MASTER

TRANSPORTATION OF SOLID COMMODITIES VIA FREIGHT PIPELINE

COST ESTIMATING METHODOLOGY VOLUME III

Part A & Part B

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**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 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, broadening 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.

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

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

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

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.

Barry Silverman, Melissa Clark-Rhodes, and Janet Hines have also contributed to this document in various capacities.

Iraj Zandi
Principal Investigator

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TRANSPORT OF SOLID COMMODITIES
VIA FREIGHT PIPELINE

July 1976

Volume III

Cost Estimating Methodology

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Volume III
Cost Estimating Methodology
Executive Summary

In order to examine the feasibility of an intercity freight pipeline, it was necessary to develop cost equations for various competing transportation modes. This volume presents cost estimating equations for rail carload, trailer-on-flatcar, truck, and freight pipeline.

Section A presents mathematical equations which approximate the fully allocated and variable costs contained in the Interstate Commerce Commission (ICC) cost tables for rail carload, trailer-on-flatcar (TOFC) and truck common carrier intercity freight movements. These equations were developed to enable the user to approximate the ICC costs quickly and easily. They should find use in initial studies of costs where exact values are not needed, such as in consideration of rate changes, studies of profitability, and in general inter-modal comparisons.

Section B discusses the development of a set of engineering cost equations for pneumo-capsule pipeline. The development was based on an analysis of system components and can readily be extended to other types of pipeline. The model was developed for the purpose of a feasibility study. It employs a limited number of generalized parameters and its use is recommended when sufficient detailed and specific engineering information is lacking.

These models were used in the comparison of modes presented in Volume I and hence no conclusions regarding relative costs or service of the modes are presented here. The primary conclusion is that the estimates of costs resulting from these models is subject to considerable uncertainty. Some of this uncertainty is inevitable, but much of it results from many factors influencing costs which could not be taken into account in as much detail as desired, such as management effectiveness, variations due to commodity characteristics, and temporal and directional variations in traffic flow. If more accurate cost estimates are desired, then much effort must be devoted to improving cost estimating methods.

VOLUME III
COST ESTIMATING METHODOLOGY

PART A

Cost Characteristics of Rail Carload, TOFC,
and Highway Intercity Freight Systems

J. A. Warner and E. K. Morlok

A - COST CHARACTERISTICS OF RAIL CARLOAD, TOFC,
AND HIGHWAY INTERCITY FREIGHT SYSTEMS

INTRODUCTION

The purpose of this paper is to present basic cost characteristics of rail carload, TOFC (trailer-on-flatcar), and highway intercity freight transport systems. The measure of cost of interest is the cost to a carrier of providing the service, rather than the cost to a shipper using the service. The latter cost or, more accurately, transportation rate, is the appropriate measure for use by a shipper in considering his choice of transport mode. Our point of view is that of the public sector planner or policy maker. In this context, the cost of providing service on a specific transport system is a relevant evaluation criterion inasmuch as it provides a measure of the public resources expended by each system.

Two extreme approaches to estimating cost are available: the engineering approach and the accounting approach. The former is grounded in the analyst's knowledge of physical and operational characteristics of the system being costed, and typically consists of determining the number of physical and operational units (or factors of production) consumed in the provision of a given service, assigning unit costs to these physical and operational units (e.g., capital cost per vehicle, in dollars per annum; employee wage rate, dollars per day), and summing the products of this arithmetic process to arrive at a total cost of providing the service. Use of the engineering approach demands, in addition to the above mentioned knowledge of physical and operational characteristics, the capability to accurately assign unit costs. Its accuracy is in inverse relation to the number of costs which are difficult or impossible to assign to any service unit (or, in extreme cases, to any service). Stated another way, as complexity of operations increases, the accuracy of the engineering cost approach decreases. The distinct advantage of the engineering approach lies in the direct and visible linkages between cost and operational characteristics. Thus, it is extremely useful in cost analysis of

operational changes, since any such change will directly affect service units and therefore cost of providing service. Its disadvantage is an inability to accurately cost complex systems--a disability arising from the difficulty, mentioned above, in assigning some costs to service units. This results in either omission of some costs, or inaccurate representation of cost behavior due to arbitrary assignment of otherwise unassignable costs.

The accounting approach overcomes this problem. It consists of the assignment of costs not to physical resources consumed in or input to the transport process under study, but rather to measures of output of the system (e.g., cents per ton-mile). Since any such assignment is to a certain degree arbitrary, the accounting approach overcomes many problems associated with complex costs in engineering costing. The analysis is typically based on a segregation of cost accounts, and a determination (perhaps through some regression technique) of the extent to which these accounts vary with measures of output. For example, a series of accounts associated with maintenance of rail track and right-of-way might be aggregated, and regressed against traffic measured in, say, million gross ton-miles. The resulting equation might indicate that the cost of maintenance of way can be estimated as the sum of a constant plus some coefficient of million gross ton-miles of traffic. Similar analyses of accounts would result in assignment of all costs to service units, and therefore any service could be costed by summing coefficients of each output measure, determining output of the service, and summing these products. The characteristics of accounting costing are opposite to those of engineering costing: although all costs can be taken into account (a difficult task in the engineering approach), the ability to predict changes in cost due to modified operational procedures (an advantage of engineering costing) is severely limited in accounting costing since these operational changes may not result in any changes in output measures (1).

Most techniques are combinations of engineering and accounting methods which attempt to use the strengths of one to offset the weaknesses of the other. The transport system costs presented in this paper are based upon data gathered,

(1). For a complete discussion of transport costing, the reader is referred to:

- a. Study of Cost Structures and Cost Finding Procedures in the Regulated Transportation Industries, prepared by R.L. Banks and Associates for the U.S. Department of Commerce, November, 1959.
- b. The Economics of Competition in the Transportation Industries, John R. Meyer, M. J. Peck, J. Stenason, C. Zwick, Harvard University Press, 1959.

tabulated and published by the Interstate Commerce Commission (ICC) (2, 3). These data have been thoroughly analyzed, evaluated, and criticized and are periodically revised and brought up to date by the Commission. The intent of this paper is not to add to the body of knowledge in transport system costing and economics which has resulted from such an evolving process. Although men of good faith can (and do) reasonably argue the sufficiency of these data in regulatory proceedings, this issue does not fall within the scope of this analysis. For our purpose--the identification of general relationships, characteristics, and trends--the data are considered accurate, and, we feel, appropriate.

One reason for making such a statement is that we bypassed one of the major points of contention in rail costing: the allocation of constant, or fixed, costs among various segments of traffic. This difficult matter was of little significance in our analyses, which were conducted on a variable cost basis. Our interest was in the additional cost incurred in transporting an additional increment of traffic over a rail transportation or highway transportation system already in operation, rather than in projecting the cost of a completely new rail system, or a completely new highway system. Given the existing rather ubiquitous intercity rail and highway networks of the United States we feel that this is a sound approach.

Another common problem we avoided was that of projecting past cost and performance trends into the future. We constrained ourselves to the present not from any lack of interest in future cost and performance, but rather out of necessity. It was simply impossible to accurately predict cost and performance trends in future years' operations, especially since the current disarray of a large portion of the rail network may be resolved in such a manner that significant changes in rail operations will become possible.

In summary, presented herein are cost and performance data based on available sources of data for a current (1973) year on a variable cost basis. The following three sections discuss each of the intercity freight modes--rail, trailer-on-flatcar (TOFC), and truck--in turn. After basic characteristics of each of the modes were established, variations in these characteristics, due to changes in several physical, operational, and organizational assumptions, were explored. Finally, a comparison was made of total origin to destination transit cost of the three systems, and the effect of density on the results of these comparisons was explored.

- (2). Interstate Commerce Commission, Bureau of Accounts, Rail Carload Cost Scales 1973, Statement No. 1C1-73, Washington, D.C. August, 1975.
- (3). Interstate Commerce Commission, Bureau of Accounts, Cost of Transporting Freight by Class I and II Motor Common Carriers of General Commodities 1973, Statement No. 2C1-73, Washington, D.C. November 1974.

The ultimate objective is illustrated in Figure 1 which depicts a relationship between transport system cost, shipment characteristics, and transport system level of service. Although the shape of any such cost surface would be dependent on many individual shipment and system characteristics, it is useful at this point to describe how the surface behaves. For a given set of shipment characteristics (distance, weight, and density) we see that cost of providing service increases as the level of service, here measured in transit time, improves. In other words, faster service is also less costly to provide. This hypothetical example illustrates a situation in which the amount of cost decrease with improved level of service is larger for initial service improvements, and then decreases as the level of service continues to improve. Similarly, for a given level of service, cost of providing service generally increases with shipment weight (other characteristics constant). Thus, the cost surface illustrated in Figure 1 would be generated by the locus of all combinations of levels of cost, shipment characteristics, and service.

This section of the report provides cost information which would be used in the generation of multidimensional cost surfaces. Level of service information is presented in Volume I of this report.

RAIL CARLOAD

Rail cost will be illustrated for two commonly used carriers of general merchandise freight: unequipped and equipped (sometimes called "damage free" or cushion underframe) general service boxcars. Although such cars are available in a wide range of sizes, capacities and equipment configurations, we will assume a car with typical characteristics - a 65 ton weight capacity and a 4900 cubic foot volume capacity. Rail costs were derived from the ICC publication Rail Carload Cost Scales 1973 (2). This publication, one of a series published annually by the ICC, contains, by region, cost scales showing variable and fully allocated unit costs as a function of short-line rail mileage and weight of load. Rail costs were presented in three forms. The first was a summary table of average regional costs. The second resolved these unit costs into terminal and line-haul components; and, the line-haul component was further resolved between way train and through train components. Finally, a detailed table was presented which contained for average trains, way trains, and through trains, by car type, variable and constant terminal and line-haul costs on a car-mile and hundredweight-

(2). Interstate Commerce Commission, Bureau of Accounts, Rail Carload Cost Scales 1973, Statement No. 1C1-73, Washington, D.C. August, 1975.

Figure 1. Illustrative Relationship Among Shipment Characteristics and Transport System Cost and Level of Service

mile basis. In addition to these basic tables, provision was made to allow the user to adjust the average costs for situations in which it was known that operational procedures are different from regional average procedures. For example, the route circuitry of a specific movement may differ from the regional average or the empty return ratio may be different. Provision for several such adjustments existed, and examples of these will be illustrated in Appendix A to this report (see p. 38).

This paper focused on illustrating costs for ICC region III, which is known in the rail industry as "Official Territory". It includes those states east of Wisconsin and Illinois (a portion of Virginia is excluded). Costs of providing basic rail boxcar service in the region were summarized in Figures 2 and 3, for various shipment weights and distances. Referring to Figure 2A, which shows incremental total shipment cost in hundreds of dollars as a function of shipment size for actual rail distances of 42, 585, and 1,170 miles, we see that the effect of increasing shipment size has a minimal impact on incremental total shipment costs. Another way of stating this is that the ICC assumes that the cost of moving a car is the greatest proportion of shipment cost, and that marginal increases in shipment size have a small effect on incremental total shipment costs. This point is emphasized in Figure 2B which shows unit costs in dollars per hundredweight as a function of shipment weight for the same three distances. That is, the convexity of these curves is highly influenced by the large cost of moving a car. Finally, Figure 3 presents the unit distance cost in cents per ton-mile, as a function of shipment weight. As noted in Figure 3, the largest decrease in ton-mile costs occurs as distance increases from short distances and this effect diminishes as distances become large.

Intuitively expected is that the many different size, weight, and configuration rail cars would have wide variation in cost characteristics. Figure 4 illustrates this variation in unit cost (cents per hundredweight) for a representative (50 ton) load as a function of distance. As can be seen, the two rail cars for which cost data were presented above, unequipped and equipped general service boxcars, lie in the middle range of a ranking by car costs. Least expensive to operate are large liquid tank cars; and most expensive (depending on distance of shipment) were several types of special service cars such as refrigerated cars, special service boxcars and special service gondolas. It is important to keep these variations due to car type in mind when analyzing specific commodity movements.

Another major variation in rail cost, and one for which provision could be made through use of the ICC cost data, was the effect of variations in intermediate yardings on incremental total shipment cost. Figure 5 illustrates this effect

Figure 2A. Rail Carload Total Shipment Cost

Figure 2B. Rail Carload Unit Cost

Figure 3. Rail Carload Unit Distance Cost

Figure 4. Variation in Unit Cost of Rail Cars

Figure 5. Variation in Rail Carload Costs with Operational Changes.

for a general service unequipped boxcar carrying 25 tons. The top line shows cost per hundredweight as a function of distance for a movement including the average number of intermediate yardings. These may be of three types: (1) an interchange movement between two railroads; (2) an intertrain switching between trains of the same railroad company; or (3) an intra-train switching of cars of the same train. Unfortunately, the number of such intermediate switchings was not stated. However, another ICC publication assumes two hundred miles per intertrain or intratrain switching (4). For example, there would be five intertrain or intratrain switchings in a thousand mile haul, resulting in an average distance between inter and intra-train switchings of one hundred sixty-seven miles. The lower cost curve in Figure 5 illustrates cost as a function of distance for a movement with no intermediate yardings. As can be seen, the cost difference was substantial, especially for longer hauls. The intermediate curves illustrate cost based on the assumption of one interchange every 1,000 miles, or one intermediate yarding every 100 or 300 miles. This information was especially significant when viewed in conjunction with the effect of intermediate yardings on origin to destination travel time, which will be discussed in Volume I.

TRAILER-ON-FLATCAR

TOFC costs were developed based on information contained in the same Rail Carload Cost Scales 1973. Cost scales were not presented, however, and the method of computation used for this mode was quite different from that used for the rail mode. Costs were computed on the basis of an assumed cost per ton-mile of service, and other operational characteristics of TOFC presented on a regional average basis. This method allows an analyst to explicitly vary such operational characteristics as the number of trailers required for the shipment being costed (which varies inversely with commodity density), the number of trailers assumed to be carried on each rail flatcar, and the weight involved in the shipment. Absent information on these characteristics of the shipments, the analyst may employ regional average data provided in the publication.

There are several TOFC plans available to shippers with variations in the degree to which responsibility for a shipment is divided between the railroad and shippers. Costs herein will be illustrated for Plan II, in which rail carriers perform the entire movement of containers from consignor to consignee. Figure 6 illustrates incremental total cost per TOFC shipment for various shipment weights

(4). Interstate Commerce Commission, Bureau of Accounts, Explanation of Cost Finding Procedures and Principles Relating to the Use of Costs, Statement No. 7-63, Washington, D.C., November, 1963, p. 119.

Figure 6. TOFC Total Shipment Costs

for distances of 25 and 1,000 miles. Because TOFC cost computations assumed a linear relationship between cost and distance, estimation of shipment costs for distances between 25 and 1,000 miles was a simple matter of linear interpolation. The cost curves of Figure 6 illustrate three interesting characteristics of the ICC's TOFC cost estimates: (1) the significant contribution to total movement cost of terminal related costs; (2) the influence on total cost of the number of trailers required to carry any given shipment size; and (3) the relatively minor influence on total cost of shipment size carried in any given number of trailers. The first point can be confirmed by a comparison of single trailer cost curves for 25 and 1,000 mile distances. For shipment weight of 128 hundredweight, cost of the 25 mile movement was approximately \$200, while that of the 1,000 mile movement was approximately \$415. In other words, although distance of the movement was increased by a factor of 40, cost merely doubled. Quick visual inspection will confirm that this relationship is unchanged for double and triple trailer movement. A second point was that the number of trailers employed in moving a shipment rather than shipment size was the primary determinant of cost. This can be confirmed by inspection of single and double trailer cost curves for movements of the same weight and distance. For example, a shipment of 488 hundredweight moving 1,000 miles in one trailer has total shipment cost of approximately \$465. In two trailers, the same shipment costs approximate \$820. Finally, a third point that (as was true for rail boxcar movements) the effect on cost of increasing shipment weight was minimal, can be observed by inspection of any individual TOFC shipment cost curve in Figure 6. For example, a three trailer movement of 488 hundredweight moving 1,000 miles has total shipment cost of approximately \$1,200 dollars; tripling the load (to 1,317 hundredweight) increases total shipment cost to approximately \$1,304, an increase in cost of about 11%.

Figure 7 presents unit cost (in cents per hundredweight) for the same distances, shipment sizes, and number of trailer movements illustrated in Figure 6. Unit distance costs, in cents per ton-mile, are illustrated in Figure 8. Again the large influence of terminal costs can be seen by comparing unit cost for a shipment of 1,000 miles with that for a shipment of 25 miles: the decrease in unit cost with increase in distance is dramatic. This results, of course, from the fact that the total terminal cost is spread over an increasing number of ton-miles as distance increases. Figure 9 presents the three 1,000 mile unit cost curves illustrated at the bottom of Figure 8 on a scale more appropriate to their magnitudes.

