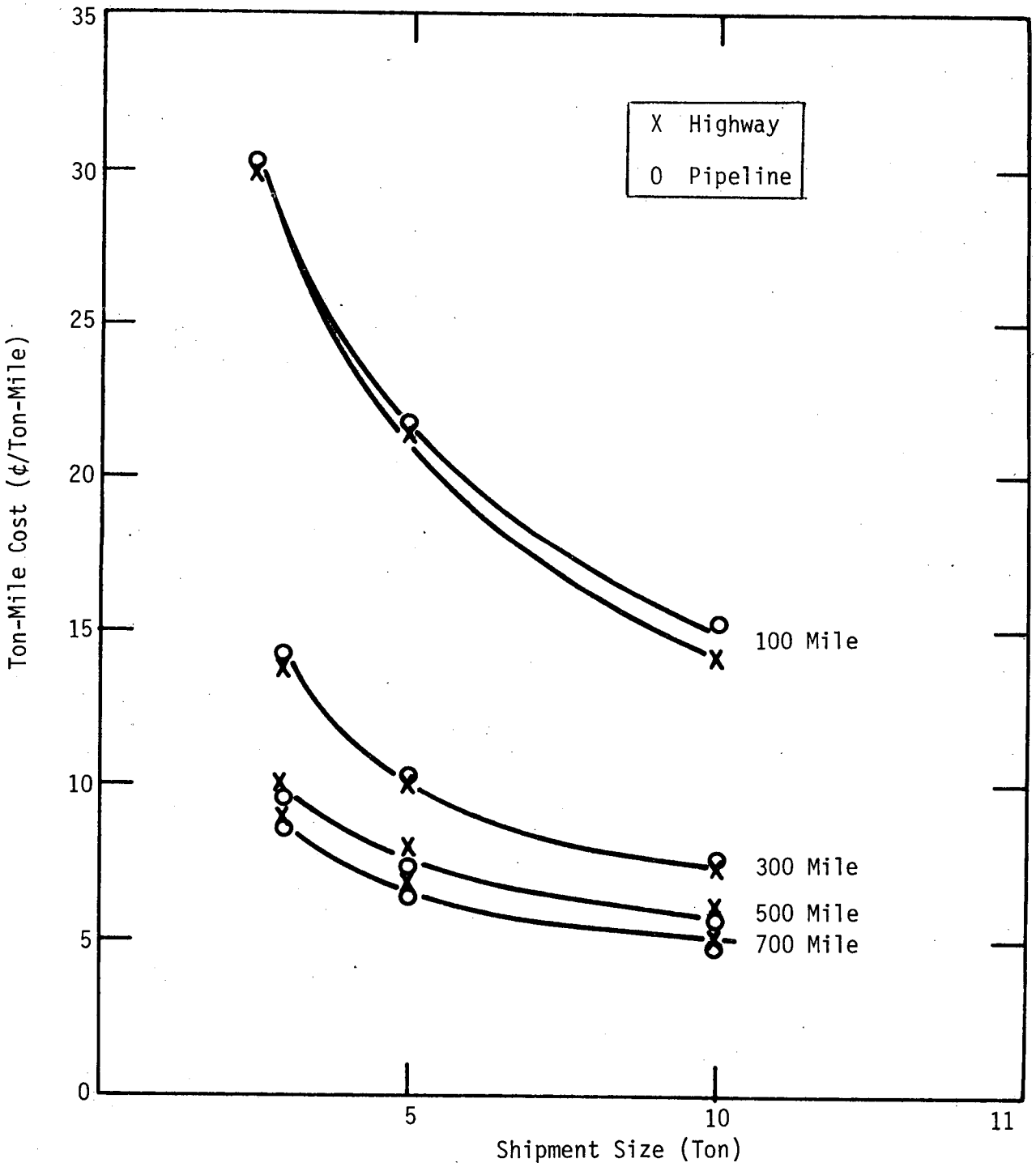
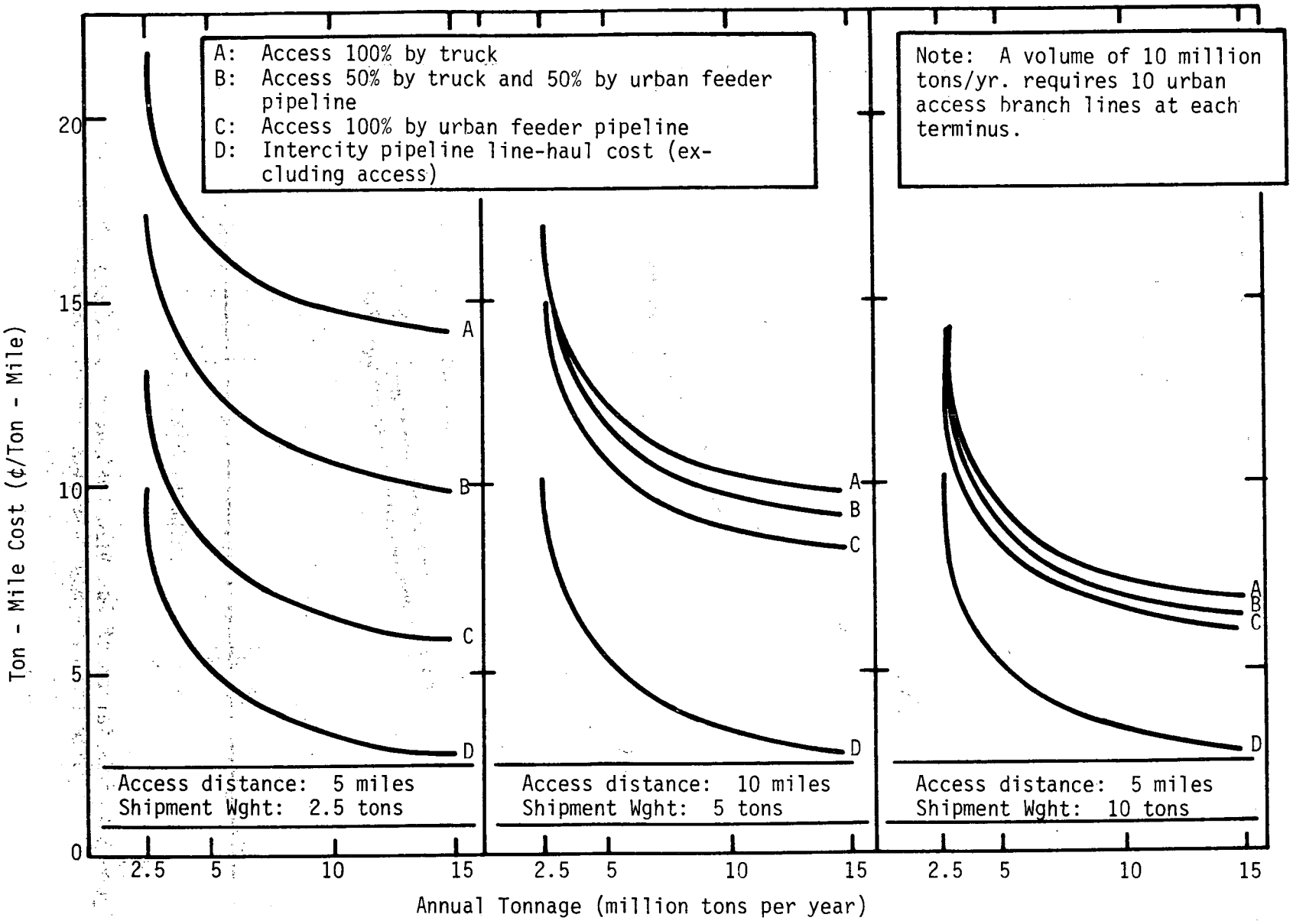


Figure E-6. Variation of Ton-Mile Cost as a Function of Shipment Size and Line Haul Distance for Highways and Freight Pipeline, 1 MM Ton/Year Capacity, for Freight Pipeline 100 Percent Truck Access.



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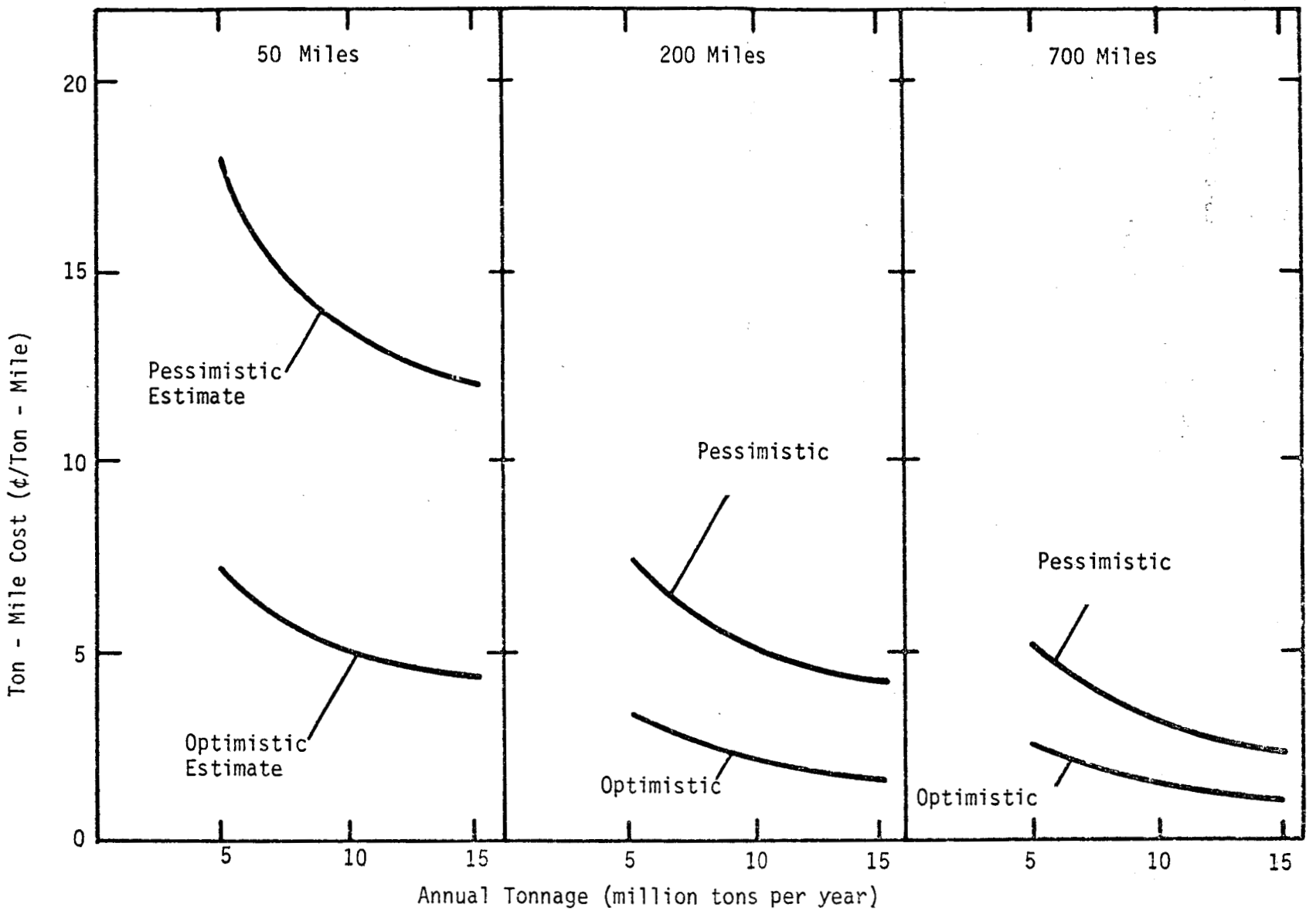


Figure E-8. Pneumo-capsule Pipeline Line-Haul Ton-Mile Cost as a Function of Annual Tonnage for Two Sets of Parameter Values and Three Distances

time on the costs of each system may vary. For example, it has been shown that pipeline costs (historically) have risen at a rate lower than that of general inflation, due to their high ratio of fixed to variable costs.

2 - Government policy may also have significant impact on the costs of each system. Recent developments such as the restructuring of a large segment of the rail industry, proposals to change substantially government regulatory policy, and the proposals to impose user charges on the nation's waterways would affect the future costs of each system.

3 - The rail, TOFC, and highway freight systems with which pipeline was compared were not an exhaustive set of all potential competing systems. For example, the first year analysis excluded private, contract, and unregulated trucking; certain rail operations such as unit trains (except as they are part of the "average costs" based on all rail operations); and specialized operations such as freight forwarders, air freight, and small package services.

4 - Costs of truck and rail were based on data gathered in the northeast and midwest areas of the country. A cursory review of truck and rail ton-mile costs for other areas indicates that there is considerable geographic variation. Caution is therefore required in any generalization of these results.

5 - The total flow of eligible products was based on 1970 data. The macro demand models were based on 1972 and 1967 data. Flows have grown historically and modal shares have changed over time.

COST AND LEVEL OF SERVICE COMPARISON

Introduction

The Department of Transportation, through contract no. DOT OS-50119 provided support for a feasibility study to evaluate the potential and limitations of the "freight pipeline" as a viable mode of cargo transport. The program of research had two particular objectives: 1) to explore the feasibility and viability of the "freight pipeline" as an effective mode of transporting solid commodities over long distances; and 2) if the conclusion of that exploration was positive, to develop the data and methodology to evaluate further the issues surrounding freight pipeline. This is the final report of the first year of study. (June 1, 1975 - May 30, 1976)

Definition

A freight pipeline is defined as a pipeline whose main purpose is to convey agricultural, mining, or industrial products. The conveyance of fluids (oil, water and gases) via pipeline is an established industry and will not be discussed here. Only those products which are in solid form are of interest in this report. In freight pipeline, the energy required for the transport of a solid is conveyed to that solid via a moving fluid.

A freight pipeline system consists of seven basic components: 1) the freight, 2) the pipeline, 3) the conveying fluid, 4) the pump or the blower, 5) the inlet structures, 6) the outlet structures, and 7) auxiliary control facilities. Each one of these components may vary either in their physical characteristics or in their structural and system design. This potential for variation of components provides the opportunity for a variety of freight pipeline systems to be created. The following systems have practical industrial and commercial applications.

Slurry Pipeline - In this system, the conveying fluid is normally water, but occasionally oil or another liquid. The freight is in bulk form and is mixed with the conveying liquid. This system obviously can be used only if the conveying liquid enhances, or at least does not destroy the properties of the freight.

Pneumatic Pipeline - In this system, the conveying fluid normally is air. In some applications, to eliminate the possibility of explosion, an inert gas may be used. Freight is in bulk and may be of uniform size or have wide size distribution.

Capsule Pipeline - The conveying fluid in this system may be either a liquid or a gas. The size of the freight package is nearly the same as the diameter of

the pipe; or, if individually smaller, they are aggregated to form capsules. If the conveying fluid is water, the pipeline is called HYDRO-CAPSULE; if it is a gas it is called PNEUMO-CAPSULE. It is possible to connect a number of capsules to form a train of capsules. The result will be either a PNEUMO-CAPSULE TRAIN or a HYDRO-CAPSULE TRAIN.

Each one of these pipelines has different characteristics and potential for commercial application. Together, they provide a wide spectrum of technological capabilities allowing almost all materials having suitable properties and dimensions to be transported via pipeline.

Issues

Whether freight pipeline will be adopted as a viable means of transporting cargo depends upon satisfactory answers to the following questions:

1. Is freight pipeline a technologically feasible transportation mode?
2. If technologically feasible, how does it compare economically with existing alternative systems?
3. What are the environmental consequences of utilizing freight pipeline?
4. How would freight pipeline be accepted by shippers?
5. What social/political problems influence the utilization of freight pipeline, and in what way?

Questions 1 through 4 have been explored in detail during our study and are the subject of this report. Examination of Question # 5 will be more meaningful once it has been demonstrated whether or not freight pipeline is a viable technology, and therefore it is not addressed in the present report.

Methodology of Analysis

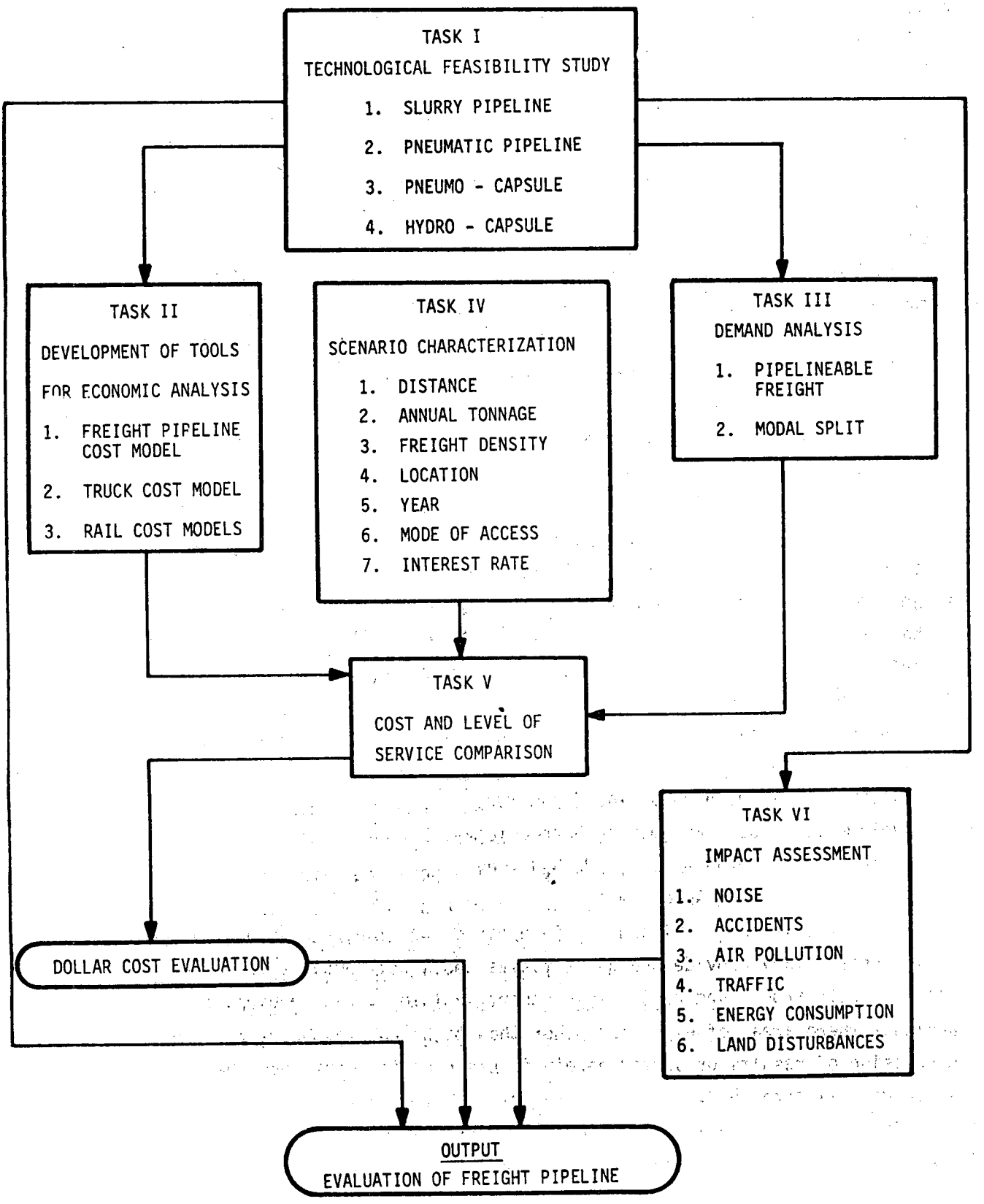
The methodology and tools of analysis are discussed in the following four volumes, submitted under separate covers:

Volume II - Freight Pipeline Technology
Volume III - Cost Estimating Methodology
Volume IV - Demand Analysis Methodology
Volume V - Impact Assessment

These volumes were written for interested individuals having technical backgrounds. They provide the quantitative tools for comparison of freight pipeline with truck and rail. This report, Volume 1, was prepared for the general audience where areas of expertise other than technical may be represented. The discussion of results presented herein is based on the work described in more detail in Volumes II through V.

Figure 1 shows various research tasks undertaken in the course of this study. These tasks are closely associated with the issues raised in Section II. Task V

Figure 1. Research Tasks



is a synthesis of the information obtained as a result of tasks I, II, III, and IV, which were designed to provide data necessary for a parametric cost comparison of various modes of transport.

Volumes II through V discuss in detail tasks I through IV, respectively. The present volume (I) describes task V: the cost and level of service comparison. This comparison was made only for pneumo-capsule pipeline because this type of pipeline has been determined to be both technologically feasible and operationally reliable (see Volume II). The comparison will be extended to other freight pipelines during the subsequent years of study.

Cost Comparison

The purpose of this section is to compare cost and level of service characteristics of the pneumo-capsule pipeline with rail carload, truck, and trailer-on-flat-car (TOFC). The comparison might have included other carriers, such as air-freight and water carriers, but this was not done since these carriers serve rather specialized segments of the merchandise traffic market. Freight forwarders and small package services (e.g., United Parcel Service) will be addressed, if necessary, in subsequent years of this study. The focus is on the direct dollar cost* to carriers of providing freight carriage via each mode, as distinct from the price or rate charged to shippers. Rates obviously bear a relationship to cost, but the relationship is subject to wide variation due to the effects of market conditions and regulations.

1 - Approach

There are two major problems inherent in comparing a pneumo-capsule pipeline with other modes of freight transport. First, the basis for estimating costs of pipeline must differ somewhat from that used to estimate costs of rail and truck. The reason is that the few commercial pneumo-capsule pipelines that now exist are in Europe and not in U.S.; therefore, U.S. historical data for them is practically non-existent, while there is a relatively greater amount of historical data available for railroad and truck. In view of this, pneumo-capsule pipeline costs were estimated based on analysis of components, where relevant experience with similar components found elsewhere (such as in liquid or gas pipelines; or, terminals of other carriers) could be synthesized. This implied a need for considerable engineering judgement to be exercised. In contrast, costs for any existing mode (including various forms of rail and truck service) were estimated on the basis of actual experience.

The second problem is that of selecting a relevant measure of cost in order

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* No consideration was given to externalities. A semi-quantitative treatment of environmental and other impacts is presented in Volume V.

that a meaningful comparison may be made. For any mode, the measure of cost used might be, for example, the total cost* incurred in moving a given volume of freight between two points; or, it might be only the marginal or additional cost* of moving an additional amount of freight. In North America, because systems for the movement of freight via both railroad and truck are virtually ubiquitous, it is most natural to think in terms of the additional costs of moving an additional amount of freight via these modes (or conversely, the savings resulting from reducing the amount of existing traffic). However, since no commercial pneumo-capsule pipelines yet exist in the U.S., to move any freight at all by this mode would require initial investment (fixed cost), as well as incurring variable costs associated with movement of any given volume of freight. Thus, one might compare the cost of moving that same additional unit of freight while pipeline cost includes fixed costs and rail/truck cost excludes fixed costs. This was the assumption made in the present study.

This assumption places pipeline at a disadvantage, since more components of cost are included in computing its unit costs. However, this assumption is regarded to be most appropriate in comparing pipeline to existing modes for most markets in North America. This assumption would not be appropriate in situations where the pipeline already exists or where railroads and highways do not. In the first case, the additional cost of moving merchandise traffic should not include the initial capital cost of the pipeline (since it already exists); and in the second case rail and truck cost should include the initial capital cost (since no prior infrastructure exists). Also, the estimated cost for rail or truck movement would not be applicable to situations where the increase in freight traffic is so great that an extraordinary expense (such as for an additional track for a rail line) would be required.

2 - Major Assumptions

In comparing the costs of moving various amounts of freight via rail, truck, TOFC, and pipeline, it was necessary to specify certain performance parameters for each type of movement. In this analysis, parameters were varied so as to represent the range of conditions under which a pneumo-capsule pipeline might be economically operated in actual practice. For ease of analysis and discussion, freight is assumed to move between two hypothetical urban centers which might be connected by either rail, truck, TOFC and/or pneumo-capsule pipeline. In estimating the marginal cost of moving traffic via truck, rail, or TOFC, using the models developed in

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* Total cost is composed of capital, operation, and maintenance costs while marginal cost includes only those variable costs which are incurred in freight service.

Volume III, the following parameters of the movement were specified: distance between the centers (via the particular mode involved), shipment weight, and commodity density.

Also, for pneumo-capsule pipeline, the means of access of shipments to and from a major line-haul mode was specified. In the case of rail carload movement, it was assumed that the shipper and consignee were both on rail sidings. Hence, the rail system included collection/distribution in the form of a local freight train. Almost all carload traffic now carried by railroads originates and terminates in such a manner. This assumption means that, in cases where shipper and receiver were both not on rail sidings, the true cost of shipping via the rail carload system was underestimated. Unfortunately, data which might indicate that portion of merchandise traffic included in these cases are not available. The truck cost model includes pickup and delivery service. Note that in the case of shipments which are less than a full truckload in size (as dictated by either weight or volume) a truck line consolidates shipments at a terminal in order to improve load factors for line-haul service. Similarly, in the case of TOFC service, truck access to rail line-haul (termed "drayage") is integral to the system, and therefore was included in the cost model. Collection/distribution cost for the the pipeline line-haul system was estimated for three cases: 1) complete access provided by truck with trans-shipment at the pipeline terminus; 2) complete access provided with an urban feeder pipeline system; and 3) access provided 50 percent by truck and 50 percent by feeder pipelines.