Discussed in previous paragraphs has been the large influence of terminal costs on incremental total shipment cost. A large part of terminal cost in TOFC

Figure 7. TOFC Unit Costs

Figure 8. TOFC Unit-Distance Costs

Figure 9. TOFC Unit Distance Cost (1000 mile shipment distance)

movements is the cost of moving a loaded trailer from the shipper's dock to the point at which it is loaded on the rail flatcar, commonly called drayage expense. Since this operation (and therefore its cost) is influenced by many local highway and labor practices, and other factors, it exhibits a wide range of variation, even within a given region. Figure 10 illustrates by means of an example the extent to which this variation might affect total shipment cost for a single trailer movement of 437 hundredweight as a function of distance (up to 1,000 miles). Drayage cost assumed in this curve (Figure 10A) was the average for the non-urban areas of region III. As can be seen, drayage cost comprised approximately 42 percent of total shipment cost for shipments of 25 miles; and approximately 18 percent at the 1,000 mile distance. Figure 10B shows total and drayage cost for shipments of similar characteristics moving between two of the major urban areas of region III, New York City and Chicago. Drayage costs in New York City were the highest in the U.S. (for the year 1973): \$99.37 per trailer. Chicago was also higher than most urban areas at \$66.33, although several other cities, including Philadelphia, had drayage costs in this range. The significance of these drayage costs can be seen in a comparison of the region III non-urban average (\$42.17 a trailer) with the costs of these two cities, as illustrated in Figures 10A and 10B. In Figure 10B, drayage cost comprises 59 percent of the total cost for a 25 mile trip; and 31 percent for a 1,000 mile trip.

HIGHWAY COMMON CARRIER

Highway intercity freight system costs were estimated using the ICC document, Cost of Transporting Freight by Class I and II Motor Common Carriers of General Commodities, 1973 (3). This document presents (in several tables) updated unit costs and operational characteristics, which allow an analyst to develop cost scales for various shipment weights or weight brackets. As was the case for rail and TOFC, cost estimates are presented for various regions or territories of the U.S. To facilitate comparisons among the three modes, highway costs were estimated for Eastern-Central Territory, which is roughly similar to the rail industry's Official Territory, although it includes more of Illinois, and none of Virginia.

There were two significant differences between the highway system cost estimating procedures and those described above for rail boxcar and TOFC. First, it was not necessary that the analyst have as much detailed knowledge of the physical

- (3). Interstate Commerce Commission, Bureau of Accounts, Cost of Transporting Freight by Class I and II Motor Common Carriers of General Commodities 1973, Statement No. 2C1-73, Washington, D.C. November 1974.

Figure 10A. Drayage Cost: Non-urban Areas

Figure 10B. Drayage Cost: Chicago-New York

and operational characteristics of the highway service being costed. Data were presented for a wide range of shipment sizes and distances, and an assumption implicit in the unit costs associated with these characteristics was that a shipment moves in a service having "average" characteristics. This might mean, typically, that a smaller shipment would be handled in local pickup and delivery service by a suitable small vehicle; and would be consolidated with other shipments having common destinations such as to fill a larger over-the-road vehicle for the inter-city line haul portion of the total movement.

The second difference, and one related to the first, was that in highway costing the density of the shipment being costed is explicitly taken into account. Since vehicle capacities are limited not only by weight but also by volume, it follows that a highway costing technique which does not include explicit determination of the number and type of vehicles required for a given shipment must include some other method for taking variations in space-occupancy of different commodities into account. Providing a density adjustment to the average unit costs was such a method, which will be discussed in more detail in the section beginning on page 30.

Figures 11 and 12 illustrate the variation of cost with shipment size for the highway mode. Figure 11A shows cost per shipment as a function of shipment weight for both 25 and 1,000 mile hauls. The lower curve at each distance indicated is for the higher density commodity, in these examples a density of approximately 20 to 30 pounds per cubic foot (typical of office machines, leather goods, fabrics and electronic equipment). The higher of the two lines is for a lower density of approximately 10 to 15 pounds per cubic foot (typical of footwear, furskins, and vehicles). Intuitively, it is to be expected that shipment density will be a factor in platform operations, on the pick-up and delivery portions of terminal costs, and on line-haul cost. The density effect was taken into account in the ICC source document by a weighted factor adjustment to line-haul unit costs. Figure 11B shows unit costs in cents per hundredweight for the same ranges of shipment sizes and distances as shown in Figure 11A. As was expected, unit cost decreased with increasing shipment size, probably due in part to efficiencies associated with larger vehicles, and in part to a reduction in shipment platform handling by the carrier. (The probability that a shipment will be picked up at the consignor's dock and transported in a single truck to the consignee's dock without intermediate terminal handling by the carrier increases as the shipment size increases). The rate of decrease in unit cost, however, became much lower after a shipment weight of approximately 399 hundredweight was reached. One possible explanation is that this shipment size corresponds to the point beyond which vehicle size,

Figure 11A. Highway Total Shipment Cost

Figure 11B. Highway Unit Cost

Figure 12. Highway Unit Distance Cost

because of existing regulations cannot be further increased and therefore the economies previously realized by increasing shipment size were no longer available.

Finally, Figure 12 shows the variation of unit distance cost in cents per ton-miles of service for the highway mode. As can be seen, the reduction in unit cost with increased shipment distance was quite large. For short distances, the reduction in unit cost with increasing shipment size was substantial, although the rate of decrease became lower as shipment size increased to that typically moved in the largest sized trucks. The rate of decrease at the longer distances was not nearly so great. Possibly this was due to the common use of the largest sized over-the-road trucks for all movements at this distance (i.e., the truck carrier would consolidate small shipments into full loads for the larger sized trucks).

COMPARISON OF SYSTEMS

Previous sections have presented the ICC estimates of the cost characteristics of three different intercity freight transport systems. This section will compare these characteristics for origin to destination intercity movements, at several levels of shipment size and distance.

The TOFC and highway systems as described in preceding sections were assumed capable of providing such a "dock-to-dock" service subject only to the constraint that both origin and destination shippers had highway loading and unloading facilities. For almost all shippers of general merchandise freight, such is the case. Some shippers, however, may not have direct rail access. It was necessary, therefore, to include in the rail system cost estimates provision for highway access at either origin or destination, or both, if required.

The highway portions of these access segments were assumed to be similar to pick-up and delivery operations included in estimates made of highway cost; and their cost was estimated on this basis. The line-haul transport of cargo was assumed to be accomplished by rail. On this basis for the rail mode, highway access cost at both origin and destination was composed of the highway origin and destination terminal cost which included the following items:

- (1) pick-up and delivery
- (2) highway platform handling
- (3) billing and collecting; and

a rail platform handling charge estimated at 13.58236 cents per hundredweight per handling (i.e., at each end) (5). Figure 13 presents highway access cost as

(5) ICC, Statement No. 101-73, p. 149.

Figure 13. Cost of Highway Access to Rail Carload Line-Haul

a function of shipment size on both unit and shipment cost bases, for highway access at either origin or destination or highway access at both origin and destination.

Figures 14, 15, and 16 present shipment, unit and unit distance costs for 175 and 1,000 mile (line-haul rail distance) movements as a function of shipment size for each of the three cases:

- (1) no highway access required (i.e., both shipper and receiver had direct rail access;
- (2) highway access required at either origin or destination, but not both; and,
- (3) highway access required at both origin and destination.

Costs were estimated for box, general service, equipped rolling stock, which is being used in an increasing percentage of general merchandise movements. Noted from Figures 14, 15, and 16 is that costs increased significantly as greater amounts of highway access were assumed.

Another factor which had to be taken into account before direct comparison could be made among the three intercity freight modes was route circuitry: the deviation of the path actually followed by a shipment from a reference distance between its origin and destination. This was an area similar to travel time, in that no reliable data were found for intercity freight transport modes. Absent such data, results of a recent study were adopted which assigned a circuitry (with reference to great circle distance) of 1.25 to rail and 1.20 to truck (6). Given this lack of data, the similarity of these estimates, and our knowledge that other estimates (of cost and travel time, for example) may well have variations of the magnitude of the differences between these circuitry values, it was assumed that these systems could be compared on an equal distance basis.

Now it was possible to compare costs of the three modal systems under the assumption that they were providing the same type of service. Such a comparison is illustrated in Figure 17 for a 1,000 mile line-haul movement, and in Figure 18 for a 175 mile line-haul movement.

In Figure 17, it is observed that truck is least costly for shipments up to about 220 hundredweight; that TOFC was least costly from that point up to a full (by weight) trailer load of about 488 hundredweight; and that relative ranking of modes according to least cost above that weight depended on whether or not highway

(6). Hannon, B. "A Railway Trust Fund", Transportation Research, Vol. 8, No. 4/5, October 1974. p. 364.

Figure 14. Rail Carload-Line Haul Plus Highway Access Total Shipment Cost

Figure 15. Rail Carload Line-Haul Plus Highway Access Unit Cost

Figure 16. Rail Carload Line-Haul Plus Highway Access Unit Distance Cost

Figure 17. Comparison of Costs: 1000 Mile Shipment Distance

Figure 18. Comparison of Costs: 175 Mile Shipment Distance

access to the rail boxcar system was necessary. If access at both ends is not required, then conventional rail is least costly for loads above 488 hundredweight. If, however, highway access service to rail was required at both origin and destination, then TOFC remained the low cost mode for loads up to 874 hundredweight, and above about 1,220 hundredweight.

As was discussed in the section on TOFC costs above, drayage cost had an important effect on total TOFC cost levels. The results cited in the example of Figure 17 would vary with changes in costs of drayage involved, which was assumed here to be at average non-urban area (relatively low) levels.

Figure 18 illustrates a similar comparison for a line-haul distance of 175 miles. The effect of distance on relative cost ranking was significant. With the exception of a small region around 485 hundredweight, within which TOFC is less costly than highway, the least cost system was either highway or conventional rail. The relative rank of conventional rail and highway depended again on the extent to which highway feeder service to rail line-haul was required. If highway access was not required, then rail remained the low cost system above 360 hundredweight. If highway access was required at both origin and destination, then the highway mode was least costly for all shipment sizes.

Figures 19 and 20 compare the same systems, loads, and distances on a unit distance cost (cents per ton-mile) basis.

COMMODITY DENSITY EFFECTS

Implicit in the system comparisons described above was the assumption that weight, rather than volume, was the limiting characteristic in determining the number of vehicles or containers necessary to transport any given shipment. Thus, a density of about 20 pounds per cubic foot was assumed in the highway cost calculations (Figures 17 through 20). This explains the "breaks" in the TOFC cost curves: once a single trailer was loaded to its weight capacity (around 25 tons), any remaining portion of a large shipment required a second trailer. Similarly, for a shipment size of 65 tons (1,300 hundredweight) in a conventional 40-foot boxcar the corresponding minimum density was about 27 pounds per cubic foot. These constraints were not addressed in the examples above, except as they are taken into account in the highway cost scales.

Figure 21 illustrates the interplay between the weight and volume capacities of the three systems in line-haul operation. Costs indicated by each curve were developed using the same basic data sources cited above. The difference, however, is that these costs for highway and conventional rail systems were "engineered" on the basis of costs per basic units of capacity and these were then used to

Figure 19. Comparison of Unit Distance Costs: 175 Mile Shipment Distance

Figure 20. Comparison of Unit Distance Costs: 1000 Mile Shipment Distance

Figure 21. Effect

on Cost Ranking of Systems

determine costs per vehicles required taking into account both weight and volume limitations of the vehicle used. The shipment size under analysis was 488 hundredweight--slightly less than the maximum highway trailer load by weight. Trailers in both highway and TOFC service were assumed to be of 2,300 cubic feet capacity (7). Conventional boxcars (4,900 cubic feet) are also assumed (8).

Figure 21 shows the effect of cargo density on volume occupancy, the number of vehicles required for a given shipment of specified weight and density, and therefore, the effect of shipment density on relative least cost ranking. For cargo density between about 11.1 and 21.2 pounds per cubic foot, conventional rail boxcar was least costly (refer to Figure 21) for all distances, and TOFC became second least costly above 400 miles. For more dense commodities, however (say, greater than about 21.2 pounds per cubic foot), highway was least costly below 125 miles, conventional rail between 125 and 700 miles, and TOFC above 700 miles. At the higher cargo densities a single trailer (either highway or TOFC) was able to carry the entire 488 hundredweight shipment. Thus, the effect of changes in cargo density may (as in our example) change the least cost ranking of the three modal systems for certain ranges of shipment distance.

CONCLUSIONS

This paper has presented the variable costs of providing conventional rail boxcar, trailer-on-flatcar and highway intercity freight services, based on Interstate Commerce Commission cost data and models. The presentation has taken two forms:

- (1) basic costs of each mode, and some discussion of the sensitivity of each to several different operating policies; and,
- (2) a comparison of the costs of each mode in the provision of total dock-to-dock freight transport service under various market conditions.

Our major findings were:

- (1) The high cost of local access to line-haul facilities (exemplified herein by highway access to rail line-haul) has significance for any multi-modal system which includes existing technology and current operating policies. Specifically, potential reductions in line-haul cost may be

(7). ICC, Statement No. 201-71, p. 23.

(8). Morlok, E.K., "An Engineering Analysis and Comparison of Railroad and Truck Line-Haul Work (Energy) Requirements", Measuring Energy Efficiency in Freight Transportation, (papers presented at Transportation Research Board Annual Meetings, 1976), American Trucking Associations, Inc., Washington, D.C.

more than offset by the high costs of local drayage and transfer between the modes.

- (2) Variations in cargo density result in very substantial variations in system costs, to the extent that the ranking by least cost of the three systems was changed.
- (3) Implicit in these conclusions was the inescapable but significant finding that the particular set of constraints (assumed conditions) under which service must be provided can in effect determine which of the modal systems was the least costly. A major implication of this is that it is not very meaningful to attempt to describe one modal system as always being preferred over some other mode. Instead, comparisons of these systems are only meaningful when the conditions to be satisfied are taken into account.
- (4) Although the costs portrayed in this paper were reasonable estimates of average cost obtaining in 1973 in the Northeast and Midwest region, they were deficient in the following respects:
 - (a) Because of the regional average basis of both unit costs and service units, these costs would not be a sound basis on which to evaluate specific services in any but the most cursory analysis.
 - (b) The current unsettled status of the rail system in the region might be resolved in such a way that institutional, operational and managerial changes would cause the cost assumptions used in this analysis to become obsolete.
 - (c) Item (b) notwithstanding, the passage of time lessens the accuracy of any estimates based on historical data.
- (5) To correct these deficiencies, research on the basic nature of transport system costs would be required. The direction of this research should be toward the goal of achieving a synthesis of traditional engineering and accounting cost methods, which combines the capability of engineered costs to replicate the relationships between the physical functions and the economic characteristics of a system with the comprehensiveness of accounting costs.

APPENDIX A: COST EQUATIONS

The purpose of this section is to present in equation form the cost information which was presented graphically in the main body of this paper. These cost equations will enable an analyst to estimate modal system costs with greater accuracy than would be possible through direct reference to graphs. The equations are also amenable to computer calculation, should this be required.

The format of this appendix follows that of the main paper in that each mode-- rail carload, trailer-on-flatcar, and truck-- was addressed in an independent section. Each section begins with a step-by-step explanation of the use of the cost equations (which includes the equations themselves), and includes a discussion of the accuracy of their fit to ICC cost data and a summary of the methods used in their development.

RAIL CARLOADUse of Basic Rail Carload Cost Formula (including highway access)

1. Determine shipment characteristics:

- S shipment weight, in hundredweight (1 cwt = 100 lbs)
- L shipment distance, in actual miles. If this is not available, two reasonable estimates are 1.25 times great circle distance; or 1.18 times rail short-line miles (for boxcar movements).
- D commodity density, in pounds per cubic foot. If this is not available, it can be computed (if shipment volume, V, in cubic feet, is known) using the formula:

$$D = \frac{100S}{V} \quad (1)$$

- t type of rail car used. Cost formulae for both unequipped and equipped general service boxcars are presented below.

- a highway access coefficient. There are three possible values which can be taken by a:

- (1) 0, indicating highway access at neither origin nor destination
- (2) 1, indicating highway access at either origin or destination, but not both;
- (3) 2, indicating highway access at both origin and destination.

2. Compute the number of rail cars required for shipment.

Volume capacity of an average rail boxcar is 4900 cubic feet. Deducting 10 percent for "broken stowage" (space which cannot be used due to irregularities in commodity shape, or non-optimum package dimensions, or the need for internal cushioning apparatus) results in usable space of 4410 (say, 4400) cubic feet.

Then the number of cars, n_D , to meet volume requirements is given by

$$n_D = \left\lceil \frac{100S}{4400D} \right\rceil = \left\lceil \frac{S}{44D} \right\rceil \quad (2)$$

where the brackets, $\lceil \rceil$, indicate the lowest integer greater than or equal to the enclosed quotient. This number can be adjusted upward for smaller than average and downward for larger than average rail cars; and upward for commodities having less space-efficient and downward for more space-efficient stowing characteristics.

Weight capacity of an average rail boxcar is 65 tons (1300 cwt). Then the number of cars, n_S , to meet weight requirements is given by

$$n_S = \left\lceil \frac{S}{1300} \right\rceil \quad (3)$$

Finally, the number of cars, n , required for any shipment of weight S and density D is the greater of n_S and n_D

$$n = \max(n_S, n_D)$$

3. Select applicable rail cost formula and compute rail cost.

For car type $t = 1$ (box, general service, unequipped):

$$c_1 = 116n + 0.00036S + L(0.31735n + 0.0001482S) \quad (4)$$

For car type $t = 2$ (box, general service, equipped):

$$c_2 = 116n + 0.00036S + L(0.42249n + 0.0001482S) \quad (5)$$

where $c_{(t)}$ is variable rail cost, in dollars per shipment.