Finally, for each system, various parameters, such as the weight and volume capacity, and type of rail boxcar and TOFC trailer, and the annual tonnage via pipeline, must be specified. Table I presents a complete description of the specific freight system parameters assumed for each transportation mode.

3 - Existing Freight Systems

Estimates of rail carload costs were based on Interstate Commerce Commission (ICC) data for 1973, for Class I railroads operating in Official Territory. These data do not reflect the initial capital cost, rights of way, and other fixed costs. However, they provide a useful guide to the approximate long run marginal cost of rail movement. Because averages are used, these estimates may over or underestimate the cost of a particular movement by substantial amounts. The estimated costs were based on movement in both standard unequipped and equipped general service boxcars.

The ICC data include movement of the empty car to the shipper's siding, taking the loaded car to a classification yard, movement of the loaded car in mainline trains through intermediate classification yards (on the average, one yarding every

Table 1. Summary of Major Assumptions Made for Cost and Service Comparisons

Operating Characteristic	Assumed Values
Distance between cities in miles	
Great circle ("airline"), nominal distance	50, 100, 300, 500, 700
Pipeline (circuity 10 percent)	55, 110, 330, 550, 770
Rail (circuity 25 percent)	62, 125, 375, 625, 875
Truck (circuity 20 percent)	60, 120, 360, 600, 840
Commodity density (lbs/cubic foot)	10, 20, 30, 40
Annual tonnage via line-haul pipeline (tons/year, sum of both directions)	5 million, 15 million, 25 million
Annual tonnage via urban feeder pipeline (tons/year, one way)	0.5 million
Pipeline peaking factor (takes into account directional imbalance of traffic; and seasonal and within-day peaking)	For purposes of estimating equipment utilization, fleet size, and fixed facility size requirements: maximum demand is assumed to be twice average demand.
Terminal access to line-haul	
Pipeline, percent via urban feeder pipeline system/percent via truck	50/50; 0/100; 100/0
Rail carload	Access integral to line-haul system
Truck and TOFC	Access integral to line-haul system
Capacity (in tons and cubic feet)	
Rail boxcar, equipped	70, 4900
Rail boxcar, unequipped	70, 4900
TOFC trailer	24.5, 2550

200 miles), interline transfer from one carrier to another (at the average frequency of such transfers), placement of the loaded car at the consignee's siding, and finally, return of the emptied car to the pool of empties available for the next shipment. Also included were clerical costs, and that portion of car ownership costs determined to vary with annual tonnage.

For estimating the number of cars required, it was assumed that a typical boxcar had a weight capacity of 70 tons and a volume capacity of 4900 cubic feet. Cars of this type were recently purchased for the National Boxcar Pool by the Railbox Corporation. However, it should be noted that some other rail freight car designs have weight capacities of up to 100 tons and other designs have volume capacities of up to 7500 cubic feet.

The trailer on flat car cost estimates were similarly based on data developed by the Interstate Commerce Commission, and they contain the same basic elements and cost structure, although carload terminal operations are replaced to a great extent by the highway access to rail line-haul terminal points. For purposes of determining the weight and volume capacity of the system's units, each forty foot trailer was assumed to have a weight capacity of 24.5 tons and a volume capacity of 2550 cubic feet.

The truck cost models were also based on data developed by the Interstate Commerce Commission on the basis of the 1973 operating experience of Class I and II motor common carriers in the Eastern-Central Region, which is essentially identical to rail Official Territory. There seems to be a general consensus within industry that the ICC cost data present the truck costs rather well, particularly for the larger regulated common carriers. However, considerable evidence exists that smaller and unregulated carriers often have costs substantially below those of the regulated carriers, although the data upon which such conclusions are based are very fragmentary, and not generally available. Highway carrier costs are very sensitive to, among other characteristics, equipment utilization. In many cases, carriers have been able to reduce empty mileage to near zero, thereby significantly reducing their unit costs. Our cost models tend to overstate the costs of such a carrier, since they are based on the average experience of all carriers with regard to empty mileage and other operating characteristics.

4 - Pipeline

The pipeline cost model was developed by summing up the estimated cost of various components of a freight pipeline system. Cost relationships for these components were developed on the basis of engineering design and experience with identical (or as nearly similar as possible) components in existing freight pipelines, other transport media and technological facilities.

The cost model includes capital, operating and maintenance costs. It takes account of the major system components such as pipeline, compressor (pumping) stations, terminals, capsules, and communications facilities. It includes the operating costs such as taxes, administration, energy requirements, maintenance, and insurance. The model was developed based on existing pipeline cost data adjusted according to our best engineering judgement. Judicious selection of the model's engineering parameters allows cost estimates within acceptable limits (perhaps ± 15 percent). In the selection of values for these parameters, two estimates were made: a pessimistic one and an optimistic one*. The arithmetic means of costs based on these two sets of parameters were used in comparing the cost of pipeline with that of other modes of transportation. The parameters were varied to examine the impact of each on total pipeline cost.

Detailed development of the costs of each of the four systems is explained in Volume III.

5 - Comparison of Carrier Costs

Given the cost models described above (and detailed in Volume III) and operating assumptions summarized in Table 1, the comparison of costs of the various freight modes is straightforward. The examination of models shows that the variation of ton-mile cost with shipment weight is substantial in the case of truck, TOFC, and rail carload. On the other hand, for pipeline line-haul, ton-mile costs vary with annual tonnage and type of access. Another important parameter for all of the modes is the line-haul distance. Therefore, these were the primary characteristics upon which this analysis was focused.

A convenient format for the comparison is that of the graphs in Figures 2 through 5. These show the ton-mile costs for movement from origin to destination for each freight mode as a function of the shipment weight and shipment distance. Each graph represents ton-mile costs for a given airline distance varying from 100 through 700 miles (actual route lengths being different for each of the carriers between cities) see Table 1). Although ton-mile cost for any given shipment weight might vary by as much as 2:1 over the densities (10-40 pounds per cubic foot) we have analyzed, the relative position of the modes does not change and hence the variation is not significant to our conclusions. The ton-mile costs of each mode are illustrated, therefore, for a median density of 20 pounds per cubic foot.

The pipeline ton-mile costs are very sensitive to the annual tonnage** and to the form of access. The ton-mile costs for two annual tonnages - 5 million

* The optimistic estimate assumes that conditions are favorable to pneumo-capsule pipeline, while the pessimistic estimate assumes otherwise.

** The railroad and truck ton-mile costs do not show the dependency on the annual tonnage because the costs, as explained before and detailed in Volume III, are marginal costs.

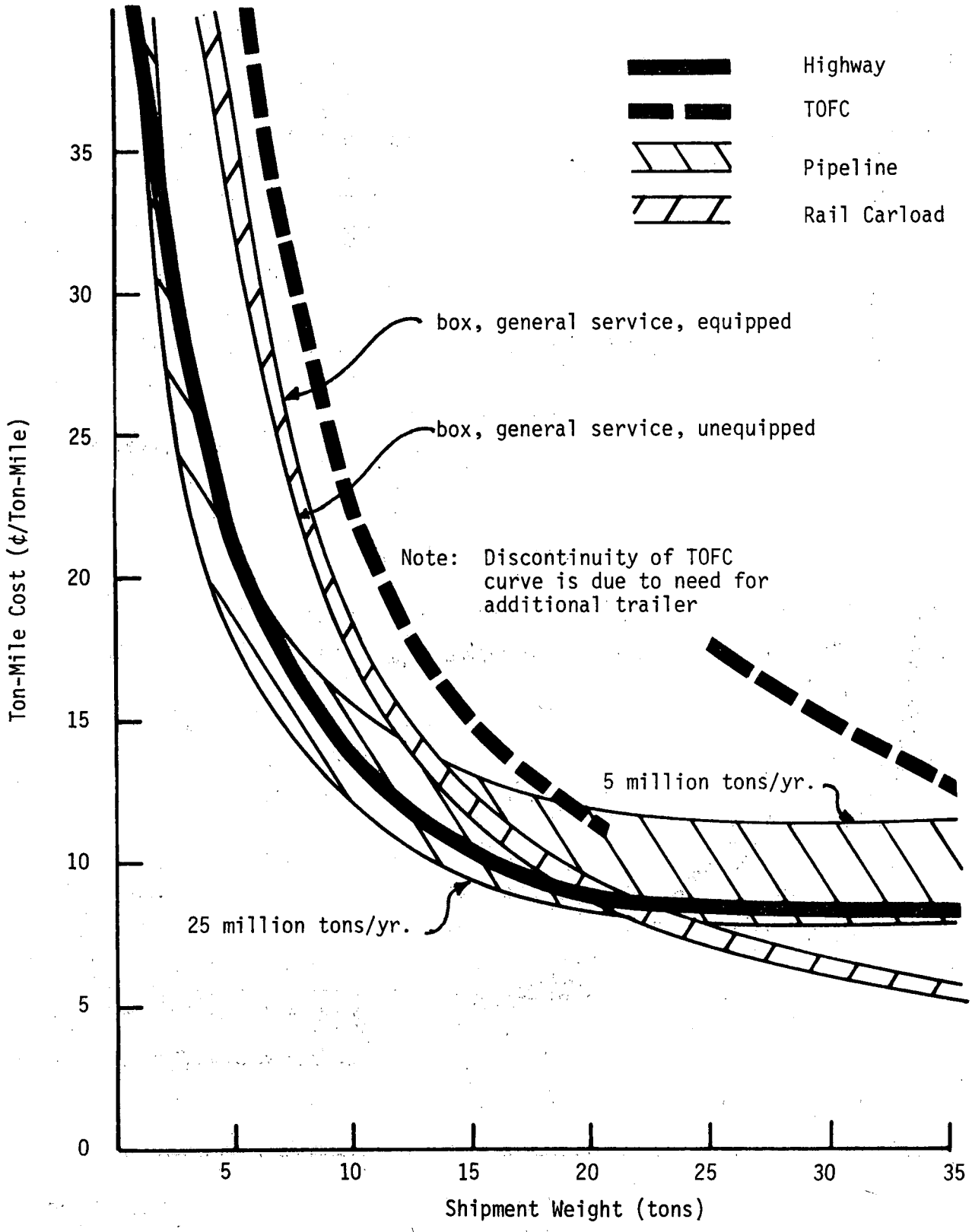

Figure 2. Ton-Mile Cost as a Function of Shipment Weight, 100 Miles Distance, 20 Lbs. per Cubic Foot Density, 100 Percent Truck Access for Pipeline