4. Select applicable highway access formula and compute highway access cost.

Highway access cost is a function of shipment weight (S) and the number of access moves (a) required. The five formulae are:

$$h_s = a(4.628S^{0.463} - 0.1358S) \quad , \quad S < 100 \quad (6)$$

$$h_s = a(0.6338S - 0.001454S^2) \quad , \quad 100 \leq S < 200 \quad (7)$$

$$h_s = a(0.4748S - 0.000659S^2) \quad , \quad 200 \leq S < 300 \quad (8)$$

$$h_s = a(0.363S - 0.000286S^2) \quad , \quad 300 \leq S < 437 \quad (9)$$

$$h_s = a(0.2381S) \quad , \quad S \geq 437 \quad (10)$$

where $h_{(s)}$ is variable highway access cost, in dollars per shipment.

5. Total variable cost

$$c_{(t,s)} = c_{(t)} + h_{(s)}$$

Adjustments to Basic Formula

A. Car Type. Different types of rail cars have different cost characteristics (see Figure 4). These can be taken into account by substituting for the basic coefficient values of equation 4, as follows.

Equation 4 is of the form

$$c_i = B_i n + 0.00036S + L(E_i n + 0.0001482S)$$

Table A-1 presents coefficient values for B_i and E_i , the two coefficients which vary with car type. The wide variation among car types in weight and volume capacity requires that these characteristics be determined for each situation being analyzed.

The analyst must also use care in estimating highway access cost for other than general (manufactured) commodities, since equations 6 through 10 are based only on experience with such traffic.

B. Interchange/Intermediate switching. The costs estimated by the basic rail formulae include the cost of average interchange (between two railroads) and intermediate (within a single railroad) switching experience. If the analyst knows that the movement being costed experiences other than average interchange switching he may proceed as follows. (This example is for box, general service, unequipped.) The cost for x interchanges is given by

$$c_x = (36.54x - 0.06669L)n \quad (11)$$

The cost for y intermediate switchings is given by

$$c_y = (12.04y - 0.06017L)n \quad (12)$$

This value (c_x or c_y) should be added to the basic cost computed using equation 4.

C. Other adjustments are explained in the basic reference to this section, Rail Carload Cost Scales.

Discussion

The rail cost equations presented in this section give results essentially identical to the ICC cost data presented in the main body of this paper. Some error is introduced by the highway access cost estimating equations, especially at the low end of the shipment weight range. The greatest error is of the magnitude of three quarters of one percent; typical errors are much less than this. For this reason, the ICC estimates of shipment cost shown in Figure 12 are essentially identical to the equation estimates of these costs and a (duplicate) graph of the equation estimates is therefore not necessary here.

TABLE A-1

Cost Parameter Values of Common Railcars

<u>CAR TYPES</u>	<u>B_i</u>	<u>E_i</u>
Box, general, unequipped	116	0.31735
Box, general equipped	116	0.42249
Box, special	125	0.48218
Gondola, general	125	0.36845
Gondola, special	125	0.42881
Hopper, open, general	125	0.36958
Hopper, open, special	125	0.39423
Hopper, covered	125	0.42981
Stock	125	0.38486
Flat, general	125	0.37857
Refr, meat, mechanical	83	0.56499
Refr, o/t meat, mechanical	83	0.53508
Refr, meat, non-mechanical	83	0.53285
Refr, o/t meat, non-mech.	83	0.51725
Tank, 10,000-18,999 gal.	83	0.53861
Tank, 28,000-31,999 gal.	83	0.61566

TRAILER ON FLATCAR (TOFC)

Use of TOFC Cost Formula

1. Determine shipment characteristics:

- S shipment weight, in hundredweight (1 cwt = 100 lbs)
- L shipment distance, in actual miles. If this is not available, two reasonable estimates are 1.25 times great circle distance; or 1.09 times rail short-line miles.
- D commodity density, in pounds per cubic foot. If this is not available, it can be computed (if shipment volume, V, in cubic feet, is known) using the formula

$$D = \frac{100S}{V}$$

2. Compute number of trailers required for shipment.

Volume capacity of an average highway trailer is 2550 cubic feet. Deducting 10 percent for "broken stowage" (space which cannot be used due to irregularities in commodity shape, or non-optimum package dimensions, or the need for internal cushioning apparatus) results in usable space of 2295 (say, 2300) cubic feet.

Then the number of trailers to meet volume requirements, n_D , is given by

$$n_D = \left\lceil \frac{100S}{2300D} \right\rceil = \left\lceil \frac{S}{23D} \right\rceil \quad (13)$$

where the brackets, $\lceil \rceil$, indicate the lowest integer greater than or equal to the enclosed quotient. This number can be adjusted upward for smaller than average and downward for larger than average trailers, and upward for commodities having less space-efficient and downward for more space-efficient stowing characteristics.

Weight capacity of an average trailer is 24.5 tons (490 cwt). Then the number of trailers, n_S , to meet weight requirements is given by

$$n_S = \left\lceil \frac{S}{490} \right\rceil \quad (14)$$

Finally, the number of trailers, n , required for any shipment of weight S and density D is the greater of n_S and n_D .

$$n = \max(n_S, n_D)$$

3. Select applicable cost formula and compute cost.

$$c_1 = 193 + 0.00118S + (0.206 + 0.0001367S)L, \quad n = 1 \quad (15)$$

$$c_2 = 378 + 0.00118S + (0.379 + 0.0001367S)L, \quad n = 2 \quad (16)$$

$$c_3 = 566 + 0.00118S + (0.585 + 0.0001367S)L, \quad n = 3 \quad (17)$$

$$c_4 = 750 + 0.00118S + (0.758 + 0.0001367S)L, \quad n = 4 \quad (18)$$

where c_n is total variable cost, in dollars per shipment.

Adjustments to Basic Formula

A. Interchange/Intermediate Switching. These adjustments are similar to those explained in the preceding section on rail carload costs. The formulae are:

For x interchange switchings,

$$c_x = (30.79x - 0.04266L) \left[\frac{n}{2} \right] \quad (19)$$

For y intermediate switchings,

$$c_y = (10.14y - 0.033610L) \left[\frac{n}{2} \right] \quad (20)$$

In each case, the brackets, $\left[\right]$, indicate the lowest integer greater than or equal to the enclosed quotient.

B. Other adjustments are explained in the basic reference to this section,

Rail Carload Cost Scales.

Discussion

The TOFC cost equations presented in this section are essentially identical to the ICC TOFC cost estimates presented in the main paper in Figure 6. All deviations are substantially less than one half of one percent.

HIGHWAY COMMON CARRIER

Use of Highway Cost Formula

1. Determine shipment characteristics. This step is identical to that required in the TOFC cost estimation explained in the preceding section.
2. Select applicable cost formula and compute cost.

$$c_s = 924S^{-0.537} + (8.8286 + 0.16901L)(0.855 + 1.32e^{-0.1447(D-2.5)}) + (0.29293S^{-0.736})L \quad S < 100 \quad (21)$$

$$c_s = 70.51 - 0.2907(S-100) + (12.107 + 0.18098L)(0.855 + 0.68e^{-0.16176(D-7.5)}) + (0.00988 - 6.38 \times 10^{-5}(S-100))L \quad 100 \leq S < 200 \quad (22)$$

$$c_s = 41.44 - 0.1317(S-200) + (6.75 + 0.17275L)(0.885 + 0.68e^{-0.16176(D-7.5)}) + (0.0035 - 2.99 \times 10^{-5}(S-200))L \quad 200 \leq S < 300 \quad (23)$$

$$c_s = 28.27 - 0.0571(S-300) + (2.706 + 0.1509L) \\ (0.885 + 0.68e^{-0.16176(D-7.5)}) + 0.00051L \\ 300 \leq S \leq 437 \quad (24)$$

$$c_s = 23.153 + 0.13406L + 0.10261e^{-0.16176(D-7.5)}L \\ S > 437 \quad (25)$$

where c_s is unit variable highway cost, in cents per hundredweight. Total variable shipment cost, C_s in dollars per shipment, is given by

$$C_s = \frac{c_s S}{100} \quad (26)$$

Accuracy

The truck costs estimated by equations 21 through 25 are shown in Figure A-1. To facilitate comparison, the ICC costs from the source document Cost of Transporting Freight by Class I and II Motor Common Carriers of General Commodities (2) (which are also presented in Figure 11a) are shown on the same graph. The reader will note that the fit of the estimating equations is not as good as those for the rail modes. The errors, at representative shipment weights and distances, are presented in Table A-2. The size of the errors can best be discussed through reference to the procedure by which the equations were fit.

Discussion

The ICC highway cost estimates are composed of several components:

- 1) terminal (pick-up/delivery, platform handling, billing/collecting)
- 2) line-haul
- 3) intermediate transfer
- 4) density adjustment.

Each of these was estimated by a separate function. The accuracy of each function was influenced, of course, by the form of the underlying cost component. A more important determinant, however, was the necessity to balance the increased accuracy which might have been achieved by more complex functions against the practical requirements of computational efficiency. The density adjustment ratio, for example, varies with both distance and shipment size. The function selected to estimate it ignores the distance variation, thereby introducing an error of up to ± 3 percent in this factor. Similar small errors in each of the cost components can result in errors of the magnitude of those shown in Table A-2.

It is necessary, therefore, that an analyst using these equations be aware of the potential errors involved, although for the most common shipment distances and weights (e.g., 450 miles, 600 pounds) the total cost error is less than five percent.

Figure A-1. Highway Freight Shipment Total Cost: Comparison of Costs Estimated by Equations and ICC Base Estimates

Table A-2. Absolute and Percentage Deviations of Costs
Estimated by Equations from ICC Base Estimates

S (cwt)	Error											
	25 miles				400 miles				1000 miles			
	absolute		percentage		absolute		percentage		absolute		percentage	
	10-15 (\$/shipment)	20-30	10-15 (percent)	20-30	10-15 (\$/shipment)	20-30	10-15 (percent)	20-30	10-15 (\$/shipment)	20-30	10-15 (percent)	20-30
3.72	+1.3	+1.3	+8.0	+8.0	+1.6	+1.7	+7.6	+8.5	+2.3	+2.3	+8.7	+9.3
6.43	+0.3	+0.2	+1.3	+0.9	+0.2	+0.3	+0.7	+1.0	+0.6	+0.6	+1.5	+1.6
12.8	+0.6	+0.4	+1.9	+1.3	-0.1	-0.1	-0.2	-0.2	-0.5	-0.2	-0.1	-0.4
27.8	-1.2	-1.5	-2.5	-3.1	-3.2	-3.2	-4.2	-4.5	-3.8	-3.9	-3.4	-3.9
64.4	+3.1	+2.4	+4.4	+3.5	-0.2	-0.2	-0.2	-0.2	+0.2	--	+0.1	--
127.8	+17.4	+14.7	+19.8	+17.3	+7.7	+7.4	+3.5	+3.8	+11.07	+10.2	+3.0	+3.3
243.8	+13.1	+12.3	+10.7	+10.6	+7.8	+3.2	+2.4	+1.2	+28.5	+12.2	+4.9	+2.5
339.2	-7.5	-8.2	-6.1	-7.0	-2.0	-7.5	-0.1	-2.4	+13.5	-6.1	+1.9	-1.1
436.9	-13.1	-13.4	-9.6	-10.4	-5.7	-13.1	-1.2	-3.4	+14.0	-11.4	+1.6	-1.6

References

1. Interstate Commerce Commission, Bureau of Accounts, Rail Carload Cost Scales 1973, Statement No. 1C1-73, Washington, D.C., August 1975.
2. Interstate Commerce Commission, Bureau of Accounts, Cost of Transporting Freight by Class I and II Motor Common Carriers of General Commodities 1973, Statement No. 2C1-73, Washington, D.C., November 1974.

APPENDIX B: COMPUTER PROGRAMS

This section presents a computer program which performs the calculations described in Appendix A for each of the freight modes. Because the programs follow directly the logic of the manual computations described for each mode we have included no separate flow chart in this appendix. Included following each program is a sample of input data, and a sample of the output of that program.

Each program can be used separately, as we have illustrated here; or it can be included as a subroutine in a larger application. The programs were compiled in WATFIV and run on an IBM 370-168 computer. The cost of each program application on this system is approximately 33 cents.

The rail carload program is at pages 47-49; the TOFC at pages 50-51; and the highway at pages 52-53 .

COMPUTES VARIABLE COST OF RAIL CARLOAD FREIGHT SHIPMENTS

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INPUTS REQUIRED

SHIPMENT CHARACTERISTICS

WGHT = SHIPMENT WEIGHT IN HUNDREDS OF POUNDS (CWT)
 DSTNCE = SHIPMENT DISTANCE IN ACTUAL MILES
 DNSITY = COMMODITY DENSITY IN POUNDS PER CUBIC FOOT
 ACCESS = HIGHWAY ACCESS TO RAIL LINE-HAUL INDEX
 ACCESS = 0 IMPLIES HIGHWAY ACCESS REQUIRED AT NEITH-
 ER ORIGIN NOR DESTINATION
 ACCESS = 1 IMPLIES HIGHWAY ACCESS AT EITHER ORIGIN OR
 DESTINATION, BUT NOT BOTH
 ACCESS = 2 IMPLIES HIGHWAY ACCESS REQUIRED AT BOTH
 ORIGIN AND DESTINATION

RAIL SYSTEM CHARACTERISTICS

CRGROS = WEIGHT CAPACITY OF RAILCAR IN CWT
 CRCUBE = VOLUME CAPACITY OF RAILCAR IN CUBIC FEET
 MCRTYP = CAR TYPE INDICATOR (SEE TEXT FOR LIST)

PROGRAM OUTPUTS

VARCST = TOTAL VARIABLE COST PER SHIPMENT IN DOLLARS
 UNCCOST = VARIABLE UNIT COST IN CENTS PER CWT
 UNDCS = VARIABLE UNIT DISTANCE COST IN CENTS PER TON-MILE

8 100 FORMAT (14X,F6.0,19X,F6.2,14X,F6.3)
 9 200 FORMAT ('1',30X,'VARIABLE COST OF RAIL CARLOAD FREIGHT SHIPMENTS')
 10 300 FORMAT ('0',5X,'SHIPMENT COST IN DOLLARS',5X,'CENTS PER CWT',5X,
 1'CENTS PER TON-MILE ')
 11 400 FORMAT ('0')
 12 PRINT 200
 13 PRINT 300
 14 PRINT 400

COMPUTE NUMBER OF CARS REQUIRED

15 CARSC = (100.*WGHT)/(0.9*CRCUBE*DNSITY)
 16 NCARSC = CARSC
 17 IF (CARSC - NCARSC) 1,1,2
 18 2 NCARSC = NCARSC + 1
 19 1 CARSG = WGHT/CRGROS
 20 NCARSG = CARSG
 21 IF (CARSG - NCARSG) 3,3,4
 22 4 NCARSG = NCARSG + 1
 23 3 IF (NCARSG.GE.NCARSC) NCARS = NCARSG
 24 IF (NCARSG.LT.NCARSC) NCARS = NCARSC

SELECT CAR TYPE AND COMPUTE COST

25 GO TO (5,6), MCRTYP
 26 5 RLCOST = 116.*NCARS + DSTNCE*(0.31735*NCARS + 0.0001482*WGHT)
 27 GO TO 12
 28 6 RLCOST = 116.*NCARS + DSTNCE*(0.42249*NCARS + 0.0001482*WGHT)

SELECT COST FORMULA AND COMPUTE HIGHWAY ACCESS COST

29 12 IF (WGHT.GE.100.) GO TO 7
 30 ACCOST = ACCESS* (4.62*WGHT**0.463 - 0.1358*WGHT)
 31 GO TO 11

```

32      7 IF (WGHT.GE.200.) GO TO 8
33      ACCOST = ACCESS * (0.6338 * WGHT - 0.001454 * WGHT **2 )
34      GO TO 11
35      8 IF (WGHT.GE.300.) GO TO 9
36      ACCOST = ACCESS * (0.4748 * WGHT - 0.000659 * WGHT **2 )
37      GO TO 11
38      9 IF (WGHT.GE.437.) GO TO 10
39      ACCOST = ACCESS * (0.3630 * WGHT - 0.000286 * WGHT **2 )
40      GO TO 11
41      10 ACCOST = ACCESS * 0.2381 * WGHT
      C
      C      TOTAL VARIABLE COST C
      C
42      11 VARCST = RLCOST + ACCOST
      C
      C      CENTS PER CWT
      C
43      UNCONST = 100.*VARCST / WGHT
      C
      C      CENTS PER TON-MILE
      C
44      UNDSCTS = 20.* UNCONST / DSTNCE
      C
45      PRINT 100, VARCST, UNCONST, UNDSCTS

```

WGHT = 800.
DSTNCE = 1000.
DNSITY = 25.
ACCESS = 2.
CRGROS = 1300.
CRCUBE = 4900.
MCRTYP = 2

VARIABLE COST OF RAIL CARLOAD FREIGHT SHIPMENTS

SHIPMENT COST IN DOLLARS	CENTS PER CWT	CENTS PER TON-MILE
--------------------------	---------------	--------------------

1038.	129.75	2.595
-------	--------	-------

```

C      COMPUTES VARIABLE COST OF RAIL TOFC FREIGHT SHIPMENTS
C
C      INPUTS REQUIRED
C
C      SHIPMENT CHARACTERISTICS
C          WGHT = SHIPMENT WEIGHT IN HUNDREDS OF POUNDS (CWT)
C          DSTNCE = SHIPMENT DISTANCE IN ACTUAL MILES
C          DNSITY = COMMODITY DENSITY IN POUNDS PER CUBIC FOOT
C
C      RAIL SYSTEM CHARACTERISTICS
C          TRGROS = WEIGHT CAPACITY OF TRAILER IN CWT
C          TRCUBE = VOLUME CAPACITY OF TRAILER IN CUBIC FEET
C
C      PROGRAM OUTPUTS
C          VARCST = TOTAL VARIABLE COST PER SHIPMENT IN DOLLARS
C          UNCAST = VARIABLE UNIT COST IN CENTS PER CWT
C          UNDCS = VARIABLE UNIT DISTANCE COST IN CENTS PER TON-MILE.
C
C      *****
6      100 FORMAT (14X,F6.0,19X,F6.2,14X,F6.3)
7      200 FORMAT ('1',30X,'VARIABLE COST OF RAIL TOFC FREIGHT SHIPMENTS')
8      300 FORMAT ('0',5X,'SHIPMENT COST IN DOLLARS',5X,'CENTS PER CWT',5X,
9          1'CENTS PER TON-MILE ')
10     400 FORMAT ('0')
11     PRINT 200
12     PRINT 300
12     PRINT 400
C
C      COMPUTE NUMBER OF TRAILERS REQUIRED
C
13     TARSC = (100.*WGHT)/(0.9*TRCUBE*DNSITY)
14     NTARSC = TARSC
15     IF (TARSC - NTARSC) 1,1,2
16     2 NTARSC = NTARSC + 1
17     1 TARSG = WGHT/TRGROS
18     NTARSG = TARSG
19     IF (TARSG - NTARSG) 3,3,4
20     4 NTARSG = NTARSG + 1
21     3 IF (NTARSG.GE.NTARSC) NTARS = NTARSG
22     IF (NTARSG.LT.NTARSC) NTARS = NTARSC
C
C      SELECT COST FORMULA AND COMPUTE COST
C
23     GO TO (5,6,7,8),NTARS
24     5 VARCST = 193. + 0.00118*WGHT+ (0.206+0.0001367*WGHT)*DSTNCE
25     GO TO 9
26     6 VARCST = 378. + 0.00118*WGHT+ (0.379+0.0001367*WGHT)*DSTNCE
27     GO TO 9
28     7 VARCST = 566. + 0.00118*WGHT+ (0.585+0.0001367*WGHT)*DSTNCE
29     GO TO 9
30     8 VARCST = 750. + 0.00118*WGHT+ (0.758+0.0001367*WGHT)*DSTNCE
C
C      CENTS PER CWT
C
31     9 UNCAST = 100.*VARCST / WGHT
C
C      CENTS PER TON-MILE
C
32     UNDCS = 20.* UNCAST / DSTNCE
C
33     PRINT 100, VARCST, UNCAST, UNDCS

```


WGHT = 243.8
DENSITY = 12.5
DSTNCE = 1000.
TRCUBE = 2550.
TRGRDS = 490.

VARIABLE COST OF RAIL TOFC FREIGHT SHIPMENTS

SHIPMENT COST IN DOLLARS	CENTS PER CWT	CENTS PER TON-MILE
433.	177.45	3.549

COMPUTES VARIABLE COST OF HIGHWAY FREIGHT SHIPMENTS

INPUTS REQUIRED

SHIPMENT CHARACTERISTICS

WGHT = SHIPMENT WEIGHT IN HUNDREDS OF POUNDS (CWT)

DSTNCE = SHIPMENT DISTANCE IN ACTUAL MILES

DNSITY = COMMODITY DENSITY IN POUNDS PER CUBIC FOOT

HIGHWAY SYSTEM CHARACTERISTICS

TRGROS = WEIGHT CAPACITY OF TRAILER IN CWT

TRCUBE = VOLUME CAPACITY OF TRAILER IN CUBIC FEET

PROGRAM OUTPUTS

VARCST = TOTAL VARIABLE COST PER SHIPMENT IN DOLLARS

UNCOST = VARIABLE UNIT COST IN CENTS PER CWT

UNDSCS = VARIABLE UNIT DISTANCE COST IN CENTS PER TON-MILE

```

6 100 FORMAT (14X,F6.0,19X,F6.2,14X,F6.3)
7 200 FORMAT ('1',30X,'VARIABLE COST OF HIGHWAY FREIGHT SHIPMENTS')
8 300 FORMAT ('0',5X,'SHIPMENT COST IN DOLLARS',5X,'CENTS PER CWT',5X,
  1'CENTS PER TON-MILE ')
9 400 FORMAT ('0')
10 PRINT 200
11 PRINT 300
12 PRINT 400

C
C SELECT COST FORMULA AND COMPUTE UNIT COST
C
13 IF (WGHT.GE.100.) GO TO 7
14 UNCONST = 924.*WGHT**(-0.537)+(8.8286 + 0.16901*DSTNCE)*
  1(0.855 + 1.32*EXP(-.1447*(DNSITY-2.5)))+(0.29293*WGHT**(-0.736))*
  2 DSTNCE
15 GO TO 11
16 7 IF (WGHT.GE.200.) GO TO 8
17 UNCONST = 70.51 - 0.2907 * (WGHT - 100.) + (12.107 + 0.18098*DSTNCE
  1) * (0.885 + 0.68 * EXP(-0.16176*(DNSITY-7.5)))+
  2(0.00988 - 0.0000638 * (WGHT - 100.))* DSTNCE
18 GO TO 11
19 8 IF (WGHT.GE.300.) GO TO 9
20 UNCONST = 41.44 - 0.1317 * (WGHT - 200.) + (6.75 + 0.17275*DSTNCE
  1) * (0.885 + 0.68 * EXP(-0.16176*(DNSITY-7.5)))+
  2(0.00351 - 0.0000299 * (WGHT - 200.))* DSTNCE
21 GO TO 11
22 9 IF (WGHT.GE.437.) GO TO 10
23 UNCONST = 28.27 - 0.0571 * (WGHT - 300.) + (2.706 + 0.1509 *DSTNCE
  1) * (0.885 + 0.68 * EXP(-0.16176*(DNSITY-7.5)))+ 0.00051*DSTNCE
24 GO TO 11
25 10 UNCONST = 23.153 + 0.13406*DSTNCE + 0.10261*EXP(-0.16176*(DNSITY-
  1 7.5))*DSTNCE

C
C DOLLARS PER SHIPMENT
C
26 11 VARCST = WGHT * UNCONST / 100.

C
C CENTS PER TON-MILE
C
27 UNDCS = 20.* UNCONST / DSTNCE
C
28 PRINT 100, VARCST, UNCONST, UNDCS

```

WGHT = 64.4
DSTNCE = 1000.
DENSITY = 12.5
TRGROS = 490.
TRCUBE = 2550.

VARIABLE COST OF HIGHWAY FREIGHT SHIPMENTS
SHIPMENT COST IN DOLLARS CENTS PER CWT CENTS PER TON-MILE

206. 319.64 6.393

APPENDIX C: COST UPDATING

Although the costs presented above are useful in providing us with information on general cost behavior in the study year (1973), most applications would require more current estimates.

One means of updating is based on the Bureau of Labor Statistics (BLS) indices of rail freight costs. (Note that the BLS term "cost" corresponds to our term "rate"- the price charged to shippers by transportation firms - rather than to our "cost" - the cost to transportation firms of providing service). For example, in 1973 the index stood at 129.3 (1); and, its last reported level was 187.4 for June, 1976 (2). If we assume that rate increases mirror increases in carriers' costs, then we can update our 1973 cost estimates presented here by increasing them by the ratio of the current to the 1973 rate index. In the example above, this would mean multiplying the 1973 rail carload and TOFC cost estimates by 1.45.

A similar set of indices for highway common carrier costs (rates) is scheduled for release by BLS early in 1977.

(1). U.S. Department of Labor, Bureau of Labor Statistics, Monthly Labor Review, June, 1975, p. 20.

(2). U.S. Department of Labor, Bureau of Labor Statistics, Wholesale Prices and Price Indexes, U.S. GPO, Washington, D.C., 20402, June, 1976, Table 14.

VOLUME III

COST ESTIMATING METHODOLOGY

PART B

Freight Pipeline Cost Model

K. K. Gimm and Iraj Zandi

B - FREIGHT PIPELINE COST MODEL

I - Introduction

The purpose of this chapter is to present a model which allows one to estimate the total cost of construction and operation of various pipelines. Although the model is intended for pneumo-capsule freight pipeline systems, it may be used with minor modifications to estimate the cost of oil, water, sewer, and gas pipelines. The model has been developed for the purpose of a feasibility study. It employs a limited number of generalized parameters and its use recommended when sufficient, detailed and specific engineering information is lacking. Figure 1 shows the structure of the model and the cost categories included in the present analysis.

Each of the seven cost components identified in Figure 1 is analyzed separately and added to yield the cost equation:

$$C = \sum_{i=1}^7 \left\{ C_i - C_{si} \frac{1}{(1+r)^{n_i}} \right\} F_i + \sum_{i=1}^7 O_i \quad (1)$$

where

C = the total annual cost of the system in dollars,

C_i = capital cost of i -th cost component in dollars,

O_i = operation and maintenance cost of i -th cost component in dollars,

C_{si} = salvage value associated with capital cost component i , at the end of the useful life of the component, in dollars,

r = annual interest rate ($0 \leq r \leq 1.0$),

n_i = life span associated with i -th cost component, in years,

F_i = capital recovery factor equal to $\frac{r}{1 - (1+r)^{-n_i}}$,

i = index for counting cost components.

Pipeline Construction Cost, C_1 and C_2^*

Existing commercial freight pipeline installations (see Volume II) are too few to provide sufficient basis for cost analysis. However, from the standpoint of pipeline construction there will not be much difference between cost for gas, water, oil and freight pipelines, therefore data for existing commercial pipelines was analyzed to develop an expression for C_1 . This method of analysis provides a conservative estimate for freight pipeline construction costs because both oil and gas pipelines have to meet much more stringent safety regulations.

Many papers and reports are available which present and discuss pipeline construction cost data (1-20). Examination of this data shows that costs vary consider-

* In the present paper, "construction cost" implies the cost of pipe plus the cost of installation.

1-20 - These references are given in the bibliography to this chapter.

Figure 1.

ably, sometimes as much as fivefold even for seemingly identical projects. Several investigators have analyzed the data and have presented equations (sometimes tables or graphs) which allow the estimation of average construction costs. However, the accuracy with which these equations predict is rather poor. Even the most elaborate Koenig (21) equation predicts values which, when compared with the actual cost data, has only 68 percent probability to be within the range of ± 40 percent of actual values. It is obvious that an improved method of cost estimation is highly desirable. The present section offers such a method.

Table 1 lists the available equations:

Table 1
Pipeline Construction Cost

<u>Equation</u>	<u>Reference</u>	<u>Type of Pipeline For Which the Equa- tion Has Been De- veloped</u>	<u>Year</u>
$C_c = 1890D^{1.29}L'$	Lineweaver & Clark (22)	Oil, Gas, Water	1962
$C_c = 2160D^{1.2}L'$	Illinois Water Survey (23)	Water Main (6" through 48")	1967
$C_c = 3700DL$	Zimmerman (24)	All types	1963
$C_c = 15082D^{1.13}L'$	Paintal (25)	Sewer (Chicago)	1973
$C_c = (36130 + 14450Dt')L'G_f$	Research Council of Alberta (26)	Steel Pipeline	1973
$C_c = \alpha(D' + \beta)^{\gamma} LA_f \left(\frac{I_{R-68}}{I_{N-68}} \right) \left(\frac{I_c}{I_{c-68}} \right)$	Koenig (21)	All types	1968

- (21). Koenig, Louis. "The Cost of Pipelines in the United States" Louis Koenig Research, San Antonio, Texas, June, 1970.
- (22). Linaweaver, F.P., Jr., and C. Scott Clark. "Costs of Water Transmission" Journal of American Water Works Association. December, 1964.
- (23). Singh, Krishan P.. "Economic Design of Central Water Supply Systems". Water Resources Bulletin, Vol. 1, No. 1, February 1971.
- (24). Zimmerman, O.T., and Irvin Lavine. "Steel Piping", Cost Engineering, July, 1963.
- (25). Paintal, A.S. "Interceptor Sewer Cost Analysis". Water and Sewage Works, November, 1975.
- (26). Research Council of Alberta. TDA-RCA Capsule Pipeline Project: Capsule Pipeline System Analysis, Part 2 - Capsule Pipeline Techno-Economic Simulation Model. Alberta Research Information Series No. 67, October, 1974.

Pipeline Construction Cost (cont'd)

Equation	Reference	Type of Pipeline For Which the Equation Has Been Developed	Year
(See Table 2)	EPA (27)	Sewer	1972
$C_c = 138 + 4.9(d' - 11) + 2.5(d' - 72)$	Klegerman (28)	Sewer ($D' > 36$)	1964

where C_c is the construction cost in dollars, D and t' are the inside pipe diameter and the wall thickness respectively in inches. L' is the length of the pipeline in miles, and G_f is the geographic factor. Other notations are subsequently defined in the text, whenever they first appear, and are also shown in Nomenclature.

Table 2

Installed Cost* of Reinforced Concrete Pipe at Different Depths and Diameters, in \$ per Linear Foot, EPA Recommendations (27).

Depth of Cut (feet)	Expected Cost at Nominal Diameter					
	15 Inch	21 Inch	27 Inch	33 Inch	48 Inch	60 Inch
5	\$12.2	\$18.6	\$22.6	\$31.9	\$47.1	\$61.8
11	15.2	21.8	26.0	35.1	51.4	66.3
15	17.5	24.4	28.4	37.3	54.4	69.5
19	20.4	27.2	31.2	40.0	57.6	72.8
23	23.6	30.3	34.2	42.3	61.2	76.4

* U.S. Average Cost in September 1972 Dollars.

The first five equations in Table 1 are simple and self-explanatory. The two remaining ones, however, require some explanation.

a) Koenig (21) examined the cost data for 825 completed pipeline projects in the U.S. between 1936 and 1968 (many of which were for steel oil and gas lines, but also included 27 concrete water pipelines). Through statistical analysis, he developed the following equation for inland construction:

$$C = \alpha(D' + \beta)^{\gamma} L' A_f \left(\frac{I_{R-68}}{I_{N-68}} \right) \left(\frac{I_c}{I_{c-68}} \right) \quad (2)$$

(27). Environmental Protection Agency. Guidelines for Cost Estimates of Municipal Wastewater Systems, February, 1973.

(28). Klegerman, M.H. Fairfax County Integrated Sewerage Program, Sanitary Sewer Service in the Accontink and Dohick Creek Watersheds, Preliminary Design, Cost Estimates, Financial Requirements. A Feasibility Report Prepared for Fairfax County, Virginia, Alexander Potter Associates, New York, 1964.

where α , β , γ , and A_f are constants given in Table 3. I_{N-68} and I_{R-68} are the base year (1968) Engineerings News Record's Building Cost Index for the U.S. as a whole (national) and the region where the pipeline project was constructed, respectively. I_c and I_{C-68} are the composite pipeline index for the selected year of estimation and the base year (1968), respectively. I_c , for any given year, may be estimated from the following relationship:

$$I_c = \frac{I_B + I_{ICC}}{2} \quad (3)$$

where I_B is the Bureau of Reclamation Index for the concrete pipe and I_{ICC} is the Interstate Commerce Commission's Pipeline Index ratio (see Table 4).

Table 3
Constants for the Koenig Equation (21)

Block Name	Region	A_f	α	β	γ
Main	Atlanta	1.039			
	Baltimore	.081			
	Boston	1.778			
	Chicago	.849			
	Cincinnati	1.022			
	Cleveland	.888			
	Denver	.775	1280.180	2.044	1.379
	Los Angeles	.860	(For all cities in this category)		
	Minneapolis	.987			
	St. Louis	.820			
	Philadelphia	1.0			
	San Francisco	1.0			
Low Slope	Birmingham	1.025			
	Detroit	.781			
	New Orleans	1.176			
	New York	1.136	6378.012	.353	.931
	Pittsburgh	1.038	(For all cities in this category)		
	Seattle	.843			
High Slope	Dallas	1.10			
	Kansas City	.90	113.097	5.660	1.980
			(For all cities in this category)		

For offshore lines, Koenig proposed a cost adjustment factor using the following equation.

$$C_o = [1.08157 \ln(D) - 0.942702] C_c \quad (4)$$

where C_o is the construction cost of offshore pipeline projects in dollars.