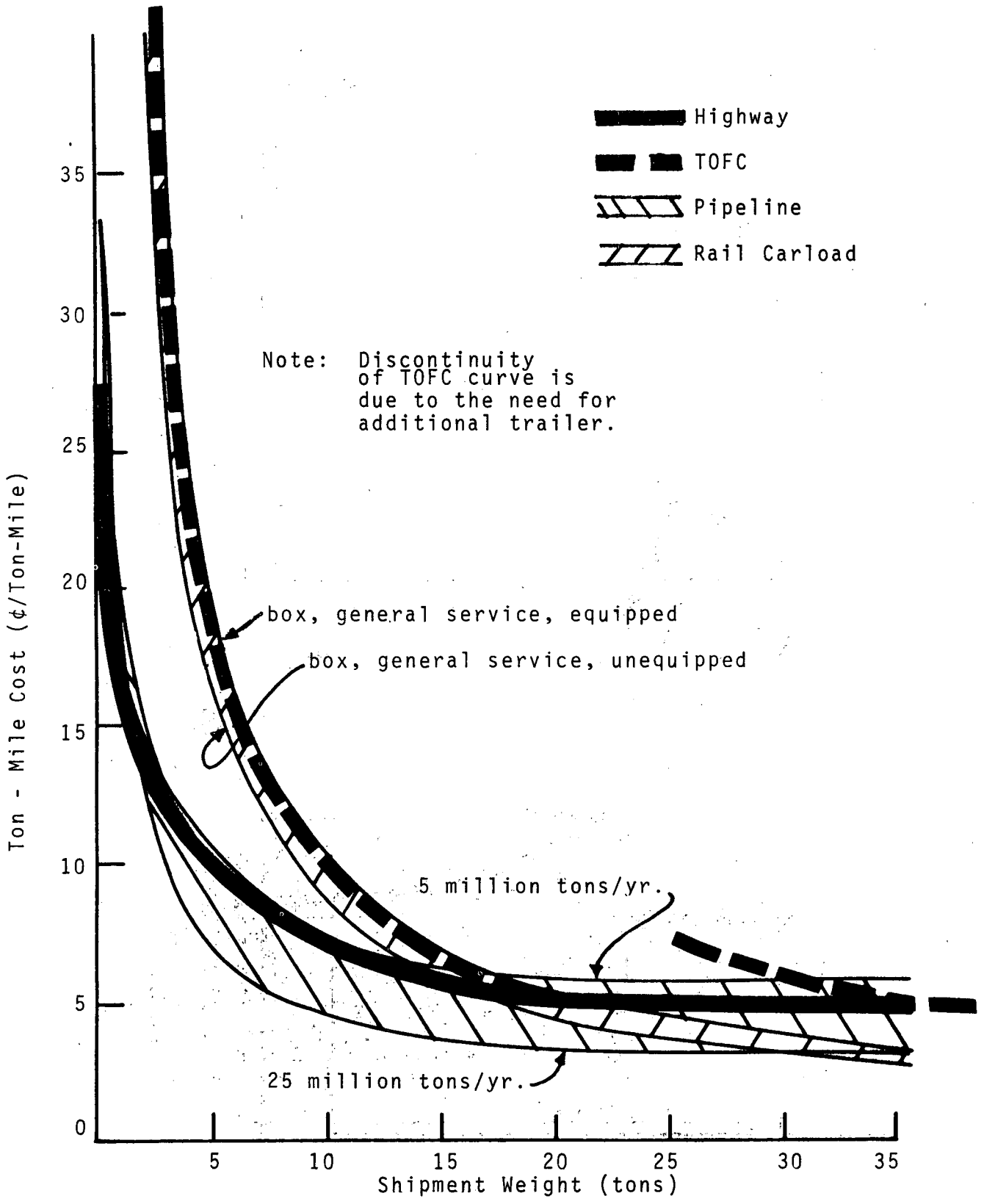

Figure 3. Ton-Mile Cost as a Function of Shipment Weight, 300 Miles Distance, 20 lbs. per Cubic Foot Density, 100 percent Truck Access for Pipeline.

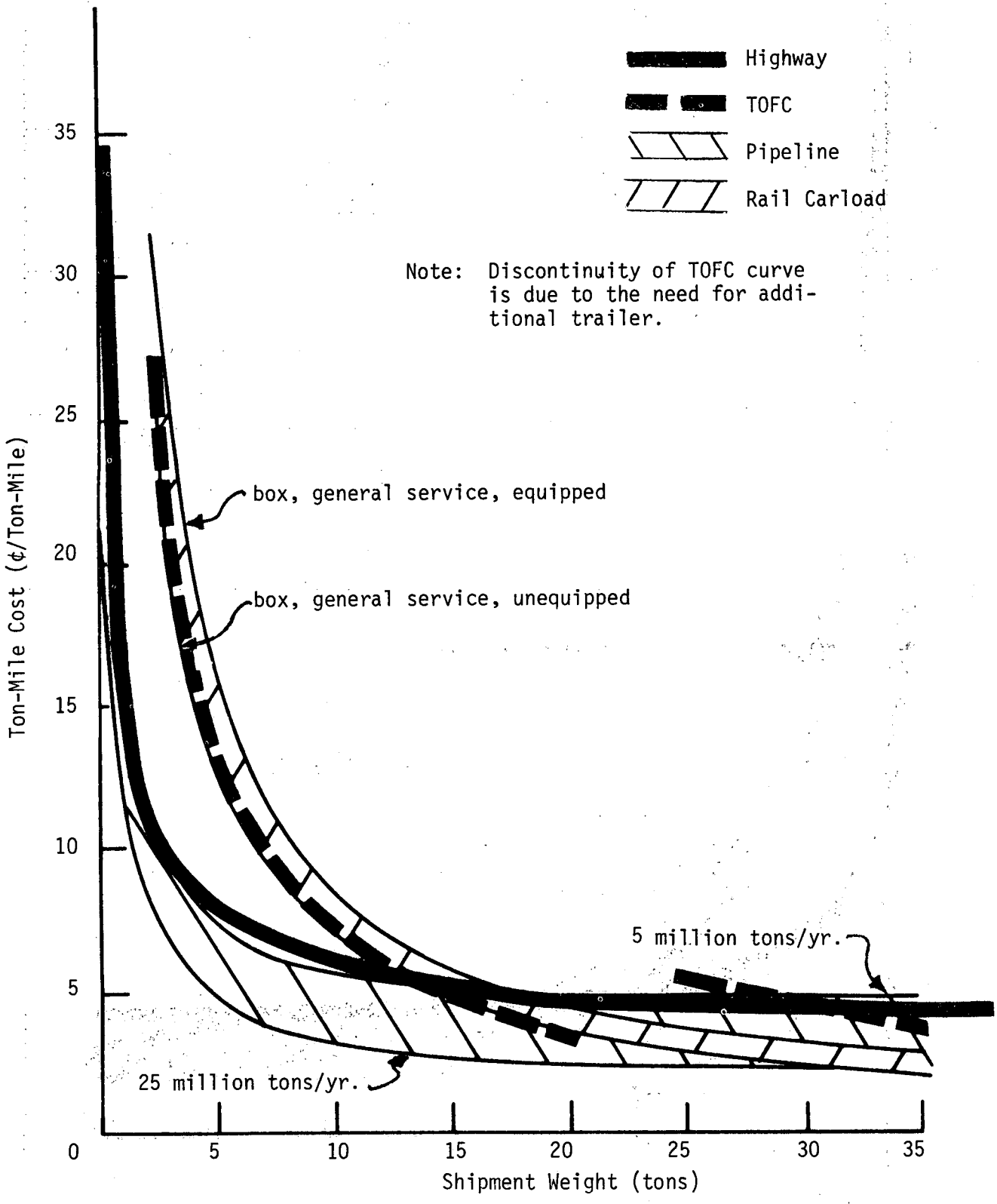

Figure 4. Ton-Mile Cost as a Function of Shipment Weight, 500 Miles Distance, 20 lbs. per Cubic Foot Density, 100 Percent Truck Access for Pipeline.

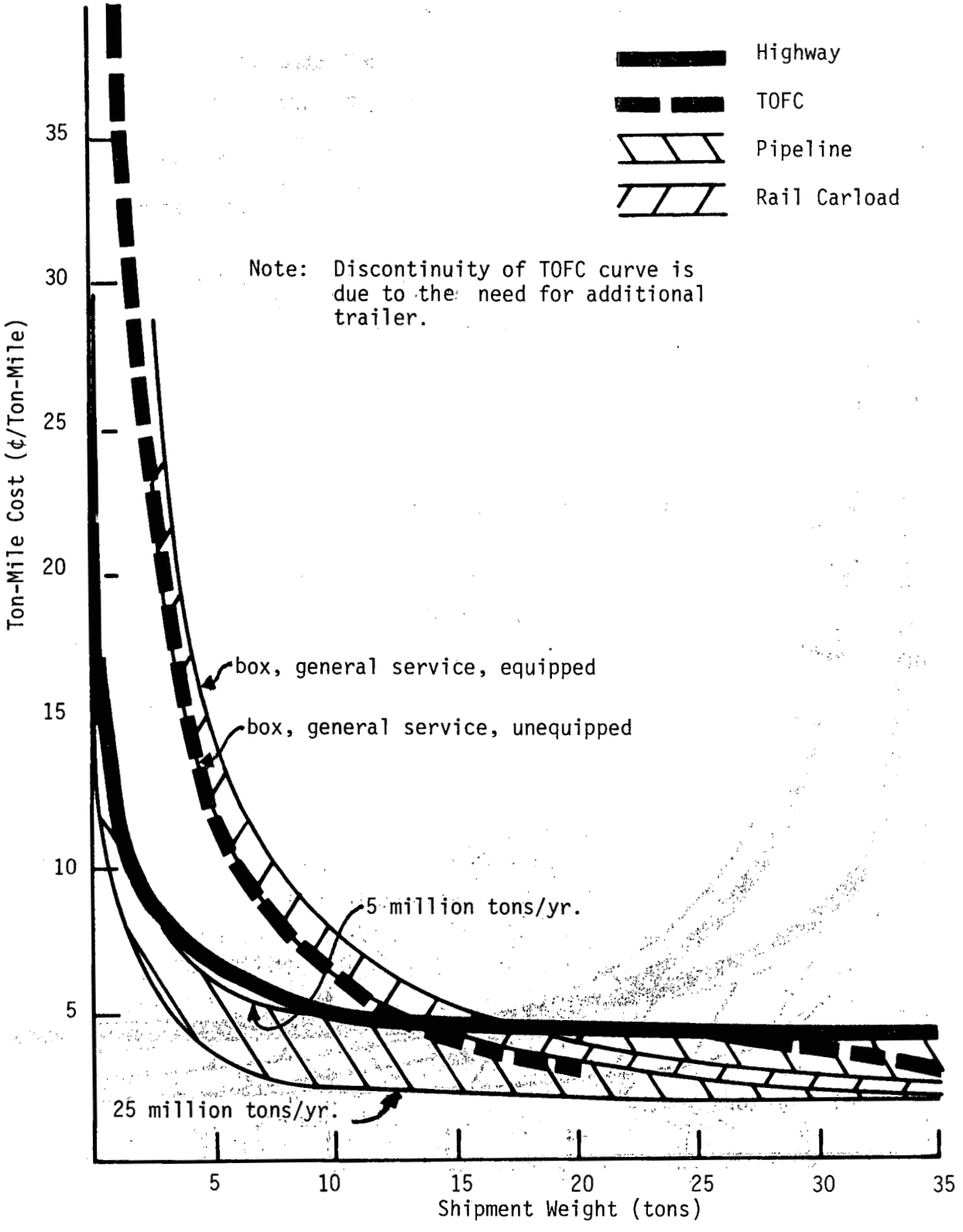

Figure 5. Ton-Mile Cost as a Function of Shipment Weight, 700 Miles Distance, 20 lbs. per Cubic Foot Density, 100 Percent Truck Access for Pipeline.

and 25 million tons per year (in both directions) - are shown in Figures 2 through 5 and exhibit a range of possible values. To put these volumes of traffic into perspective, the lower value corresponds to 200 rail cars per day, each loaded with fifty tons of freight moving in each direction for 250 days per year; the larger volume corresponds to 1000 such cars per day under the same conditions.

Rail carload system ton-mile costs are represented by a band: the upper boundary indicating the ton-mile cost of equipped and the lower of unequipped boxcars. TOFC ton-mile costs are discontinuous. When the shipment weight exceeds about 400 to 500 hundredweight (for the density of 20 pounds per cubic foot) a second trailer is required to carry the shipments*.

The ton-mile cost comparison of pneumo-capsule pipeline with truck, rail, and TOFC indicates that there are two (not necessarily mutually exclusive) transportation situations under which pipeline is cost competitive with other modes: 1) when the annual tonnage is high (25 million tons per year, see Figure 6), or the distance is long (longer than 300 miles, see Figure 7), and the shipment size is large (about 35 tons); or 2) when the size of shipment is small (below 10 tons), even if the distance is short (about 100 miles) and annual tonnage is small, see Figure 8.

The estimated pipeline ton-mile costs shown in Figures 2 through 8 were based on the range of conditions considered to be most representative of those which would be found in actual practice. It is important to know the range of variation in these costs due to changes in the assumed values of parameters.

Figure 9 shows how the pneumo-capsule pipeline is influenced by each of three access conditions assumed in the analysis. The first condition assumes that half of the tonnage per year is delivered to or removed from the line-haul by a branch pipeline network consisting of several feeder pipelines, each of which accommodates 0.5 million tons per year; and the other half of the access is achieved by local truck service. The second condition assumes that all the pick-up and delivery tonnage is moved by truck. The third condition assumes that all the pick-up and delivery is moved by urban feeder lines, each accommodating 0.5 million tons per year. For shipment weight below 10 tons, the all-pipeline network is a less costly alternative. However, as shipment weight increases, the advantages diminish.

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* This discontinuity is not observed for pneumo-capsule pipeline or rail because 1) capsules' capacities are very small (about 1500 lbs.) and we assume that shipments are consolidated at origin terminal so that each capsule is fully loaded; and, 2) rail boxcars are of different sizes so the range of capacities can be approximated by a continuous curve.