Table 4
Indexes of ICC and Bureau of Reclamation

Year	ICC Index Base: 1947 = 100	I_{ICC}	Bureau of Reclamation Index (I_B) Base: 1967 = 1.0
1950	129	.71	.70
1955	149	.82	.93
1960	182	1.01	.96
1965	176	.97	.96
1966	179	.99	.96
1967	181	1.00	.99
1968	187	1.03	.103
1969	191	1.06	1.05
1970	198	1.09	1.00
1971	211	1.17	1.16
1972	221	1.22	1.28
1973	235	1.30	1.36
1974	279	1.54	1.45
1975			1.77

In the course of his study, Koenig made a number of interesting observations: 1) for lines longer than two miles there was no apparent correlation between the unit cost per mile and the length of the pipeline, 2) the cost of water pipelines did not differ from the cost of oil and gas pipelines of the same diameter, 3) there was no statistical evidence of the difference between the cost of concrete and steel pipes.

b) The Environmental Protection Agency (EPA) "Guidelines for Cost Estimation of Municipal Wastewater Systems" (27) is based on the analysis of cost data for reinforced concrete interceptors. Table 2, taken from this publication, gives the average national cost as a function of pipe diameter and the depth of excavation. Regional values may be estimated by applying an appropriate regional factor selected from Table 5.

Figures 2 and 3 show the inadequacy of existing cost equations. In these figures, the ratio of $\left(\frac{\text{predicted cost}}{\text{actual cost}}\right)$ is plotted against pipe diameter. To eliminate the visual bias which would be produced if the same vertical scales were used above and below the ratio of one, the lower scale was selected to reflect the multiplier effect. Any point below or above two lines designated "acceptable limits" indicates a poor prediction. These limits were selected arbitrarily, but in our judgement are reasonable.

II Construction Cost Equation *

Examination of cost data shows the dependence of cost on a multitude of variables. These include the characteristics of the pipe (diameter, length, thickness

* There are a number of price indexes used in the present analysis. Whenever a base year index is referred to, it means the value of that index for 1973.

Figure 2. Comparison of Predicted Cost, Using Koenig's Equation, with Actual Cost for Steel Cross-Country Pipelines*

Figure 3. Comparison of Predicted Cost, Using EPA's Method, with Actual Cost for Urban RCP.*

* Note that vertical scale changes ratio when ratio of predicted to actual cost becomes less than unity.

Table 5

Factors to Change National Average Sewer Costs to Regional

<u>City</u>	<u>Multiplying Factor*</u>
Atlanta	.89
Baltimore	1.03
Birmingham	.84
Boston	1.05
Chicago	1.05
Cincinnati	1.06
Cleveland	1.07
Dallas	.81
Denver	.84
Detroit	1.09
Kansas City	1.08
Los Angeles	1.03
Minneapolis	1.07
New Orleans	.82
New York	1.23
Philadelphia	1.09
Pittsburgh	.95
St. Louis	1.01
San Francisco	1.02
Seattle	.97

* Multiply estimates in Table 2 by this factor to obtain regional estimates.

of the wall and the material of construction); characteristics of location (cross-country, urban, central business district), installation, depth, wages, and governmental policies (safety regulations and right-of-ways). These parameters have to be taken into account to develop a comprehensive cost equation. In the present analysis, actual cost data were scrutinized in order to isolate the effect of the most important parameters.

The data bank consisted of information on 500 oil and gas pipelines, 600 urban sewers and water mains, and 80 tunnel constructions for the purpose of installing pipelines. These data were collected from published reports and periodicals between 1961 and 1975 (1-20). The Federal Power Commission (FPC) and the Interstate Commerce Commission (ICC) receive and file the completed cost data for all gas and oil pipelines. The Engineering News Record publishes most of the major sewer, water main, and tunnel cost data taken from bidding tables.

An initial comparison between urban pipelines (mostly sewers and water mains) and cross-country pipelines revealed significant differences in their construction characteristics (see Table 6). Because of these differences it was decided to analyze the data for each type of pipeline separately.

A - Cross Country Pipeline, C1

An examination of the cost data bank shows that for a pipeline project,

Table 6

Differences Between Typical Urban & Cross-Country Pipelines

<u>Variables</u>	<u>Urban</u>	<u>Cross Country</u>
Use	Sewage, Water Trans- mission	Oil & Gas Transmission
Pipe Material	Concrete, Iron	Steel
Depth of Installation	3'-40' Cover	3' Average Cover
Hydraulic Characteristics	Gravity Flow, Pressure Flow	Pressure Flow
Length/Project	Short, L' < 5 miles	Long, L' > 40 miles
Topography	Mostly Flat	Various Terrain Condition
Population Density	High	Moderate and Low

Table 7

Pipeline Cost Breakdown in Percent of Total Project Cost (2,18-20)

<u>Item</u>	<u>Kind of Pipeline</u>		
	<u>Crude Oil</u>	<u>Product Oil</u>	<u>Gas</u>
Line Pipe	39.0	42.8	38.5
Installation	52.2	50.5	47.3
Right-of-Way	3.6	3.0	6.6
Misc.	5.2	3.7	7.6
TOTAL	100.0	100.0	100.0

construction cost can be divided into four major categories. Further scrutiny of data, however, indicates that generally about 90 percent of the total project cost is due to the cost of "line-pipe"* and its installation as shown in Table 7. The present study, therefore, concentrates mainly on these items. However, it explicitly takes into account the cost accrual due to special structures (such as river crossings), and right-of-ways and damage. The impact of other variables are incorporated into the analysis via proper coefficients.

The construction cost, C_1 , of a pipeline project can be written as:

$$C_1 = \left[(p_m + p_i) + P_w \right] (L_i - L_r) + P_r L_r + P_o \quad (5)$$

where p_m is the cost of pipeline delivered at the project site, p_i is the cost of installation of the pipe, p_w is the cost of right-of-way and damages, P_r is the cost of river crossings, and P_o is the cost of other items, all in dollars per lineal foot of pipe. L_i is the length of the cross-country pipeline in feet, and L_r is the length of the river crossing in feet. In the following analysis each of these items is determined separately.

a) Cost of the "line-pipe", p_m - The cost per lineal foot of a pipe, of diameter D , pipe, grade g , for the year y , at the project site S ; p_{fDS}^{gy} ; can be written as:

$$p_{fDS}^{gy} = p_{fDM}^{gy} + T_{fDS}^y + F_{fDS}^y \quad (6)$$

where p_{fDM}^{gy} is the cost at the steel mill, T_{fDS}^y are taxes, and F_{fDS}^y are the freight charges in dollars per lineal foot of pipe. Subscripts, f , D and S specify the unit of lineal foot, the diameter and the site. Steel mill price, p_{fDM}^{gy} , itself is a function of the wall thickness, t , and the quality of pipe material g (known as the grade of the pipe). The dependency of p_{fDM}^{gy} on the wall thickness, t , is shown in Figure 4 where costs per lineal foot of the same grade of pipe, obtained from a survey of various steel mills, are plotted vs. pipe diameter. The variation seems to be related to the amount of steel used in the production of pipes of various thicknesses. The explicit impact of wall thicknesses, however, disappears when we plot the steel mill price in units of dollars per ton of pipe, p_{TM}^{gy} (instead of dollar per lineal foot, p_{fDM}^{gy}) versus the pipe diameter (see Figure 5). The data points not only converge to a single line but become almost independent of pipe diameter indicating that for any given grade the most significant cost parameter (at the mill) is the weight of steel used in the pipeline construction. We can write:

*"Line-pipe" implies the cost of pipe, delivered at the site of the project.

Figure 4.
Steel Mill Price of Line Pipe in \$/Feet⁽²⁹⁾
Grade = APL 5L = B

Figure 5.
Steel Mill Price of Line Pipe in \$/Ton⁽²⁹⁾
Grade = APL 5L = B

$$p_{fDM}^{gy} = p_{TM}^{gy} W_r \quad (7)$$

where W_r is the weight per lineal foot of pipe in tons and can be calculated from the following relationship:

$$W_r = \pi D t s \quad (8)$$

where D is the inside diameter in feet, t is the thickness in feet and s is the specific weight of steel in tons per cubic foot. Substituting W_r from equation (8) into equation (7) yields:

$$p_{fDM}^{gy} = p_{TM}^{gy} \pi D t s \quad (9)$$

Substituting equation (9) into equation (6) yields:

$$p_{fDS}^{gy} = p_{TM}^{gy} \pi D t s + T_{fDS}^y + F_{fDS}^y \quad (10)$$

For any given and specific project where the location of the project, the year of the construction, and the variables of design are known, equation (10) can be used to estimate the value of p_{fDS}^{gy} directly. But often in feasibility studies, one is interested in estimating the costs of various combinations of parameters. Therefore, it is useful to convert equation (10) into a general relationship which, with a minimum of specific information, will yield a reasonable and acceptable cost estimate.

To this end, an expression will first be developed from the study of available data taken from existing pipelines for the average of the sum of $T_{fDS}^y + F_{fDS}^y$. Second, this expression will be rendered sensitive to time by using an appropriate price index. Thirdly, the revised equation (10) (after substitution of the calculated values of $T_{fDS}^y + F_{fDS}^y$) will be modified to take into account the grade variation.

Let $R_{fDS}^y = T_{fDS}^y + F_{fDS}^y$. Equation (10) can then be written as:

$$R_{fDS}^{gy} = p_{fDS}^{gy} - p_{TM}^{gy} \pi D t s \quad (11)$$

Equation (11) can be modified by expressing the terms in units of dollars per ton,

i.e., $R_{fDS}^y = R_{TS}^y \pi D t s$ and $p_{fDS}^{gy} = p_{TS}^{gy} \pi D t s$:

$$R_{TS}^y = p_{TS}^{gy} - p_{TM}^{gy} \quad (12)$$

where subscript TS specifies the cost per ton for the job site S. Now the terms in the right hand side will be evaluated separately.

Two sets of data are available: 1) information in the data bank, described

previously, yields p_{TS}^{gy} for each project, and 2) information regarding p_{TM}^{gy} provided by three steel manufacturers (29-31). From this information, an average value of R_{TS}^y / p_{TM}^{gy} for each year of the data bank can be calculated in the following manner.

First, from equation (12) for each project:

$$\frac{R_{TS}^y}{p_{TM}^{gy}} = \frac{p_{TS}^{gy}}{p_{TM}^{gy}} - 1 \quad (13)$$

Second, an annual average value for $\frac{R_{TS}^y}{p_{TM}^{gy}}$ designated as X^y , can be calculated:

$$X^y = \left[(\sum p_{TS}^{gy}) / k \right] / \left[(\sum p_{TM}^{gy}) / m' \right] - 1 \quad (14)$$

where k is the number of projects in year y and m' is the number of manufacturers who provided information on p_{TM}^{gy} .

Now the average value of X^y can be approximated as follows:

$$X = \frac{\sum X^y}{n'} = \left\{ \sum \left\{ \left[(\sum p_{TS}^{gy}) / K \right] / \left[(\sum p_{TM}^{gy}) / m' \right] - 1 \right\} \right\} / n' \quad (15)$$

where n' is the number of years for which data is available. Assuming that the ratio X remains constant*, equation (11) can be written as:

$$p_{TS}^{gy} = p_{TM}^{gy} (1 + X) \quad (16)$$

which may be heuristically generalized with respect to both time and the grade of pipeline via the use of appropriate indexes, and assuming the knowledge of a steel

* In the present analysis, it is assumed that the location will only influence the cost of installation (see next section). Impact of location on the cost of line-pipe has not been taken into consideration.

(29). Bethlehem Steel Corporation. Tubular Products Prices: Section Q=3, Electric Fusion Weld Pipe. September 1, 1975.

(30). United Steel Corporation. Price List for "USS Submerged Arc Welded Steel Pipe", September 1975.

(31). Sumitomo Metal America, Inc., Price Quotation for Submerged Arc Welded or Spiral Welded Line Pipe. October, 1975.

mill price for a specific year and specific grade (base mill price):

$$P_T = G I_m p_{TM}^B (1 + X) \quad (17)$$

where p_T is the average cost per ton of "line pipe" of any grade g , at the average project site, at any given year; G is a ratio accounting for the variation in the grade; and I_m is a ratio incorporating the pipe price change with the year; p_{TM}^B is the base mill price for one ton of steel at the mill, of a given grade in a given year. The influence of the diameter and thickness upon the cost calculations can be made explicit by rewriting equation (17) in the following manner:

$$P_m = G I_m p_{TM}^B (1 + X) \pi D t s \quad (18)$$

where P_m is the cost of line-pipe of diameter D , thickness t , grade g and in the year y , in dollars per foot.

The generalization of line-pipe cost as achieved in equation (17) ties the process of estimation to the knowledge of a base mill price p_{TM}^B . But since the prices for the present (or for years in the past) are known, this does not generate any difficulty for the cost prediction of future projects. The values of G and I_m are given in Table 8 and Table 9, respectively.

b) Installation Cost, P_i - The installation cost consists of two major components: labor and equipment. The labor cost is a function of both wage rates and the required man-hours. The equipment cost depends on both the cost of the equipment itself and the required equipment hours. When specific information regarding a given project is known, these items can be evaluated with a reasonable degree of accuracy and used to estimate the cost. This procedure is normal practice in the field of pipeline design. However, when specific project information is lacking, as is always the case for preliminary studies, a general methodology of cost estimation is required. This section describes one such methodology.

The installation cost is a function of the following variables: pipe diameter, year of construction, wage rate, congestion (population density), topological conditions (flat, hilly, mountain), ground conditions (wet, dry, swamp, off-shore, rocks), government and union regulations (safety, work rules), weather and seasons (cold, heat, rain, snow, wind), labor quality or productivity (war and peace, recession and boom, degree of activity, company reputation, labor relation), and pipe material (steel, concrete).

An examination of the information in the data bank shows that the first six variables are generally responsible for the major portion of the total cost. The re-

Table 8 - Values of G for Steel Pipe

<u>Grade</u>	<u>G</u>	<u>Specification</u>
B (Base)	1.0	API STD. 5L and 5LX
X-42	1.04	API STD. 5L and 5LX
X-46	1.05	API STD. 5L and 5LX
X-52	1.10	API STD. 5L and 5LX
X-56	1.135	API STD. 5L and 5LX
X-60	1.145	API STD. 5L and 5LX
X-65	1.18	API STD. 5L and 5LX

Table 9 - Steel Pipe Price Index*

<u>Year</u>	<u>Price Index</u>	
	<u>Trunk Line Index(I_t)**</u>	<u>Wholesale Price Index(I_w)***</u>
1960	91.6	104.5
1961	91.6	102.9
1962	91.6	103.5
1963	92.7	106.7
1964	95.8	103.6
1965	97.9	97.9
1966	97.9	97.9
1967	100.0	100.0
1968	100.5	104.0
1969	104.2	109.2
1970	108.4	114.7
1971	112.6	124.7
1972	118.4	113.7
1973	125.8	139.1
1974	180.5	189.8
1975	200.0	227.8

- (*) I_m can be calculated from this table by finding the ratio of I_t for any desired year over the I_t for the base year. Since I_t is not readily available, one may use the I_w .
- (**) I_t is developed for the present study from the steel mill price (trunk line pipe) provided by the U.S. Steel Corporation, Pittsburgh, Pa.
- (***) I_w is published monthly by the U.S. Department of Labor⁽³²⁾. This index is developed from the price survey of 12" O.D. steel pipe.

maining variables contribute in minor ways, except for a few special cases such as the trans-Alaskan pipeline and cross country concrete pipelines. Thus, in the present analysis, only the six major variables will be considered. In mathematical terms, this statement can be formulated as:

$$P_i = P_i(D, y, w, P_d, T_f, W_f) \quad (19)$$

where the terms on the right hand side, either directly or indirectly represent the major variables. D is the diameter of the pipe in ft., y is the year of construction, w is the wage rate in dollars per hour, P_d is the population density in persons per square mile, T_f is the topographical factor and W_f is the ground condition factor -- both expressed in per cent.

The explicit form of equation (19) was derived through a step-by-step systematic application of information in the data bank. At the outset, it should be noted that much of the analysis which will follow is empirical and intuitive. The goal has been to develop an installation cost equation which is capable of predicting values which are reasonably close to the published data. Much less attention has been paid to mathematical rigor. The general procedure has been to select a group of data representing the least number of variables with the largest influence on cost and, through mathematical transformation, converting them to a set of similar cost data which are a function of only one variable. The functional relationship between cost and this one variable was then evaluated. This relationship was generalized step-by-step to include the impacts of other variables.

Diameter Effect - The data bank was searched to identify the sets of data for which 1) all variables within each set were the same, except for the pipe diameter, and 2) projects having different pipe diameters were sufficiently numerous to represent a broad range of sizes. It was found that for 1969, in four states, these conditions were satisfied. Figure 6 shows the cost data plotted versus diameter for these four states.

Each set of data could be represented by the following equation:

$$P_i = \phi(y, w, P_d, T_f, W_f) D \quad (20)$$

where ϕ is a new function of y, w, P_d, T_f, W_f .

Time Effect - The yearly variation of ϕ can be heuristically assumed to be related to the variation of the Pipeline Construction Index*:

* This index is published by the Interstate Commerce Commission (32)

(32). Interstate Commerce Commission Account No. 105-155 (Pipeline Construction) in Schedule of Annual Indices for Carriers by Pipeline, 1948 through 1974.