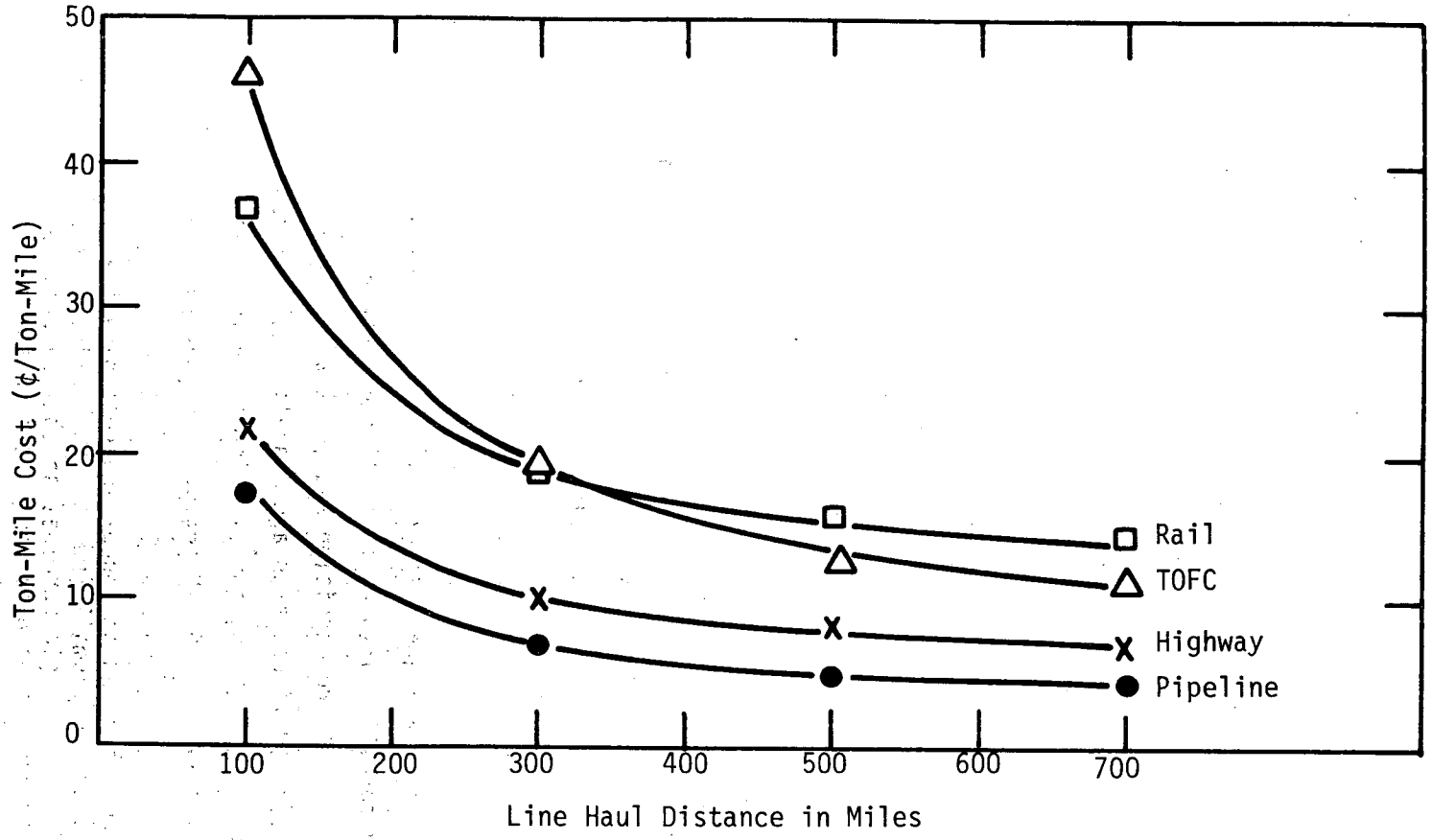


Figure 6. Ton-Mile Cost as a Function of Line Haul Distance. It Was Assumed That the Density of Freight Was 20 lbs Per Cubic Foot, Shipment Weight Was 5 Tons;and for Pipeline, Access Was 100 Percent by Truck and Annual Tonnage of 25 Million Tons.

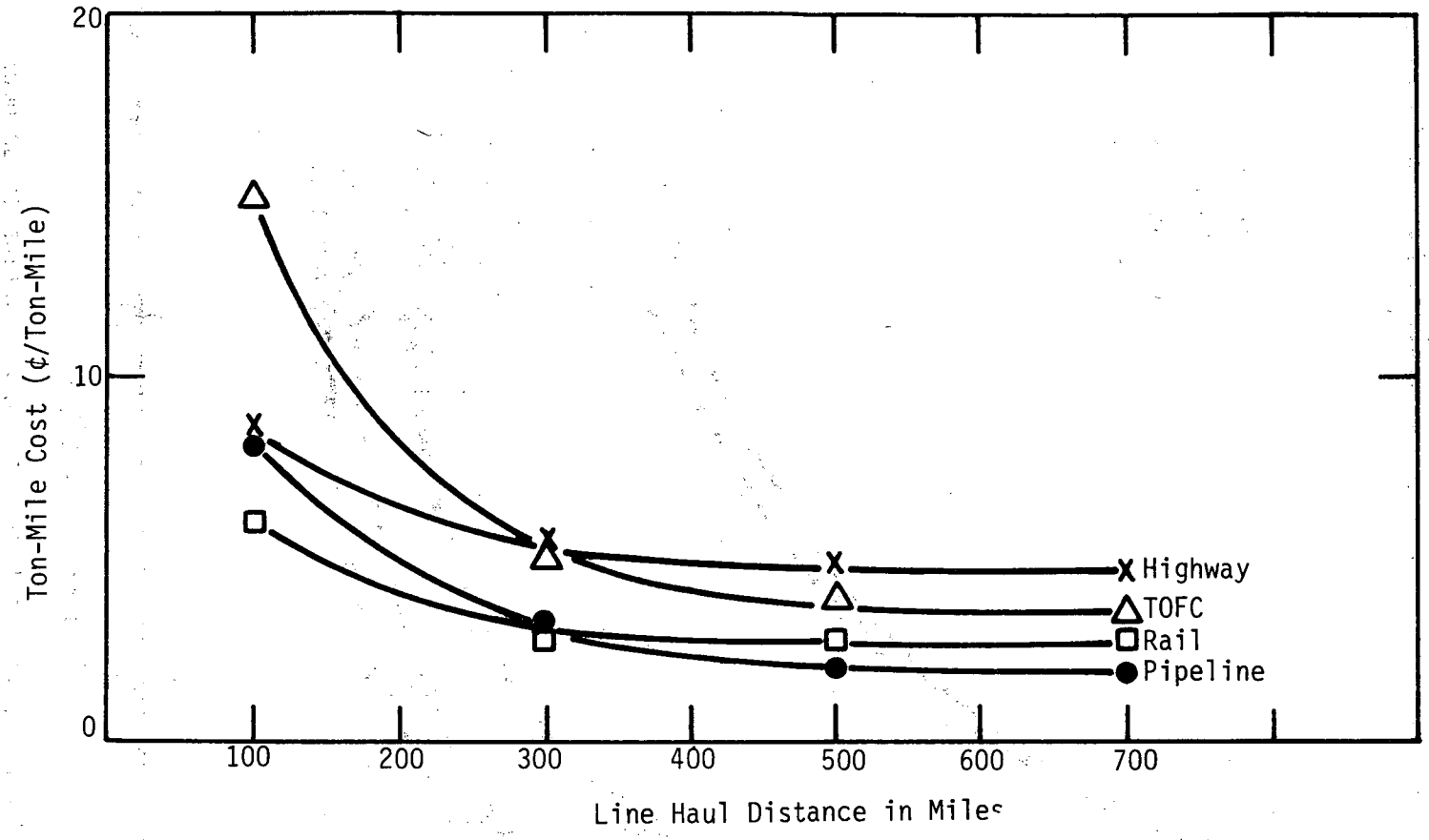


Figure 7. Ton-Mile Cost as a Function of Line Haul Distance. It Was Assumed That the Density of Freight Was 20 lbs Per Cubic Foot, Shipment Weight Was 35 Tons; and for Pipeline, Access Was 100 Percent by Truck and Annual Tonnage of 25 Million Tons.

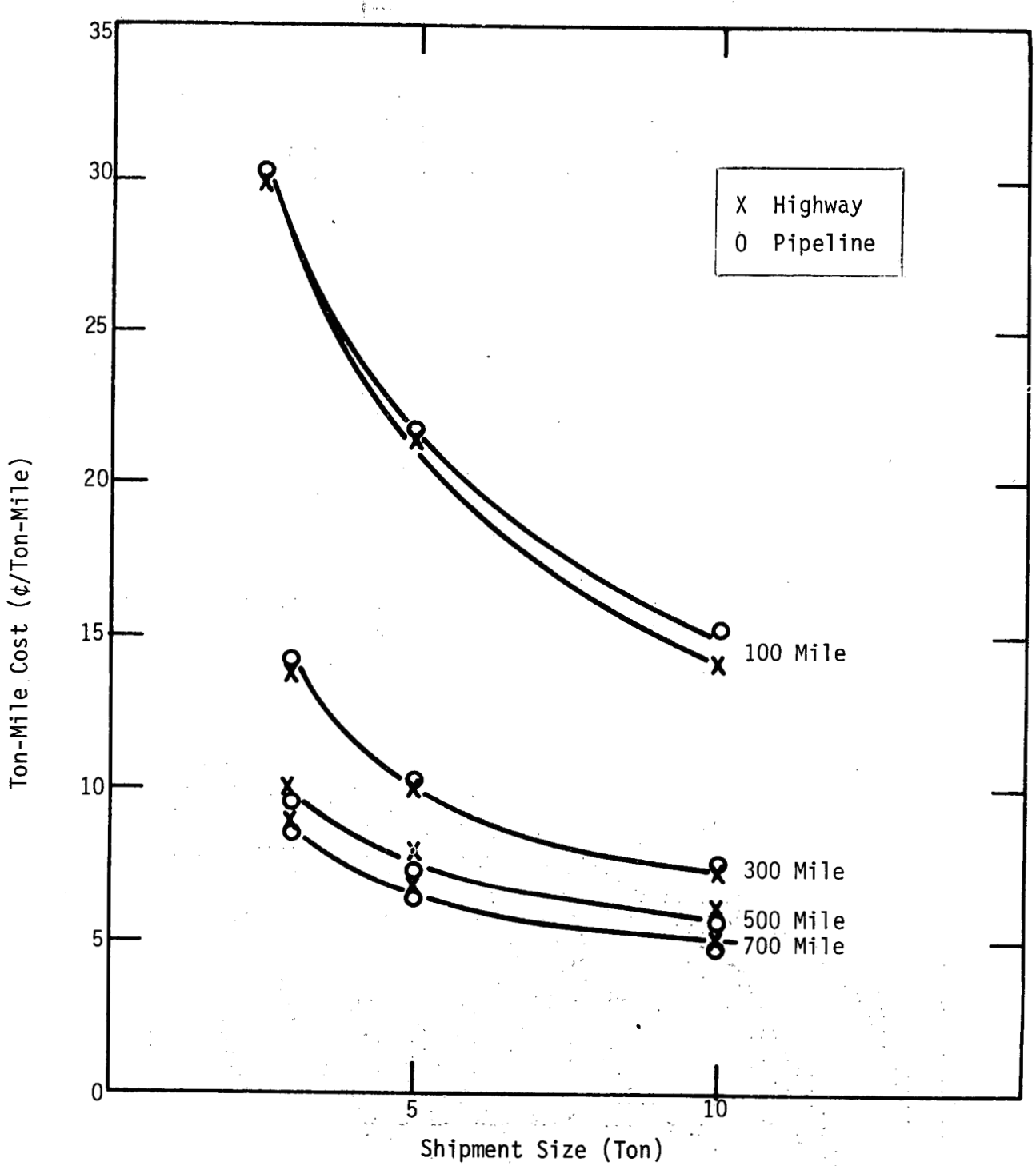


Figure 8. Variation of Ton-Mile Cost as a Function of Shipment Size and Line Haul Distance for Highways and Freight Pipeline, 1 MM Ton/Year Capacity, for Freight Pipeline 100 Percent Truck Access.

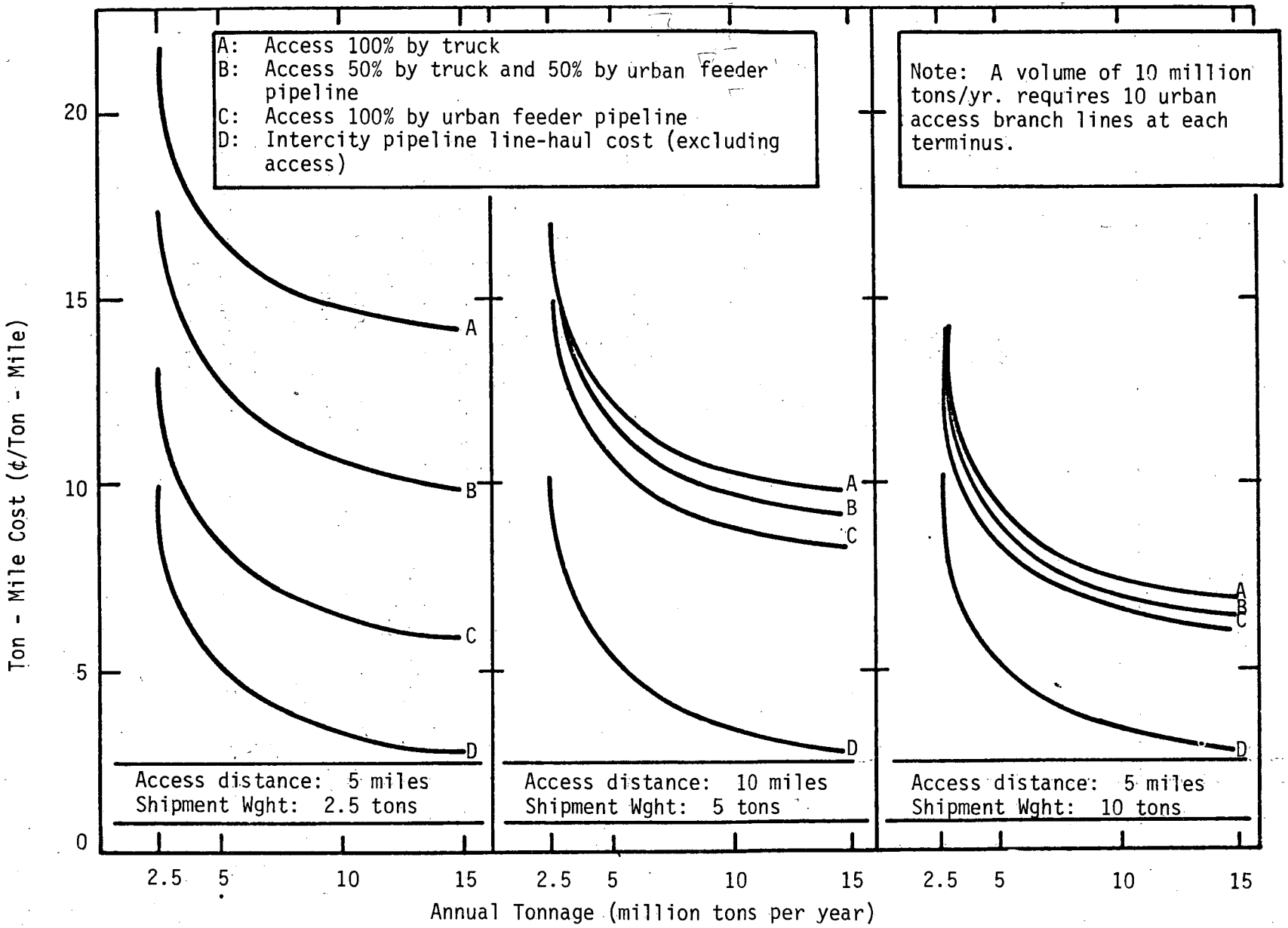


Figure 9. Variation of Ton-Mile Cost as a Function of Annual Tonnage for Three Access Assumptions, 200 miles Distance, 60 Inch Pipeline, 20 lbs. per Cubic Foot Density, 0.5 million tons/yr. for each urban access line.

Figure 10 shows the estimated line-haul cost in cents per ton-mile of a pneumo-capsule pipeline under two sets of conditions and for three distances. One of these conditions corresponds to a rather pessimistic set of assumptions. The other condition corresponds to an optimistic set of assumptions and favors pipeline. (See Volume III for detailed descriptions of these cases.) In actual practice, the situation is expected to be somewhere between these extremes.

Figures 11 and 12 present a series of charts showing the contribution to cost (per ton-mile) of the various pipeline components. Both capital costs (Figure 11) and annual costs (Figure 12) are shown. These figures indicate that pipeline construction costs ($C_1 + C_2$) are the major component of capital cost (more than 50%). The figures also show how the relative share of the components of capital and operating costs vary as either the pessimistic or optimistic assumptions are made.

Table 2 shows the sensitivity of the pneumo-capsule ton-mile cost as various independent variables and cost components vary. The table is self explanatory and shows the relative significance of each item in column (1). For instance, a 100 percent change of density produces about 21 percent change in total dollar per ton-mile cost. Column 5 shows that the cost is most sensitive to estimates of pipeline capital cost, although a 100 percent mis-estimate would change the result only 37 percent.

The Demand for Intercity Freight Pipeline

In order to assess the economic potential of freight pipeline, it is necessary to know the potential demand for such a facility.

Estimating demand for a freight pipeline service was a two part process. The first part consisted of determining the amount of products flowing in any given transportation corridor which are physically capable of transport by pipeline (hereafter, "eligible products"). The second part related to acceptance of this mode of transport by shippers. The first question is best explored within a particular geographical setting. Therefore, the geographical area from Chicago to New York City was chosen for intensive investigation of goods flow.

As illustrated in Figure 13, a hypothetical pipeline network was assumed running from Chicago through Gary, South Bend, Toledo (with a spur to Detroit), Cleveland, Akron, Youngstown, Pittsburgh, Johnstown, Harrisburg, Philadelphia and thence to New York. A branch was included from St. Louis through Indianapolis, Dayton, Columbus, Wheeling, connecting at Pittsburgh. The flows of goods given by the

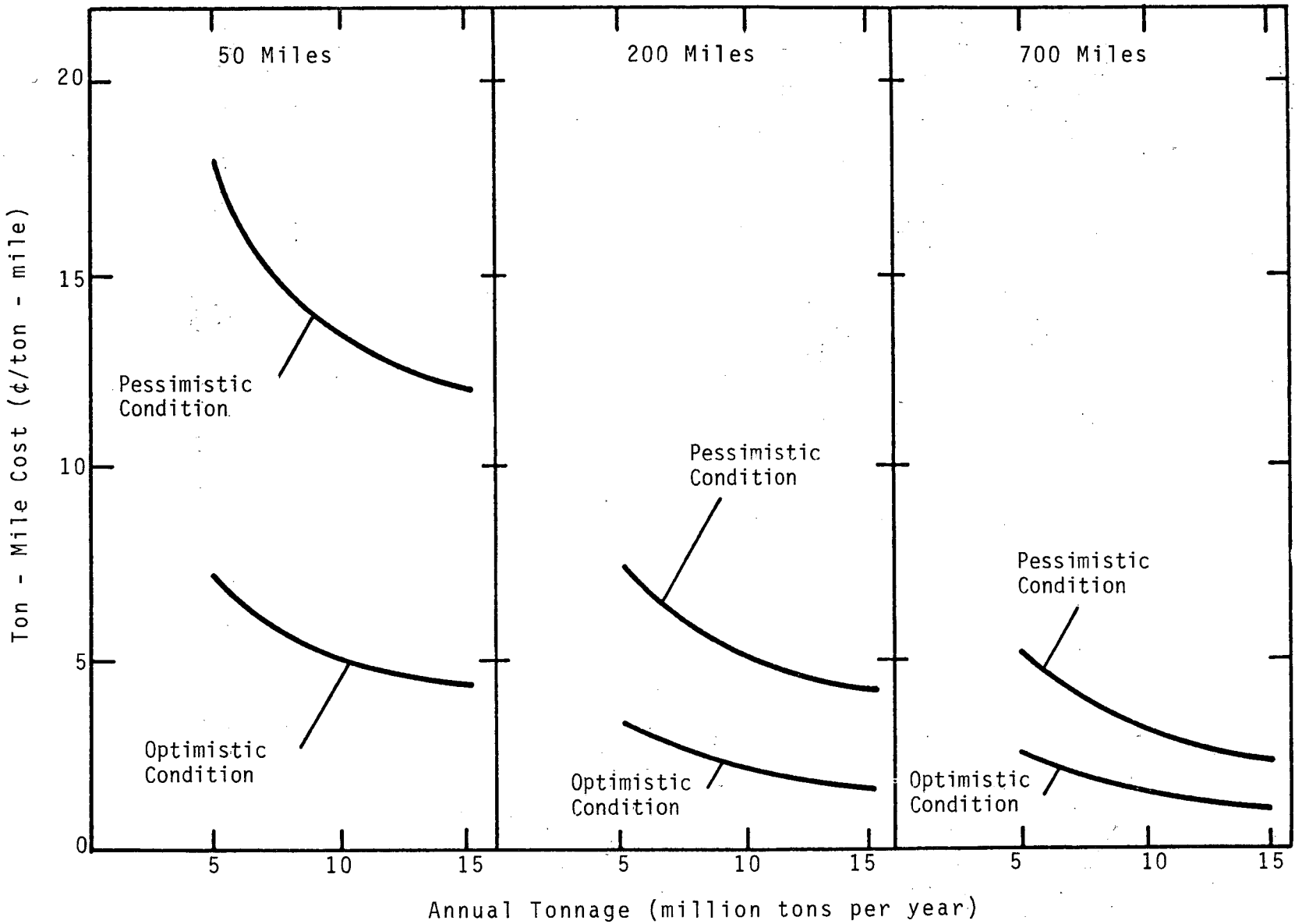
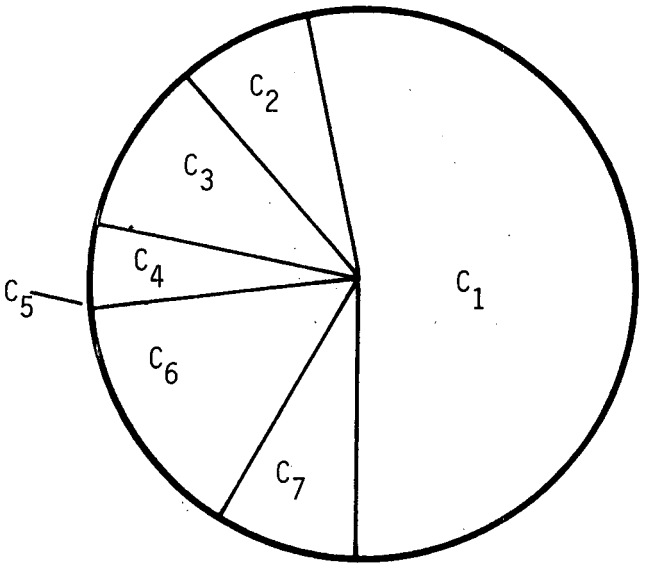
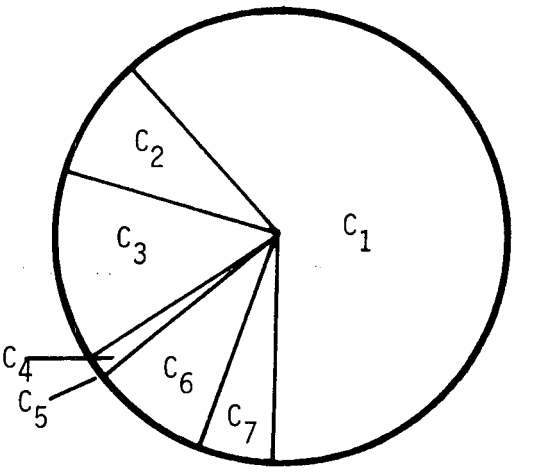


Figure 10. Pneumo-capsule Pipeline Line-Haul Ton-Mile Cost as a Function of Annual Tonnage for Two Sets of Parameter Values and Three Distances

A - Pessimistic Condition
Capital Cost:
$1,221 million.

B - Optimistic Condition
Capital Cost:
$869 million.