Figure 6. Plot of P_i Against D for Four States.

$$\phi(y, w, P_d, T_f, W_f) = \frac{I_y}{I_b} \psi(w, P_d, T_f, W_f) \quad (21)$$

where I_y is the index for the year y and I_b is the index for a base year b . If we let $I_i = \frac{I_y}{I_b}$, then equation (20) becomes:

$$P_i = \psi(w, P_d, T_f, W_f) I_i D \quad (22)$$

Table 10 provides information regarding I_i .

Table 10 - Values to Find I_i and I_f

Year	ICC	USDA
	Pipeline Construction Index 1947=100 (I_y)	Farm Real Estate Index 1967=100 ($I_f y$)
1940	62.0	18.0
1950	120.0	40.0
1955	125.0	52.0
1959	152.0	65.0
1960	152.0	68.0
1961	152.0	69.0
1963	149.0	76.0
1964	149.0	81.0
1965	154.0	86.0
1966	168.0	94.0
1967	176.0	101.0
1968	185.0	107.0
1970	206.0	117.0
1971	227.0	122.0
1972	245.0	132.0
1973	265.0	150.0
1974	297.0	187.0

Wage Rate Effect - Equation (22) is now modified to show the explicit influence of the variation of the wage rate. This is accomplished by assuming that the functional relationships between the national annual average installation costs and national annual average wage rates, for a given pipe diameter, will be identical with installation costs as a function of the geographical variation of annual average wage rates for the same year. This is a reasonable assumption so long as labor requirements and/or the installation technology does not change significantly. The following procedure, then, was followed.

1) All pipeline cost data for a single diameter, 30 inches, were identified within the data bank. There were 263 data points in this category. Cost data for each year of the record were then averaged to yield C' which is the national average cost of installation for a 30 inch pipe in the year y . Figure 7 shows that C' plotted

Figure 7. Plot of C' Against $W_{N,y}$

against average annual national wage rates* $w_{N,y}$, for the year y approximately exhibits the relationship

$$C' = b(w_{N,y})^{0.92} \quad (23)$$

The functional relationship presented in equation (23) (related to time) is now assumed to prevail between installation cost and local wage rates, that is:

$$C'_S = b'(w_{S,y})^{0.92} \quad (24)$$

where C'_S is the annual average installation cost of a 30 inch pipe in geographical location S , b' is a constant, and $w_{S,y}$ is the annual average wage rate in the geographical location S in year y . Combining equations (23) and (24):

$$C'_S = b_1(w_{S,y}/w_{N,y})^{0.92} \quad (25)$$

where b_1 is equal to $C'(b'/b)$.

Equation (25) holds only when the data belong to pipelines with 30 inch diameters. A comparison of equations (25) and (22) allow us to write:

$$P_i = \theta(P_d, T_f, W_f)W^{.92}I_i D \quad (26)$$

where W is the ratio $(w_{S,y}/w_{N,y})$, and θ is a new coefficient. W , for the base year 1973, is given in Table 11.

Congestion, Topological and Ground Effects - Evaluating θ involves finding some quantifiable expressions for congestion, topological conditions and ground conditions. In the present study, we assumed that congestion can be described in terms of population density, P_d . Topological conditions may be characterized by a terrain factor, T_f , defined as the percentage of the area covered with rugged terrain and can be estimated from the land surface maps published by the U.S. Geological Survey (33). Table 11 lists these terrain factors for various states. The ground conditions will be identified by a wet land factor, W_f , defined as the percentage of wet or swampy areas in the state. W_f is estimated for each of the states with more than 1% of the wet land, using a U.S. Department of Interior publication (37). These values are listed in Table

* The annual wage rates were obtained from the Pipe Line Contractor's Association, Dallas, Texas.

(33). U.S. Geological Survey. Land Surface Map in The National Atlas of the U.S.A. 1970.

(37). Shaw, Samuel P., and Gordon C. Fredine. Wet Lands of the U.S. U.S. Fish and Wildlife Service Circular No. 39, U.S. Printing Office, Washington, D.C., 1956.

Table 11 Values of P_d , W , T_f , and W_f

State	Population Density Persons/sq.mi. (P_d)	Wage Rate Factor (W)	Terrain Factor Percent (T_f)	Wet Land Factor Percent (W_f)	State	Population Density Persons/sq.mi. (P_d)	Wage Rate Factor (W)	Terrain Factor Percent (T_f)	Wet Land Factor Percent (W_f)
AL	70	.866	0	5	NB	20	.885	0	0
AK	1	1.522	0	0	NV	5	1.185	50	0
AZ	18	1.172	30	0	NH	88	.977	0	0
AR	39	.865	10	11	NJ	979	1.141	0	0
CA	132	1.251	50	0	NM	9	.889	40	0
CO	23	.926	40	0	NY	382	1.203	5	0
CT	633	1.103	0	0	NC	108	.858	10	13
DE	291	.926	0	0	ND	9	.861	0	0
FL	142	.865	0	16	OH	262	1.078	5	0
GA	82	.865	5	0	OK	39	.861	0	0
ID	9	1.088	60	0	OR	23	1.073	30	0
IL	202	1.088	0	0	PA	265	1.021	20	0
IN	147	1.014	0	0	RI	928	1.106	0	0
IA	52	.941	0	0	SC	90	.856	5	18
KS	28	.984	0	0	SD	9	.861	3	0
KY	84	.985	30	0	TN	100	.866	10	0
LA	84	.890	0	34	TX	45	.861	2	0
ME	33	.911	5	0	UT	14	1.112	50	0
MD	411	.926	0	0	VT	50	.954	0	0
MA	743	1.047	0	0	VA	121	.889	20	0
MI	159	1.088	0	9	WA	52	1.188	50	0
MN	49	1.020	0	10	WV	75	.934	75	0
MS	48	.855	0	9	WI	84	1.088	0	8
MO	69	1.140	10	0	WY	4	.873	20	0
MT	5	1.185	40	0	All Off-Shore	0	W of Shore State	0	100

* $W = W_S / W_N$, W_S in this table is an average wage rate of 4 pipeline labor groups (welders, laborers, operating engineers, and teamsters) obtained from Pipe Line Labor Manual ⁽³⁵⁾

** To find T_f , land surface form that may obstruct pipeline construction is assumed to be the land surface classes of B6, C6, D4, D5, and D6 ^(34,37)

11. For off-shore pipelines, it may be assumed that $W_f = 100$ and $T_f = 0$.

To further develop equation (26) so that it explicitly exhibits the influence of the three parameters -- P_d , T_f , and W_f -- the following steps were taken:

1) By examining the data bank, all of the installation cost data concerning projects with 30 inch pipe was separated.

2) These costs were appreciated to a reference year (1973) by the use of an installation cost index ratio, I_i .

3) Equation (25) was used to adjust the appreciated data as if they were accrued at the same wage rate (w_N , ($y=73$))

4) These adjusted data were subsequently grouped and the average value for each state was found. The average values are, at least in principle, for the same year, wage rate, and diameter, but include the variation of P_d , T_f , and W_f .

5) The set of data obtained in step 4 was searched for states with almost the same T_f and W_f . The installation cost thus selected was plotted against P_d in Figure 8.

The relationship can be expressed as:

$$C'' = b_2 \left(\frac{P_d}{200} \right)^\delta \quad (27)$$

where C'' is the average installation cost for 30" pipes, adjusted to 1973, and for the national wage rate in 1973; $\delta = 0$ for $P_d \leq 200$, $\delta = 1.1$ for $1200 > P_d > 200$ (P_d can be obtained from Table 11), and b_2 is a coefficient.

6) The set of data derived in step 5 was then readjusted by using equation (27) to convert all data to the same population density.

7) This new set was again searched for those data with almost the same W_f . The cost data thus selected was plotted in Figure 9 against T_f .

The relationship in Figure 9 can be described as:

$$C''' = b_3 e^{.01 T_f} \quad (28)$$

where C''' is the cost for a 30 inch pipe, adjusted to 1973, for the average national wage rates in 1973, and for areas with $P_d < 200$ persons/sq mile population density, and the same W_f . b_3 is a coefficient.

8) Finally, the data derived in step 6 was readjusted again with the use of equation (28) to normalize the cost data also with respect to T_f . Figure 10 shows the adjusted cost (presumably only a function of W_f) versus W_f . Although the points are dispersed, the relationship may be roughly described as:

$$C'''' = b_4 e^{0.016 W_f} \quad (29)$$

Figure 8. Plot of C'' Against P_d .

Figure 9. Plot of C''' Against T_f . Figure 10. Plot of C''' Against W_f .

Figure 11. Plot of P_w Against P_d .

where C''' is the installation cost for a 30 inch pipe, adjusted to 1973, for the average national wage rate in 1973, for areas with $P_d < 200$ and the same T_f .

Installation Cost P_i - Comparison of equations 26, 27, 28, and 29 permits the reformulation of equation 19 in the following manner:

$$P_i = \epsilon I_i DW^{.92} \left(\frac{P_d}{200}\right)^{\delta} e^{.01 T_f} + .016 W_f \quad (30)$$

where ϵ is a coefficient.

c) Cost of Right-of-Way and Damages, P_w - Costs of right-of-way acquisition and damages are one of the most widely varying elements in pipeline construction. For instance, the cost of right-of-way for a project in New Jersey may be expected to be about 8 times as much as one in Mississippi (10). Including damages, it may be 12 times as great. The cost of right-of-way and damages, P_w is assumed to be the function of population density, P_d , only. Therefore, the following steps were taken to find the relationship between the two variables: 1) All 30 inch data in the data bank was selected, 2) this data was divided into 50 states, 3) the Department of Agriculture's Farm Real Estate-Index (38) (see Table 10) was used to adjust the data for the same year, 4) the average cost value for each state was then found, 5) these averages were plotted in Figure 11 against population density, P_d , and 6) the relationship was formulated. The result is the following:

$$P_w = \sigma I_f P_d^{0.8} \quad (31)$$

where I_f is the ratio of the Farm Real Estate-Index calculated for any desired year over a base year, and σ is a coefficient.

d) River Crossing, P_r - A search of the data bank revealed that only seven projects contain full information regarding the cost of river crossings. The analysis of this data shows that P_r is the function of diameter, length of the crossing, and the installation index, giving an approximate relationship:

$$P_r = \tau D L_r^{0.55} I_i$$

where L_r is the length of river crossing in feet and τ is a coefficient.

e) Miscellaneous Cost P_o - P_o is about 10 percent of the total project cost for dry-land pipeline and up to 30 percent for wet-land and off-shore pipeline, i.e.:

(38). Farm Real Estate Market Developments, Annual Publication U.S. Department of Agriculture, Economic Research Service, U.S. Government Printing Office, Washington, D.C., 1960 through 1975.

$$P_o = \xi \left\{ \left[(P_m + P_i + P_w) \right] (L_i - L_r) + P_r L_r \right\} \quad (33)$$

where $\xi = 0.1$ for dry land projects and 0.3 for off-shore projects.

f) Construction Cost Equation - The substitution of equations (18, 30, 31, 32, and 33) into equation (5) yields the construction cost equation:

$$C_1 = \left\{ \left[G I_m P_{TM}^B (1 + X) \pi D t s + \epsilon I_i D W^{0.92} \left(\frac{P_d}{200} \right)^\delta e^{(0.01 T_f + 0.016 W_f)} + \sigma P_d^{0.8} I_f \right] (L_i - L_r) + \tau D L_r^{1.6} I_i \right\} (1 + \xi) \quad (34)$$

Equation (34) can be simplified through the following considerations: 1) $P_{TM}^B = \$239/\text{ton}$ if 1973 is the base year and B is the base grade of the steel (Table 8); 2) $X = .114$ computed from the analysis of the data bank using equation (15); 3) $S = .2448$ tons per cubic foot of steel; 4) coefficients ϵ , σ , and τ are calculated from the data bank when 1973 is chosen as the base year; $\epsilon = 4.02$, $\sigma = 0.04$, $\tau = 1.55$:

$$C_1 = \left\{ \left[205.0 G I_m D t + 4.0 I_i D W^{.92} \left(\frac{P_d}{200} \right)^\delta e^{(0.01 T_f + 0.016 W_f)} + 0.04 P_d^{0.8} I_f \right] (L_i - L_r) + 1.6 D L_r^{0.55} I_i \right\} (1 + \xi) \quad (35)$$

For the purpose of estimating cost, equation (35) requires the knowledge of the following 7 design variables: D , t , G , y , L_i , L_r , and S . All of the other parameters can be found from tables in this paper. In equation (35) the values of W , T_f , W_f , and P_d are state averages; local values should be used if the local C within the state is desired.

Verification - Equation (35) was used to predict the installation cost for all of the cross-country projects in the data bank which had full information on the six design variables. This predicted cost was then compared with the actual cost. Figure 12 shows that the proposed equation predicts "all" values within the selected range of ± 40 percent of actual values. Furthermore, 68 percent of the values lie within a ± 18 percent range of the actual cost. When Figure 12 is compared with Figure 2, the improvement over the existing equation (5) is obvious.

Equation (35) predicts, within acceptable limits, the cost of projects in such areas as the congested northeastern states and/or states with rugged terrain and swampy ground where previously available equations fail badly (sometimes up to 300 percent error).

Figure 12. Comparison of Predicted Cost, Using the Proposed Equation, with Actual Cost for Steel Cross-Country Pipelines.

Urban Pipeline, C_2

Equation (35), developed for the cross-country pipeline, is applicable only to low density areas ($P_d < 1200$). For highly developed center cities, the cost of installation will be much higher and requires special consideration. The following analysis is directed toward the development of a cost equation for urban areas with high population densities.

Examination of urban cost data in the data bank indicates that the total pipeline construction cost may be divided into four broad categories and 17 sub-categories as shown in Table 12 (information about each of these sub-categories may not be available for each project, or several sub-categories may have been combined). The common practice for estimating the cost of an urban pipeline, at the present time is to estimate the cost of each sub-category based on the completed design of the given project. This is done with the aid of "Cost Estimating Manuals", several of which are

Table 12
Cost Categories of Urban Pipeline

1. Open-Cut Pipeline
 1. Pipes including placing
 2. Mobilization
 3. Traffic control and policing
 4. Clearing
 5. Earth work - excavation, backfill (dirt or gravel)
 6. Trench sheeting and shoring
 7. Special bedding - conc. cradel and encasing
 8. Surface restoration - paving, seeding, sod
 9. Clean up
2. Tunnelled Pipeline
 10. Boring
 11. Jacking
3. Other Related Structures
 12. Manholes
 13. Gates and valves
 14. Storm drains, catch basins, and junction boxes
 15. Hydrants
4. Work Related to Existing Structures
 16. Connection to existing pipes (wyes, tees)
 17. Existing pipe removals or alterations

available (39-43). The utilization of this technique, however, requires access to much detailed information which normally is lacking during the feasibility study or is expensive to acquire. On the other hand, if equations given in Table 1 are used for this purpose, the degree of accuracy will be very poor.

Equation (5) can be modified for application to urban centers to yield:

$$C_2 = [P_{um} + (P_{ip} + P_{ie})] (L_2 - L_t) + P_{uc}L_t + P_{uo} \quad (36)$$

where C_2 is the total pipeline cost in urban communities in dollars, L_2 is the total length of the pipeline in feet, L_t is the total length of the pipeline constructed by the tunnelling technique, P_{um} is the cost of the "line-pipe", P_{ip} is the "placement cost", P_{ie} is the "earth-work" cost, all in terms of dollars per lineal foot; and P_{uo} is the miscellaneous cost in dollars. The cost of right-of-way, P_w , is not included because experience with existing mail pipelines owned by private companies seems to suggest that no such expenses levied against them when public thoroughways are used (44).

About 80 percent of urban cost data in the data bank are for reinforced concrete pipe and is not readily separable into the components shown in equation (36). Consequently, the following procedure was selected for derivation of the first three terms in equation (36) for the open-cut construction.

* "Placement cost" implies the cost of placing the pipe inside the prepared trench and joining the pipes together.

** "Earth-work cost" implies the costs of excavation, backfill, paving, relocation or reconstruction of existing structures, trench sheeting and shoring, and traffic control.

(39). Dodge Estimating Guide for Public Works Construction. McGraw-Hill Information Systems Company, New, York, N.Y. Annual Editions, since 1969 (No. 1).

(40). Godfrey, Robert S. Building Construction Cost Data. Robert Snow Means Co., Inc., Duxbury, Mass. Annual.

(41). Commercial-Industrial Construction Estimating and Engineering Standards, Richardson Engineering Services, Inc., Solana Beach, California, 1974.

(42). Englesman, Coert. 1976 Heavy Construction Cost File. Construction Publishing Company, Inc., New York, N.Y. 1976.

(43). Construction Pricing and Scheduling Manual. McGraw-Hill Information Systems Company, New York, N.Y. Annual Editions starting from 1966 (No. 1). Norman Foster, Manual Editor.

(44). U.S. Senate. Pneumatic Tube Mail Service, Hearing on S. 1426, Eighth Congress, 2nd. Session, March 29, 1948.

1 - Urban cost data for the open-cut reinforced concrete pipe (RCP) was manipulated to obtain an expression relating the construction cost C_2^C to the parameters of the system.

2 - Information provided by the "1976 Dodge Guide" was used to derive expressions for p_{um} and p_{ip} for RCP.

3 - Using the information in steps 1 and 2, an expression for p_{ie} was derived.

4 - The open-cut construction cost for steel pipe, C_2^S , was then found by adding p_{um} estimated from equation (18) to p_{ip} found in step #2 above, plus p_{ie} calculated in step #3 above.

5 - For pipes other than RCP and steel pipes, coefficients were found to adjust the construction cost for RCP, derived in step #1, to construction cost for the desired type of pipe.

Open-Cut Construction Cost for RCP Class 4, C_2^C - Examination of data indicates that the construction cost of RCP, C_2^C , is a function of pipe diameter, year of construction, geographical location, depth of trench, ground water and congestion. To find a quantitative relationship between the cost and these variables one must select quantifiable parameters to represent them. In the present analysis, the following parameters were selected. The impact of the year and geographical location was included by using the EPA sewer construction cost index (27). Actually, a ratio, I_s , was used which was calculated by forming the ratio of index at the year of construction and for the region of construction over the index at a base year and for the nation. The influence of ground water was introduced through a parameter, W_g , which varies between 0 and 100 percent (0 being dry soil and 100 representing construction under water table). Congestion was characterized by a parameter, C_f , values of which are given in Table 13.

Table 13

Values of Congestion Coefficient, C_f

C_f in percent	Building Density
10	Less than 10 houses/mile, mostly unpaved streets.
50	Residential area with 50-200 road frontage, paved streets.
100	Row houses with average 2 stories.
200	Center city with average 6 stories.

Through a step by step manipulation of data (very much like the procedure described in Section 1b) the following expression was found:

$$C_2^C = 1.1 C_f^{0.5} I_S D^{1.61} e^{0.036[(.012W_g + 1)d - (D+3)]} D^{-0.33} \quad (37)$$

where C_2^C is in dollars per lineal foot of pipe, D is the pipe diameter in feet, d is the depth of the trench in feet, and the base year is 1973. When Figure 13 is compared with Figure 3, the improvement in the accuracy of prediction by equation (37) becomes obvious.

Expression for p_{um} and p_{ip} in Open-Cut Construction - The data provided by the "Dodge Guide" (39) regarding p_{um} and p_{ip} permit formulation of an equation of the following form:

$$p_{pp} = 2.5 m I_S D^{1.606} \quad (38)$$

where $p_{pp} = p_{um} + p_{ip}$, m is a coefficient related to the type of pipe (see Table 14). When m is one the information relates to reinforced concrete pipe of class 4. The data also indicates that the "placement cost" of steel pipe, p_{ip} , can be found from equation (38) if m is taken equal to 0.58.

Table 14
Pipe Material Coefficients, m^*

<u>Pipe Material</u>	<u>Class</u>	<u>m</u>
Reinforced Concrete Pipe	3	.86
Reinforced Concrete Pipe	4	1.0
Reinforced Concrete Pipe	5	1.16
Cement Asbestos Pipe	150	2.46
Cement Asbestos Pipe	200	3.27
Ductil Iron Pipe (Mech. Joint)	1	2.46
Ductil Iron Pipe (Mech. Joint)	2	2.66
Cast Iron Pipe (Mech. Joint)	22	2.79
Cast Iron Pipe (Mech. Joint)	23	2.96
Steel Pipe Placing	Any	.58

*This table is prepared from an examination of information in reference (39).

Expression for p_{ie} - Using equation (36), (37), and (38), an expression can be developed for p_{ie} :

$$P_{ie} = \left[1.1 C_f^{0.5} I_S D^{1.61} e^{0.036[(.012W_g + 1)d - (D+3)]} D^{-0.33} \right] - 2.5 I_S D^{1.606}$$

or approximately

$$p_{ie} = \left[1.1 C_f^{0.5} e^{0.036 \{ (.012 W_g + 1) d - (D+3) \}} D^{-0.03} \right]^{-2.5} I_S D^{1.61} \quad (40)$$

Open-Cut Construction Cost for Steel Pipes, C_2^{OS} - This value can be found from combining equations (18), (36), and (38) (using $m = .58$), and (40):

$$C_2^{OS} = G I_m P_{TM}^B (1 + X) \pi D t s + 2.5 (.58) I_S D^{1.61} + \left[1.1 C_f^{0.5} e^{0.036 \{ (.012 W_g + 1) d - (D+3) \}} D^{-0.33} \right]^{-2.5} I_S D^{1.61} \quad (41)$$

Since $P_{TM}^B (1 + X) \pi s$ has the value 205 (See equation (35)),

$$C_2^{OS} = 205 G I_m D t + (1.1 C_f^{0.5} e^{0.036 \{ (.012 W_g + 1) d - (D+3) \}} D^{-0.33})^{-2.5} I_S D^{1.61} \quad (42)$$

where

$$C_2^{OS} = p_m + p_{ip} + p_{ie}$$

Open-Cut Construction Cost for Other Pipes, C_2^{OO} - A combination of equations (38) and (40) with a proper m found from Table 15 provides a means of calculating the construction cost for any pipe other than RCP class 4, and steel:

$$C_2^{OO} = \left[1.1 C_f^{0.5} e^{0.036 \{ (.012 W_g + 1) d - (D+3) \}} D^{-0.33} \right]^{-2.5(1-m)} I_S D^{1.61} \quad (43)$$

where $C_2^{OO} = p_{um}^O + p_{ip} + p_{ie}$ and p_{um}^O is the cost of "line-pipe" for pipes other than steel in dollars per lineal foot.

Expression for p_{uc} - The crossing cost is the cost of installing pipeline by tunnelling (or jacking) method which may be required when a pipe crosses such obstacles as roads, railroads, rivers, utilities, subways, etc. The estimation of p_{uc} is a very involved and costly process. Existing methods (45-47) are all of the so-called "quantity take-off" type. They require detailed engineering, geological, and design information for their execution. Sometimes as many as 200 different parametric quantities are required.

- (45). Procedure for Estimating Costs of Tunnel Construction, Appendix C, in Investigation of Alternative Aqueduct Systems to serve Southern California, Bulletin No. 78, California Department of Water Resources, Sacramento, California, September, 1959.
- (46). Parker, Albert D. Planning and Estimating Underground Construction. McGraw-Hill Book Company, 1970.
- (47). Moavenbadeh, Fred, and Michael J. Markow. "Simulation Model for Tunnel Construction Costs", J. Construction Division, Proceedings of A.S.C.E. Vol. 102, No. Co. 1, March, 1976.

At the feasibility stage of the study this detailed information obviously does not exist. The following estimating procedure has been developed to permit cost estimation for the purpose of a preliminary study. The proposed methodology is based on the analysis of cost data of 81 tunnelling projects in various parts of the country within a period of 15 years (1960-1975) stored in the Data Bank.

Examination of the data bank shows that the cost of the tunnelling depends on the pipe diameter, location of the project, year of construction, and ground conditions (ground water and rock). The two important parameters for the open-cut installation, depth and congestion, do not affect the total cost of tunnels.

To derive a relationship for the tunnelling cost, P_{uc} , the difference in the year and location was adjusted by the use of I_S , and the adjusted cost was plotted against the diameter of the tunnel as shown in Figure 14. Although the reported data did not have quantitative information on the ground condition, the description provided about the existence of ground water and rock enabled us to conclude that the data on the lower boundary of the data space belonged to what may be tentatively called "good ground". Therefore, a relationship for "good ground" condition was obtained:

$$P_{uc} = 25.5D^{1.25} \quad (44)$$

For ground conditions different than this limiting case, equation (36) was adjusted by using a coefficient R derived by examining data presented by the California Department of Water Resources Bulletin 956 (45) in the following manner:

$$P_{uc} = 25.5I_S R D^{1.25} \quad (45)$$

Table 15 gives approximate values of R suggested for various ground conditions.

Table 15

Values for Parameter R

Ground Condition	R
Dry, good soil, stratified and seamy rock	1.0
Dry, crushed or unconsolidated rock	1.5
Wet, intact and seamy rock under a saturated condition	2.9

Wet, crushed or unconsolidated rock under saturation

Expression for P_{uc} - The miscellaneous cost, P_m , includes such costs as engineering design, surveying and mapping, soil test, environmental impact studies, inspection,

Figure 14. Plot of P_{UC} Against D

interest, and contingency. It is roughly assumed to be 20 percent of the total cost:

$$P_{uo} = .20C_2 \quad (46)$$

Urban Pipeline Cost - Since all cost components in equation (36) are now formulated, the total cost of the urban pipeline, C_2 , can be expressed by two separate relationships.

a) Urban Steel Pipeline, C_2^S - Substitution of equations (42), (45), and (46) into equation (36) yields:

$$C_2^S = \left\{ \left[205 G I_m D t + (1.1 C_f^{0.5} e^{0.036 \{ (.012 W_g + 1) d - (D+3) \}} D^{-0.33} - 1) I_S D^{1.61} \right] (L_2 - L_t) + 25.5 I_S R D^{1.25} L_t \right\} 1.20 \quad (47)$$

b) Urban pipelines other than steel, C_2^O - Substitution of equations (43), (45), and (46) into equation (36) yields:

$$C_2^O = \left\{ \left[1.1 C_f^{0.5} e^{0.036 \{ (.012 W_g + 1) d - (D+3) \}} D^{-0.33} - 2.5 (1-m) \right] I_S D^{1.61} \right\} (L_2 - L_t) + 25.5 I_S R D^{1.25} L_t \} 1.20 \quad (48)$$

III - Pumping/Compressor Station Cost, C_3

The design, and therefore the cost, of pumping (compressor) stations varies according to the type of pipeline. Existing data for freight pipeline is very limited. Water pipelines are typically operated under low pressures, usually below 100 psi and are not similar to freight pipelines which typically will operate with higher pressures. Oil data, until very recently, has been confidential and not available. Data regarding natural gas pipelines is available through the Federal Power Commission who receives and publishes data on compressor stations constructed in the U.S. The operating pressures of these stations typically are above 1000 psi, and are in a range appropriate to freight pipeline. In the present study, gas pipeline data was used to derive a cost expression which was further modified by use of a proper coefficient to apply to freight pipeline.

Cost data for compressor stations constructed between 1965 through 1974 were adjusted to 1973 base year by the use of ICC Pipeline Cost Index (Account No. 158-68) (48). The ten years average of this data was about \$454 per horse power. Further examination of data indicates that this cost has been distributed amongst three compo-

(48). Interstate Commerce Commission, Account No. 158-68 (Pumping Equipment - Pumps, Engines).

ponents -- land cost, structure (building cost), and equipment cost, according to Table 16.

Table 16 - Construction Cost Breakdown (U.S. Average for 10 Years)*

Item	\$/HP	Cost Breakdown in Percent
Land	9.12	2
Structure	31.74	7
Equipment	413.14	91
Total	454.00	100

*Calculated from data reported to FPC in fiscal years 1965 through 1974. Original data included an additional category of "miscellaneous" which in this table is proportioned between the remaining categories.

Assuming that for freight pipeline the same cost relationship among the variables holds, one may write:

$$C_3 = 454 j (.02 I_f + .07 I_N + .91 I_e) H_p \quad (49)$$

where C_3 is the total cost of pumping station for a given freight pipeline, j is a coefficient accounting for the differences between various types of pipelines, I_f is the Farm Real Estate-Index ratio obtained from Table 10, I_N is the Engineering News Record Building Cost Index (49), I_e is the ratio of the Interstate Commerce Commission's Pipeline Cost Index (Account No. 158-68: Pumps and Engines) (48), and H_p is the horse power requirement of the system. Equation (49) is constructed based on the belief that various cost components change differently with time. This equation using I_f is applicable to cross-country pipeline. Should it be desired to use it for urban areas, a proper index should be substituted for I_f . For preliminary studies it may be assumed that $j=1$.

IV. Freight Terminal Cost, C_4

Unlike other cost components discussed so far, terminal cost, C_4 differs so widely for various types of pipelines that a meaningful estimate is possible only when these differences are considered explicitly. Cost estimate has to be based on an engineering design. In this section only pneumo-capsule pipeline will be discussed. Terminal cost in dollars consists of three components -- land, structure, (building), and equipment. Thus:

$$C_4 = A_s \left(\frac{K_1}{r_1} + K_s + K_e \right) \quad (50)$$

(49). Building Cost Index History 1913-1974. Engineering News-Record March 20, 1975, pp. 63.

where I_f is the Engineering News Record Building Cost Index-Farm (Index for a region)

where A_s is the floor area of the terminal structure in ft^2 , K_l is the cost of land in dollars per ft^2 , K_s is the cost of structure in dollars per ft^2 , and K_e is the cost in dollars of equipment occupying one ft^2 of the structure, and r_l is the fraction of land occupied by the structure. For capsule pipeline, A_s may be written as:

$$A_s = (1 + r_s) \{ \{ f_p (r_p Q' T_p / \gamma_p h_p) + f_c [(1 - r_p) Q' T_c / \gamma_c h_c] \} + f_l f_c N_e S_c / h_c \} \quad (51)$$

where r_s is a fraction of the terminal area allocated for non-cargo uses (such as offices, maintenance areas, etc.), f_p and f_c are space coefficients taking into account that extra space is required for handling of packaged and encapsulated freight, respectively, r_p is the fraction of the total freight entering or leaving the terminal in packaged form, $(1 - r_p)$ is the fraction of the total freight entering or leaving the terminal in encapsulated form, Q' is the design load capacity of the terminal in tons per day, T_p is the package retention time in days, γ_p is the bulk density of freight in tons per cubic feet, h_p is the height of the terminal in feet, h_c is the height of the structure containing the capsules, f_l is the load factors expressed in fraction, N_e is the maximum number of empty capsules in the terminal at any time, S_c is the space required to store an empty capsule in ft^3 , and T_c is the retention time of loaded capsules in days. Using equation (51), equation (50) may be written as:

$$C_4 = (1 + r_s) \left(\frac{K_l}{r_l} + K_s + K_e \right) \{ \{ f_p (r_p Q' T_p / \gamma_p h_p) + f_c [(1 - r_p) Q' T_c / \gamma_c h_c] \} + f_c f_l N_e S_c / h_c \} \quad (52)$$

Three types of information are required in order to use equation (52) to obtain C_4 : 1) knowledge of Q' , γ_p , γ_c and r_p , which is transportation information, must be provided to the designer, 2) design parameters such as r_s , T_p , f_p , h_p , f_c , T_c , h_c , f_l , N_e , S_c which are selected by the designer, and 3) cost information such as K_l , K_s , and K_e .

Table 16 is prepared based on our best engineering judgement, to provide information regarding typical values of design parameters in equation (52).

In the absence of cost data on capsule terminals, cost data for air freight terminal may be used to obtain an approximate value for $(K_s + K_e)$. As shown in Table 17, the combined unit costs vary even after the regional variations and inflation are adjusted to a comparable basis. If an average value of 60 is used for the base year, 1973, The combined unit costs of structure and equipment may be expressed as:

$$(K_s + K_e) = 60 I_N \quad (53)$$

where I_N is the Engineering News Record Building Costs Index-Ratio (Index for a region

Table 17 - Parameters in Equation (52)

Parameters	Pneumo-capsule		Hydro-capsule	
	Single-User Terminal	Multi-User Terminal	Single-User Terminal	Multi-User Terminal
r_s	.1	.2	.2	.4
f_p	1.8	1.8	1.8	1.8
T_p	.1	.8	.6	1.3
h_p	40.	40.	40.	40.
f_c	1.4	1.4	1.4	1.4
T_c	.1	.5	.6	1.0
h_c	40.	40.	40.	40.
f_l	1.4	1.4	1.4	1.4
S_c	$A_c L_c$			
N_e	$r_p Q' T_p / A_c L_c \alpha_c \gamma$			

in any year over index for Nation in base year) and a is a coefficient taking into account the variations between various terminals.

Table 18 - Capital Cost of Air Freight Terminal, ($K_s + K_e$) (50-53)

Air Terminal	Year	Actual	Adjusted
United Airlines, National Average	1975	60.00	50
Air Mail Facility, Phila.-Intern.	1976	62.22	48
American Airlines, NYC-JFK	1972	115.38	120
Pan American, Phila.-Intern.	1974	31.25	28
Average			61

Substitution of these typical values given in Table 16 and equation (53) in equation (52) permits the estimation of C_4 .

V - Cost of Communication Facilities, C_5

The communication system for control and operation of a freight pipeline will be identical with those used for oil and natural gas pipelines. Cost data of existing facilities published by the Oil and Gas Journal (4, 9) was used to develop the following

(50). Personnel Communication. United Airlines, Chicago, Ill., March 1976.

(51). U.S. Postal Service, Eastern District Office, Philadelphia, Penna., March 1976.

(52). Cargo Airlift, Vol. 60, No. 6, June 1972.

(53). "Pan-Am Get First to Use Cargo City." Philadelphia Inquirer, January 16, 1974. (A2)

cost equation:

$$C_5 = [25,000N_r + 1,000L']I_r \quad (54)$$

where N_r is the number of radio towers, L' is the total length of the pipeline in miles and I_r is the ratio of the ICC Pipeline Cost Index (Account No. 183-154, 156: Radio Towers and Microwave Equipment). (54).