C_1 = Pipeline Construction (Cross-Country)

C_2 = Pipeline Construction (Urban)

C_3 = Compressor Stations

C_4 = Freight Terminal

C_5 = Communication System

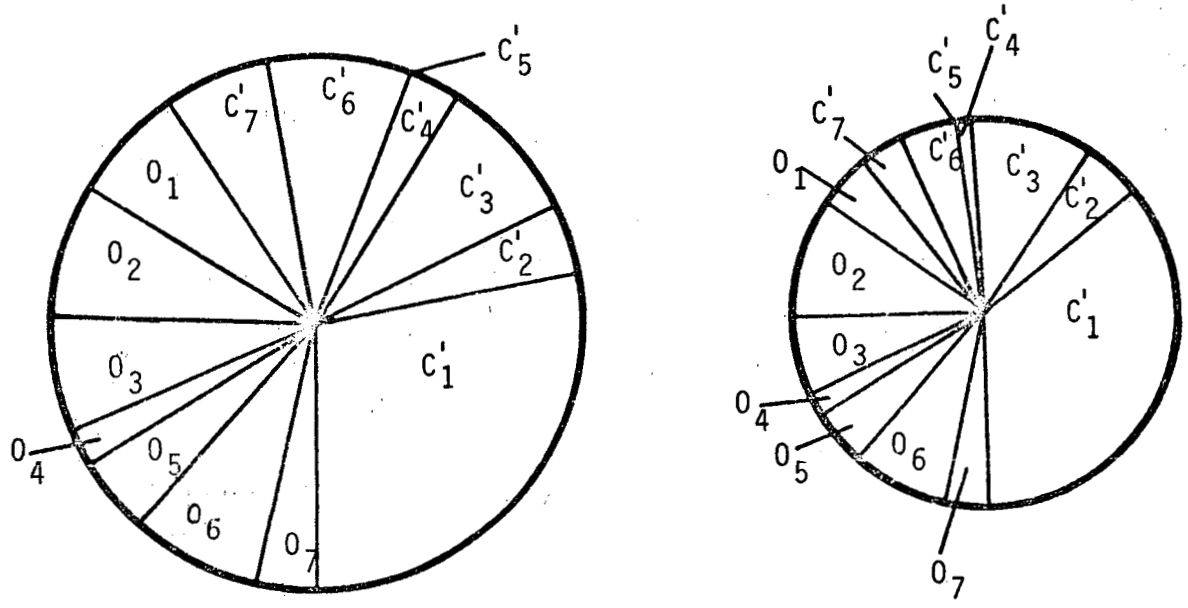
C_6 = Miscellaneous

C_7 = Capsules

Figure 11. Variation of Capital Cost Components as a Function of Conditions A and B, 700 Miles, 15 Million Tons Per Year.

A - Pessimistic Condition
Operating Cost:
$249 million/yr.

B - Optimistic Condition
Operating Cost:
$122 million/yr.



C'_1 = Annual Capital Cost of Pipeline Construction (Cross Country)
C'_2 = Annual Capital Cost of Pipeline Construction (Urban)
C'_3 = Annual Capital Cost (Compressor Station)
C'_4 = Annual Capital Cost (Freight Terminal)
C'_5 = Annual Capital Cost (Communication)
C'_6 = Annual Capital Cost (Misc.)
C'_7 = Annual Capital Cost (Capsule)
O_1 = Annual Operation (Labor)
O_2 = Annual Operation (Energy)
O_3 = Annual Operation (Repairs)
O_4 = Annual Operation (Insurance)
O_5 = Annual Operation (Administration)
O_6 = Annual Operation (Taxes & Fees)
O_7 = Annual Operation (Misc.)

Figure 12. Variation of Capital and Annual Cost Components as a Function of Conditions A and B, 700 Miles, 15 Million Tons Per Year.

Table 2. Pipeline Cost Sensitivity Analysis

(1) Variable(a)	(2) Range of Variation(b) (percent)	(3) Percentage Change of Ton-Mile Cost for the Extreme Points of Range(c) (percent)			(4) Sensitivity Factor(d)	(5) Rank(e)
Commodity Density	50 - 150	(+16)	-	(-5)	21	3
Life Span	66 - 133	(+9)	-	(-4)	20	4
Interest Rate	88 - 111	(-4)	-	(+4)	36	2
Cost Components						
Capital						
Construction	70 - 140	(-11)	-	(+15)	37	1
Pumping Station	50 - 200	(-3)	-	(+7)	07	9
Terminal	50 - 200	(-2)	-	(+4)	04	13
Communication	50 - 200	(-.01)	-	(+.03)	0	16
Miscellaneous	50 - 200	(-3)	-	(+6)	6	11
Capsules	50 - 200	(-2)	-	(+5)	1	15
Operating						
Labor	50 - 200	(-5)	-	(+12)	11	5
Energy	50 - 200	(-3)	-	(+6)	6	10
Repairs/Supplies	50 - 200	(-3)	-	(+7)	7	7
Insurance	50 - 200	(-1)	-	(+3)	3	14
Administration	50 - 200	(-4)	-	(+10)	9	6
Taxes/Fees	50 - 200	(-3)	-	(+7)	4	8
Miscellaneous	50 - 200	(-2)	-	(+4)	4	12

Notes:

a. Values of each element in this column were varied independently while the values of others were held constant.

b. The base case for the sensitivity analysis was: length, 200 miles; diameter, 60 inches; annual volume, 10 million tons; commodity density, 20 lbs per cubic foot; life span, 30 years; and interest rate, 9 percent. For example, commodity density was varied from 50 to 150 percent of the base density (10-30 lbs. per cubic foot).

c. Variation as a percentage of per ton-mile costs. For example, a density value equal to 50 percent of base (10 lbs per cubic foot) corresponds to a 16 percent increase in per ton-mile cost.

d. The sensitivity factor was calculated by dividing the range in column (3) by the range in column (2), and multiplying the resulting quotient by 100. The sensitivity factor measures the percentage change in per ton-mile cost which would result from a 100 percent change of the corresponding variable.

e. On the basis of sensitivity factor, a lower rank number indicates a greater impact on ton-mile cost.

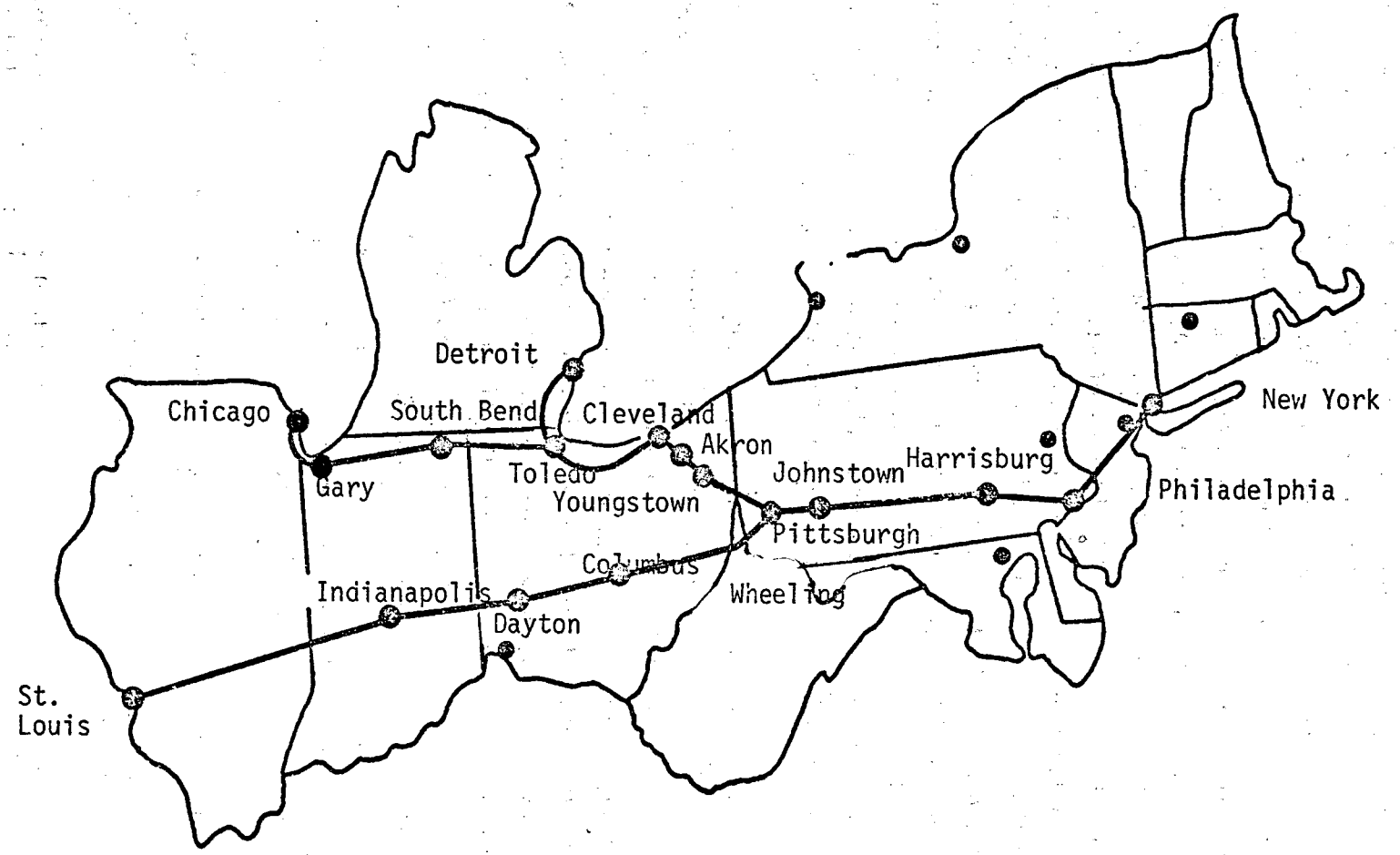


Figure 13. Hypothetical Pipeline Network

Reebie[1] container network study origin-destination matrices (90% of which were assumed to be eligible for pipeline transport) were assigned to the network on three bases. First, the most stringent requirement was that both origin and destination cities should be connected by the network. Second, a less stringent assignment allowed that either origin or destination city be connected by the network (e.g. Milwaukee to New York). Third, the least stringent requirement was that neither origin nor destination city be on the network (e.g. Milwaukee to Baltimore). In the third case, traffic flows were assigned only if excessive circuity were not involved.

Maximum density links carried 9.8 million tons of eligible products westbound between Akron and Cleveland; and 16.2 million tons eastbound between Harrisburg and Philadelphia, under the first assumption. Under the second assumption, the maximum link became Harrisburg-Johnstown with 19.3 million tons westbound and 35 million tons eastbound. Under the third assumption, the westbound maximum was South Bend-Gary carrying 22.8 million tons; eastbound was Johnstown-Harrisburg carrying 38.3 million tons. Based on this process of approximation, it was concluded that sufficient quantities of eligible products were available for movement to warrant further investigation.

The Reebie study data did not include ores, coal, and other minerals. Since such commodities are eligible - there is no physical impediment to their carriage by pipeline - their flows were calculated based on the Bureau of Mines Publication[2] and the 1% Rail Waybill Sample and these were in turn allocated to the Reebie study origins and destinations. These flows were basically north-south in the region which this study covers. This region was not a prime producer of minerals and ores. Thus large flows were not added to the Reebie study flow data, with the exception of 22 million tons added to the Philadelphia-Pittsburgh links (see Volume IV).

Two other sources were used to make rough estimates of trade flows. In a U.S. Forest Service study[3], palletizable commodity flows were investigated on the same geographical basis as the Reebie data. This data is a subset of the Reebie data and produces maximum flows of 4.6 million tons eastbound on the Harrisburg-Pittsburgh link.

In another approach, the flows of manufactured commodities reported in the

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(1) Reebie Associates, National Intermodal Network Feasibility study, prepared for U.S.D.O.T., FRA, Washington, D.C. 1976.

(2) U.S. Department of Interior, Bitumious Coal and Lignite Distribution, Calendar Year 1974, Bureau of Mines, Division of Fossil Fuels, Washington, DC, April 18, 1975.

(3) Wallin, Walter and Richard Frost, Product Flow in a National Pallet Exchange Service, Northeastern Forest Experiment Station, Forest Products Marketing Laboratory, U.S. Department of Agriculture, Princeton, West Virginia, 1973.

1972 Census of Transportation [4] were investigated. Note that these commodities were comprehended by the Reebie study. It was assumed that 60% of the flows were eligible. In this case, the maximum link flow between the hypothetical network cities was 11.7 million tons westbound between Cleveland and Detroit. These three spatial flow studies gave an indication that there is a significant potential amount of eligible commodities flow in the Chicago to New York corridor region. It is unfortunate that sufficient commodity disaggregation did not exist within this data to allow construction of origin-destination flows by individual commodity.

Once it had been established that there was a sufficient potential flow of eligible products (10 million tons plus per year), it was necessary to understand the rationale behind the geographical and modal distribution flows of such goods. This entailed a better understanding of the elements of, first, transportation demand, and second, modal split.

Using the total flows (less refined Petroleum products, STCC 291) from the 1972 Census of Transportation, it was found that a simple gravity model would explain the origin-destination distribution of 65% of the flows. While the use of such models is commonplace, the 1972 Census data had yet to be tested in the gravity formulation. Given the general stability of the gravity coefficients over time[5], the equation could also be used to generate eligible flows between cities on the hypothetical network which were not in the Census of Transportation production area data.

Although the total spatial flows of specific eligible commodities could not be disaggregated from the previously discussed data sets, it was possible to construct origin-destination matrices for some eligible products at the three and four digit Standard Transportation Commodity Code (STCC) level from the Census of Transportation. Using the 1967 Census of Transportation public use tapes, origin-destination (25 by 59) matrices were constructed for nine eligible commodities which also satisfied certain constraints with regard to tonnage shipped and non-zero entries in the matrix. These nine commodities became the basis of a macro modal split model. In addition, the total flows of all commodities (from the 1972 Census) became the basis of a macro demand model.

The nine commodity origin-destination matrices were calculated for both rail and truck - the two dominant modes in the commodities' movement. It was hypothesized

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(4) U.S. Department of Commerce, U.S. Census of Transportation, Washington, D.C. 1975.

(5) Byler, J. and P. O'Sullivan, "The Forecasting Ability and Temporal Stability of The Coefficients of Gravity Models Applied to Truck Traffic", Traffic Engineering and Control, 1974.

that the split between the two existing modes would be based upon relative transport rates, relative transport times, and other items such as relative reliability of service and relative loss and damage. However, only the former two items could be estimated at such an aggregated flow level - information on reliability and loss and damage did not exist on a route specific level. Information on rail rates was estimated from the ICC 1% Rail Waybill Sample; truck rates were estimated from data provided by Morton(6); rail times from information provided by Martland(7); and truck times from dividing miles traveled by national truck average speed plus an assumed terminal time.

Using these estimates, a modal split model was developed. This model was adapted to freight pipeline based on the abstract mode approach of Quandt and Baumol(8). The approach assumed that each mode could be described in the transportation marketplace by a vector of transportation characteristics, e.g., rate, time. Shippers purchase services of a transport mode not on the basis of the name of the mode, but rather on the value to them of this vector of characteristics. Thus, rate is of certain importance to a shipper, as is time in transport, etc.

The abstract mode model postulates that if one observes the behavior of shippers when choosing among the characteristics of existing modes, the shipper will exhibit the same behavior when facing a new mode with the same characteristic vector. Thus, observing the choice of truck versus rail, when the characteristics of rail or truck are known, will allow estimates to be made of the shipper's reactions to such characteristics. Substituting pipeline characteristics for rail characteristics in the estimated modal split equation will then yield a modal split between truck and pipeline. Likewise, substituting pipeline characteristics for truck characteristics in the estimated modal split equation yields a modal split between rail and pipeline. Making binary comparisons, i.e. where pipeline dominates truck in the former case and where pipeline dominates rail in the latter case, these estimates show that pipeline could possibly obtain a significant share of the eligible market (see Volume IV).

The above modal split model uses aggregate data (aggregate commodity types, aggregate modal characteristics, aggregates of shippers, over aggregated origins and destinations). This is distinguished from modeling urban travel behavior by dis-

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(6) Morton, A., Competition in the Intercity Freight Market, Office of Systems Analysis, U.S.D.O.T., Washington, D.C., 1971.

(7) Martland, Carl, "Rail Trip Reliability, Evaluation of Performance Measures & Analysis of Trip Time Data", Studies on Railroad Operations and Economics, Vol. 2, prepared for the Federal Railroad Administration, U.S.D.O.T., Washington, D.C. June 1972.

(8) Quandt, Richard and William Baumol, "The Demand for Abstract Transportation Modes: Theory and Measurement", Journal of Regional Science, Vol. 6, 1966, pp. 13-26.

aggregate behavioral modeling. Such an approach views an individual travel decision based on the characteristics facing the individual. The approach is relatively untried in freight modal split modeling due to data unavailability.

Data on individual shipment modal choice with regard to rates by truck and rail, transit times by truck and rail, and reliability (percentage delivered in best three continuous days) by truck and rail, as well as the actual modal choice, were collected for four major national shippers. These shippers each ship one of the nine eligible commodities used in the macro modal split analysis above. Five hundred observations were obtained for each firm. The observations for these firms were coded, punched, and a disaggregate behavior modal split model was developed for each.

The results yielded the expected signs and significant coefficients. As was done in the macro modal split analysis, pipeline characteristics were substituted for both rail and truck characteristics, following the abstract mode approach. The split by pipeline was again estimated from the binary comparisons. Freight pipeline was again able to capture a significant percent (about 30 percent) of the market.

Some question existed as to whether the modal splits estimated herein for specific flows and specific commodities could be applied to the non-commodity disaggregated macro eligible flows estimated herein. Nevertheless, the pipeline's characteristics compared very favourably to those of the existing modes. As such, the analysis herein suggests that pipeline is capable of obtaining an appreciable share (about 30 percent) of the eligible market.

The above analysis was truly a very preliminary estimate. The analysis technique described herein is still in its primitive stages. However, while the estimates were approximate, they did give a reasonable indication that, from the demand side, freight pipeline appears to be quite feasible and certainly merits further study. A further insight may be attained by examining in some detail the origin-to-destination travel times.

Figure 14 presents the mean travel time for movement from origin to destination for the various carriers. Truck time was based upon the average running speed of 42 mph reported by the Interstate Commerce Commission, assuming a 16 hour operating period in each 24 hour day. The range of travel time values results from adding another day to reflect likely time consumed in pick-up and delivery if the shipment weight were less than a truck-load quantity. The rail times are much more variable, reflecting variations in the number of intermediate yardings and carrier interchanges among railroads. In all cases, rail carload travel times were higher than those of truck. TOFC travel times were better, and in the case of special expedited trains, could approach truck travel times, even with the local drayage requirements. However, it should be noted that ton-mile costs estimated herein probably underestimate the

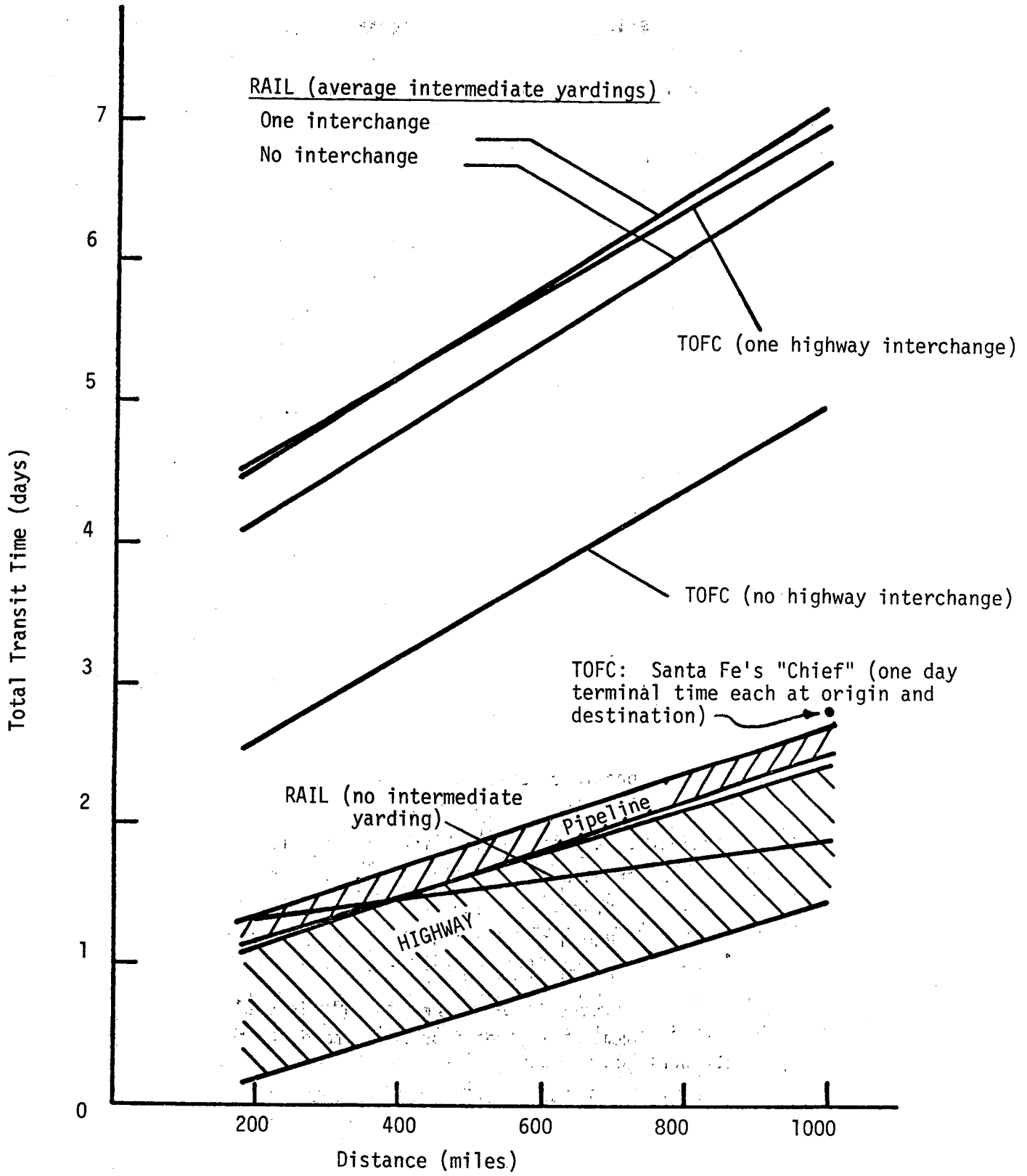

Figure 14. Comparison of Origin - Destination Transit Times

ton-mile cost of such expedited service. The one example of expedited TOFC service, the Santa Fe's "Chief", has been discontinued. Management cites insufficient shipper interest in the time saved as the reason for discontinuation.

Pipeline travel times were estimated on the basis of an assumed 24 mph line-haul speed and a range of access and terminal transfer time of from 18 to 24 hours. Thus, it is seen that pipeline probably would be considerably faster than existing rail and TOFC, and slightly slower than existing truck.

As for other aspects of service, it was relatively easy to describe rail and truck service as it now exists, but much more difficult to hypothesize likely pipeline service. Pipeline service reliability would probably be considerably better than that of rail. But it would be about the same as the truckload (TL) movement. It probably would be somewhat better than less-than-truck-load (LTL) movement, due to the similar number of handlings and the similarity of the processes. Loss and damage would likewise probably be better than rail, about the same as TL movement, and hence, somewhat better than TL movement. Packaging requirements would probably be similar to those for LTL, which are greater than those for TL movement, but not as stringent as those for rail movement.

Thus, in general, pipeline would tend to have service characteristics similar to truckload movement; and somewhat better than that of less-than-truckload movement. The one major difference would seem to be that the pipeline would not be so sensitive to interruption in bad weather, although its reliance upon truck for access and the few days in which truck or rail is interrupted in North America would seem to make this an advantage of limited value. An advantage which might make pipeline more attractive is the potential for automation and control with concomitant potential for reduction of theft. Most theft on existing systems occurs because of large delays at terminals. Therefore, full advantages will be realized only for 100 percent pipeline access to a line-haul pneumo-capsule pipeline.

Major Conclusions

1. The following freight pipelines are both technologically viable and commercially reliable modes of transport:

Slurry Pipeline
Pneumatic Pipeline
Pneumo-capsule Pipeline

Hydro-capsule pipeline has been proven to be technologically feasible, but as yet, its reliability under commercial conditions needs to be tested. These points are discussed in detail in Volume II.

2. The preliminary study of the demand for freight pipeline showed that for a specific transportation corridor (Chicago-New York) there are potential flows of

eligible manufactured products sufficient to warrant more detailed study. Volume IV discusses this point in detail.

3. Modal split analysis showed that freight pipelines could capture a sizeable share of eligible cargoes (see Volume IV).

4. The comparison of the ton-mile costs of various modes of transport in the present volume showed that the freight pipeline becomes either superior or competitive with rail, truck, or TOFC under two sets of conditions:

(a) When the annual tonnage to be transported is high and/or transport distances are long.

(b) When the size of the shipments is small even though the annual tonnage and/or the distances are small.

5. Freight pipeline is an environmentally more preferable mode of transport than trucks and possibly railroad service. These points are discussed in detail in Volume V.

6. Energy intensiveness, as defined by Btu consumption per ton-mile, of pneumo-capsule pipeline during line-haul is much smaller than energy intensiveness of truck, but may or may not be better than rail, depending upon physical conditions of transport (see Volume V).

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