VI - Miscellaneous Capital Cost, C_6

This cost is taken to be a certain percentage of the total capital cost, that is:

$$C_6 = r_o(C_1 + C_2 + C_3 + C_4 + C_5)/100 \quad (55)$$

where r_o is in percent. Since capital items are included in some detail, C_6 should not be very large. A ten percent value appears to be reasonable.

VII- Capsule Cost, C_7

The capsules are simple containers, with or without wheels, owned or leased by shippers. The total cost of capsules may be expressed as:

$$C_7 = K_c N \quad (56)$$

where K_c is the cost of a single capsule in dollars and N is the number of capsules in the system. N can be estimated for the following relationship:

$$N = (1 + \alpha) Q (Q\lambda\eta/q(350)) \quad (57)$$

where Q is the annual freight tonnage transported in both directions, α is a coefficient taking into account the reserve required in the system, λ is the cycle time of capsules in days, η is the peak to average ratio, and q is the capacity of each capsule in tons. Since λ is the combined time of line haul and retention at the terminals, it can be written as:

$$\lambda = \frac{1}{24} \left(\frac{L'}{V'_c} + T_T \right) \quad (58)$$

where V'_c is the speed of capsule in mph and T_T is the hold-up time of capsules in terminals in hours. (Note that T_T includes loading, unloading, waiting, and storing and is different than T_c which is only storage of encapsulated cargoes).

The capacity of capsules can be written as:

$$q = A_c L_c \quad (59)$$

(54). Interstate Commerce Commission, Account No. 183-154, 156 (Radio Towers and Microwave Equipment).

where A_c is the effective sectional area of capsule in ft^2 , L_c is the effective length of the capsule in ft, α_c is the load factor, and γ is the bulk density of freight.

Substituting equation (57), (58), and (59) into equation (56) yields:

$$C_7 = K_c Q_n (1 + \alpha) \left(\frac{L'}{V_c} + T_T \right) / A_c L_c \alpha_c \gamma \quad 24 (350) \quad (60)$$

VIII- Labor Cost, O_1

Labor cost can be estimated from the manpower requirements and the wage rate. Table 18 shows the manpower requirement for freight transportation by motor carrier during 1973. The table shows that one employee was required for transporting 604 tons of freight per year. Freight pipeline eliminates the need for drivers and reduces others. The more automated the pipeline system, the less manpower will be required.

Table 19 - Manpower Requirements

Area of Service	Number of Employees		
	Motor Carriers (55)	Capsule Pipeline "Assumed" fractions	"Assumed"
Garage & Equipment Maintenance	29,265	0.1	2,927
Transportation (Drivers & Helpers)	213,067	0.0	0
Terminal	146,834	0.25	36,709
Sales & Advertising	12,524	1.0	12,524
Insurance & Safety	3,731	1.0	3,731
Administration & General	22,267	1.0	22,267
Total	427,688		75,231
Tons/Year/Employee**	604		4,436

* Automated freight handling system is assumed.

** Total Freight transportation during 1973 was 258,497,587 tons.

In Table 18, figures in column designated "assumed" are our best engineering estimates for handling freight pipelines (the labor requirement for bulk freight pipelines will be much lower, according to the experience with existing pipelines).

The annual earning per employee was found by analyzing wage data of pipeline industry. Figure 15 shows the average wages.

If we assume the wage rates are similar among the different pipeline systems, the equation describing the cost of labor may be formulated as:

(55). Interstate Commerce Commission, Bureau of Labor Statistics. Eighty-Seventh Annual Report on Transportation Statistics in the U.S. for the year ended December 31, 1973. Part 7 - Motor Carriers, Table 12. Employees.

NOTE

Wages of Pipeline Personnel have been approximately the same as the wages of motor carriers and Railroad Personnel.

Figure 15. Annual Wages and Index Ratio for Pipeline Personnel

$$O_1 = W_a I_L \left(\frac{r_p Q}{q_p} + \frac{(1 - r_p) Q}{q_c} \right) \quad (61)$$

where Q is freight tonnage in tons/year, r_p is defined in equation (51) q_p and q_c are the annual packaged and encapsulated freight tonnage handled by each employee, 4400 for packaged freight, 22,000* for encapsulated freight, 88,000** for bulk freight pipelines. W_a are annual wages for pipeline personnel in dollars per year and I_L is the Wage Index ratio listed in Figure 15.

IX Energy Cost, O_2

The cost of energy can be readily calculated from the knowledge of the power requirements of the system:

$$O_2 = PK_E I_E \quad (62)$$

where p is the total energy required in Kwh, K_E is the cost in dollars of each Kwh, and I_E is the ratio of the Energy Index (57). The value of P for various freight pipelines can be calculated from a number of available equations described elsewhere (see Volume II).

X Repair and Supply Cost, O_3

This cost varies for different components of freight pipelines. Table 18 shows the values assumed in the present study and the basis of assumptions.

Table 20 - Repair and Supply Cost

Components	Suggested Values	Basis of Assumption (4, 9, 24)
Pipeline (about 12")	\$33/mile/year*	Maintenance cost of oil & gas pipeline in dry ground
Pipeline (about 12")	\$330/mile/year*	Maintenance cost of oil & gas pipeline in swampy areas
Pumps (compressors)	\$15/installed HP*	Pumping stations data
All others	6% of capital cost	Similar installations

*These values were updated to the base year (1973).

Based on information in Table 18, one may write:

$$O_3 = 33D(L'_d + 10L'_w)I_i + 15H_p I_e + 0.06(C_4 + C_5 + C_6)I_N + 0.3W \quad (63)$$

where L'_d is the length of pipe in dry ground in mile, L'_w is the length of pipe in

(57). U.S. Department of Commerce, Retail Price Indexes of Fuels and Electricity: 1940 to 1974, pp. 4-18

* Five times better labor efficiency than packaged freight is assumed.

** Existing slurry pipelines show each employee handles more than 90,000 tons/year.

wet land in mile, and O_{3w} is the annual cost of water if required.

XI - Insurance Cost, O_4

Because there is less opportunity for accidents and thefts, the insurance cost may be expected to reduce when freight pipeline is used. Table 19 shows the insurance cost for motor carriers in 1973. It also shows the reduction that may be expected when pipeline is used. For 1973, the insurance cost for motor carriers has been \$1.5 per ton of freight transported. If assumptions in Table 19 are correct, this figure would have been \$0.30 per ton for pipeline.

Table 21 - Insurance Cost Breakdown, 1973 (58)

Insurance Cost Item	Motor Truck	Capsule Pipeline	
	\$/ton	Assumed fraction	Assumed \$/ton
Cargo loss & damages	.54	.	.27
Liability & property damage	.34	.1	.03
Fire, theft & collision	.07	.1	.01
Other	.01	1.0	.01
Total			.32

Thus O_4 may be estimated from the following equation:

$$O_4 = A_4 O_{CI} \quad (64)$$

where A_4 is 0.32*for packaged freight and O_{CI} is the ratio of the Consumer Price Index (CPI item: Insurance and Finance) (59) that is, CPI's of desired year over the base year.

XII- Administration Cost, O_5

The administration cost, O_5 is assumed to be less than the administration cost of motor carriers. Motor carriers have spent \$1.35 per ton of freight transported in 1973 (61). Thus:

$$O_5 = A_5 O_{CS} \quad (65)$$

where A_5 is 0.7* for packaged freight and O_{CS} is the ratio of the Consumer Price Index (item: Services) (60).

XIII-Taxes and Fees, O_6

This cost varies considerably for different locations. In the pipeline in-

* For encapsulated freight, this value will be smaller.

(58). ICC. Motor Vehicle Insurance Cost Breakdown.

(59). U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Index. U.S. and City Averages: Special Indexes - Insurance and Finance Monthly Publications.

(60). Ibid., Item: Services.

dustry, it is usually expressed in some percentage of assessed value of the system. Thus:

$$O_6 = r_t \sum_{i=1}^7 C_i / 100 \quad (66)$$

where r_t is expressed in percentage. A value of 1 to 2 percent is normal.

XIV- Miscellaneous Operation Cost, O_7

O_7 may be taken as a certain percentage of the total operating cost. Thus:

$$O_7 = r_m \sum_{i=1}^6 O_i / 100 \quad (67)$$

where r_m is expressed in percent. A value of 10 to 15 percent is reasonable.

Conclusion

Insertion of the equations developed in the previous sections into equation (1) provides an expression for the total annual cost of a freight pipeline project. Care must be exerted to utilize those equations pertinent to the system under study. For instance, if the pipeline project is totally located outside urban centers, the value of C_2 will be equal to zero. Otherwise, that portion of the pipeline being within the cities must be estimated with the use of C_2 . Much engineering judgement is required to select proper parameters, but the problem is no different than for other technological projects. Cost per ton mile, C_{TM} , can be calculated from the following equation:

$$C_{TM} = \frac{C}{L \cdot Q} \quad (68)$$

Selection of Parameters

Table 20 shows the range of parameters selected to estimate the ton-mile cost of freight transport via pipeline, using equation 68. Three values are given for each parameter; conservative, liberal and average. These parameters were used in connection with analysis described in Volume I.

TABLE 22

Parametric Values for the Pipeline Cost Model

Variables	<u>I n t e r c i t y</u>		
	<u>Conservative</u>	<u>Liberal</u>	<u>Average</u>
D	5.	5.	5.
r	10.	8.	9.
γ_p	20.	20.	20.
n	2.	1.5	2.
L_c	15.	15.	15.
n_1, n_2, n_5, n_6	20.	40.	30.
n_3 Land	99.	99.	99.
Bldg.	40.	60.	50.
Equip.	5.	10.	8.
n_4 Land	99.	99.	99.
Bldg.	40.	60.	50.
Equip.	10.	20.	15.
n_7 Salvage Value	10.	20.	15.
Land	4.	4.	4.
Pipe	0.	2.	1.
G	1.04	1.04	1.04
t	.03125	.03125	.03125
W	1.021	1.021	1.021
P_d	265.	150.	230.
T_f	20.	0.	8.
W_f	0.	0.	0.
C_f	150.	100.	125.

BIBLIOGRAPHY

1. Engineering News-Records.
"Unit Prices." Various weekly issues.
2. Federal Power Commission.
Annual Report on Pipeline Construction Cost. Various Annual Volumes.
3. Reed, Paul and Gene Kinney,
"Pipeline Contractor's Costs." The Oil and Gas Journal, January 20, 1958.
4. "Pipeline Costs Vary All Over the Map." The Oil and Gas Journal, July 13, 1959.
5. Kinney, Gene.
"What it Costs to Build and Operate Gas Pipelines." The Oil and Gas Journal,
June 27, 1960.
6. O'Donnell, John P.
"Pipeline Installation and Equipment Costs." The Oil and Gas Journal, June
26, 1961.
7. Ibid., June 25, 1962.
8. Ibid., July 8, 1963.
9. Ibid., July 6, 1964.
10. Ibid., July 5, 1965.
11. Ibid., July 4, 1966.
12. Ibid., August 14, 1967.
13. Ibid., July 29, 1968.
14. Ibid., August 4, 1969.
15. Ibid., August 3, 1970.
16. O'Donnell, John P.
"Pipeline Economics." The Oil and Gas Journal, August 2, 1971.
17. Ibid., August 14, 1972.
18. Ibid., August 13, 1973.
19. Ibid., August 12, 1974.
20. Ibid., August 18, 1975.
21. Koenig, Louis
"The Cost of Pipelines in the United States." Louis Koenig Research, San Antonio,
Texas, June, 1970.

22. Linaweaver, F. P., Jr., and C. Scott Clark
"Costs of Water Transmission." Journal of American Water Works Association.
December, 1964.
23. Singh, Krishan P.
"Economic Design of Central Water Supply Systems." Water Resources Bulletin,
Vol.1, No. 1, February 1971.
24. Zimmerman, O. T., and Irvin Lavine
"Steel Piping" Cost Engineering, July, 1963.
25. Paintal, A.S.
"Interceptor Sewer Cost Analysis." Water and Sewage Works, November, 1975.
26. Research Council of Alberta.
TDA-RCA Capsule Pipeline Project: Capsule Pipeline System Analysis, Part 2 -
Capsule Pipeline Techno-Economic Simulation Model. Alberta Research Information
Series No. 67, October, 1974.
27. Environmental Protection Agency.
Guidelines For Cost Estimates of Municipal Wastewater Systems, February, 1973.
28. Klegerman, M. H.
Fairfax County Integrated Sewerage Program, Sanitary Sewer Service in the
Accotink and Dohick Creek Watersheds, Preliminary Design, Cost Estimates,
Financial Requirements. A Feasibility Report Prepared for Fairfax County,
Virginia, Alexander Potter Associates, New York, 1964.
29. Bethlehem Steel Corporation.
Tubular Products Prices: Section Q-3, Electric Fusion Weld Pipe. September 1,
1975.
30. United Steel Corporation.
Price List for "USS Submerged Arc Welded Steel Pipe, September, 1975.
31. Sumitomo Metal America Inc. Price Quotation for Submerged Arc Welded or Spiral
Welded Line Pipe. October , 1975.
32. Wholesale Prices and Price Indexes: Code No. 1013-0272 (line Pipe, Carbon)
U. S. Department of Labor, Bureau of Labor Statistics, Monthly.
33. Interstate Commerce Commission Account No. 105-155 (Pipeline Construction)
in Schedule of Annual Indices for Carriers by Pipeline, 1948 through 1974.
34. U. S. Geological Survey
Land Surface Map in The National Atlas of the U.S.A. 1970.
35. Statistical Abstract of the U. S.: 1975, (96th edition)
U. S. Department of Commerce, Bureau of the Census, U. S. Government Printing
Office, Washington, D. C., 1975.
36. Pipe Line Labor Manual.
Pipe Line Contractors Association, Dallas, Texas. July 1973, Revised January
1975.

37. Hammond, Edwin H.
"Analysis of Properties in Land Form Geography: An Application to Broad-Scale Land Form Mapping," Annals of the Association of American Geographers, Vol. 54, No. 1, March 1964.
38. Shaw, Samuel P., and Gordon C. Fredine.
Wet Lands of the U. S. U. S. Fish and Wildlife Service Circular No. 39, U.S. Printing Office, Washington D. C., 1956.
39. Farm Real Estate Market Developements, Annual Publication U. S. Department of Agriculture, Economic Research Service, U. S. Government Printing Office, Washington, D. C., 1960 Through 1975.
40. Dodge Estimating Guide for Public Works Construction.
McGraw-Hill Information Systems Company, New York, N.Y. Annual Editions, since 1969 (No. 1)
41. Godfrey, Robert S.
Building Construction Cost Data. Robert Snow Means Co., Inc., Duxbury, Mass. Annual.
42. Commercial-Industrial Construction Estimating and Engineering Standards,
Richardson Engineering Services, Inc., Solana Beach, California, 1974.
43. Englesman, Coert
1976 Heavy Construction Cost File. Construction Publishing Company, Inc., New York, N. Y. 1976.
44. Construction Pricing and Scheduling Manual.
McGraw-Hill Information Systems Company, New York, N.Y. Annual Editions starting from 1966 (No. 1) Norman Foster: Manual Editor.
45. U. S. Senate
Pneumatic Tube Mail Service, Hearing on S. 1426, Eighth Congress, 2nd Session, March 29, 1948.
46. Procedure for Estimating Costs of Tunnel Construction, Appendix C, in Investigation of Alternative Aqueduct Systems to serve Southern California, Bulletin No. 78, California Department of Water Resources, Sacramento, California, September, 1959.
47. Parker, Albert D.
Planning and Estimating Underground Construction. McGraw-Hill Book Company, 1970.
48. Moavenbadeh, Fred, and Michael J. Markow.
"Simulation Model for Tunnel Construction Costs," J. Construction Division, Proceedings of A.S.C.E. Vol. 102, No. Co. 1, March, 1976.
49. Interstate Commerce Commission,
Account No. 158-68 (Pumping Equipment - Pumps, Engines)
50. Building Cost Index History 1913-1974.
Engineering News-Record March 20, 1975, pp.63.

51. Personnel Communication.
United Airlines, Chicago, Ill., March 1976.
52. U. S. Postal Service, Eastern District Office, Philadelphia, Penna., March 1976.
53. Caro Airlift
Vol. 60, No. 6, June 1972.
54. "Pan Am Get First to Use Cargo City."
Philadelphia Inquirer, January 16, 1974.
55. Interstate Commerce Commission,
Account No. 183-154, 156 (Radio Towers and Microwave Equipment)
56. Interstate Commerce Commission, Bureau of Labor Statistics. Eighty-Seventh
Annual Report on Transportation Statistics in the U.S. for the year ended
December 31, 1973. Part 7 - Motor Carriers, Table 12. Employees.
57. U.S. Department of Transportation.
Summary of National Transportation Statistics, Table 13. June 1975.
58. U. S. Department of Commerce.
Retail Price Indexes of Fuels and Electricity: 1940 to 1974, pp. 418
59. ICC
Motor Vehicle Insurance Cost Breakdown.
60. U.S. Department of Labor, Bureau of Labor Statistics.
Consumer Price Index, U.S. and City Averages: Special Indexes - Insurance and
Finance Monthly Publications.
61. Ibid., Item: Services.
62. ICC
Adm. Cost.

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