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COMPARATIVE COAL TRANSPORTATION COSTS: AN ECONOMIC AND ENGINEERING ANALYSIS

BARGE TRANSPORT
Volume 4

by
Michael Rieber and Shao Lee Soo

Center for Advanced Computation
University of Illinois at Urbana-Champaign

August 1977
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NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the subject of this report.
Title and Subtitle: Comparative Coal Transportation Costs: An Economic and Engineering Analysis of Truck, Belt, Rail, Barge, and Coal Slurry and Pneumatic Pipelines; Volume 4 - Barge Transport

Abstract: Coal transportation by dedicated-integrated tows is described and costed for the major inland waterways. Facility descriptions are provided. Each waterway (including locks and dams) is described for use in the costing analysis. The estimation of line-haul costs is disaggregated. It includes a separable estimation of user costs.
FOREWARD

This report was prepared by the Center for Advanced Computation of the University of Illinois at Urbana-Champaign under USBM Contract No. J0166163. The contract was initiated under the Office of University Relations. It was administered under the technical direction of the Division of Interindustry Analysis with Mr. Ronald Balazik acting as the Technical Project Officer. Mr. Robert Carpenter was the contract specialist for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period May 1976 to August 1977. This report was submitted by the authors on August 1977.

This volume is a part of the eight volume report completed for this contract. The draft final report was submitted in May 1977.

The principal authors, Michael Rieber and Shao Lee Soo, are, respectively, Research Professor, Center for Advanced Computation, the Graduate College; and Professor of Mechanical Engineering, College of Engineering; both at the University of Illinois at Urbana-Champaign.
Subject Inventions

This is to certify that, to the best of my knowledge and belief, there were no Subject Inventions made or have resulted from the performance of this contract.

August 1977

Michael Rieber
Principal Investigator
FINAL REPORT

COMPARATIVE COAL TRANSPORTATION COSTS: AN ECONOMIC AND ENGINEERING ANALYSIS OF TRUCK, BELT, RAIL, BARGE AND COAL SLURRY AND PNEUMATIC PIPELINES

VOLUME 4

BARGE TRANSPORT

by

Michael Kiefer and Shao Lee Soo
with
P. King, Y. T. King, T. Leung, H. Wu and J. Wu

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Bureau of Mines, Department of the Interior
and the
Federal Energy Administration
Contract No. JO166163

Center for Advanced Communiation
University of Illinois
at Urbana-Champaign
Project 46-26-17-372

August 1977
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4. BARGE TRANSPORT

4.1 INTRODUCTION

Commodity transportation by barge is possible on about 25,000 miles of navigable inland waterways in the contiguous 48 states. Barge operations are used chiefly for the movement of bulk raw materials ranging from farm products to iron ore, coal, and other bulky semi-finished as well as finished products such as steel, chemicals and petroleum [3,p.7-9].

The barge industry, unlike other transportation industries, is largely unregulated. This is because all liquid bulk commodities, most dry bulk commodities transported by for-hire carriers and companies engaged in private transportation of their own commodities are exempted from Interstate Commerce Commission regulations. As a result, about 15 percent of the total ton-miles of barge traffic each year is under Interstate Commerce Commission regulation [13,p.14-25].

The approximately 1700 companies engaged in commercial barge operations use a total of about 4100 towboats and tugs with a combined horsepower of 5,088,221; 21,876 dry cargo barges with a total cargo capacity of 25,525,896 net tons and 3,534 tank barges with a cargo capacity of 8,201,561 net tons. Of these, 2,404 towboats; 17,345 dry cargo barges with a cargo capacity of 21,031,652 net tons; and 2,903 tank barges with a cargo capacity of 6,117,768 net tons operate on the Mississippi River system and the Gulf Intracoastal Waterway [14,p.2-3].

Even though the railroads have carried the major portion of the coal produced in this country, the inland waterways have borne a substantial percentage of the total. In 1974, domestic barges carried 122,581,992 net tons of coal [3,p.30]. The location of the major river systems may make waterways a significant means by which to move the projected increases in coal production from central Appalachia and the northern Great Plains to the Midwest. In this study we examine the cost and capacity parameters of those waterways that affect the movement of coal.

Because the emphasis in this study is on the eastern movement of western coal and the northern movement of Appalachian coal, a limited number of the potentially most important rivers have been investigated for the costing analysis. In particular, the major tributaries of the Ohio River have been excluded. Shipments of coal on the Green and Kanawha Rivers move, unidirectionally, to the Ohio River. Virtually all coal transport on the Monongahela
River goes into the Ohio. Finally, over one-half of the shipments on the Allegheny River moves towards the Ohio River. Thus, these rivers were considered outside the scope of this study. Capacity considerations on the principal rivers are discussed and evaluated in the Summary and Conclusions (see especially Table 1.20). The estimates are averages for each waterway taken as a whole rather than based on analyses of each lock and dam. The latter is beyond the budgeted scope of this project.
4.2 SIZES AND TYPES OF TOWBOATS AND BARGES FOR COAL TRANSPORTATION

The movement of traffic on the inland waterway system is accomplished primarily by towboats pushing flotillas of barges ahead of the towboat. Brief descriptions of both the towboats and the barges are presented.

4.2.1 Towboats

The towboats that operate on the inland water system range in size from less than 1000 h.p. to 10,500 h.p. The distribution probably represents the optimal sizes given the present state of the art in towboat design. Any further increases in horsepower are limited due to such physical restrictions of the waterway system as lock size and channel depth. A significantly higher horsepower rating requires such a large propeller system that it is infeasible at the present channel depth of 9 ft.

Boat sizes vary according to their power but are constrained in their maximum size by the size and width of the locks through which they pass. Typical towboat dimensions are found in Table 4.1. (Note: all tables and figures are collected at the end of each major section.)

Most towboats used in the movement of bulk commodities are over 1000 h.p. with an average power rating of about 5000 h.p. Table 4.2 provides a list of the more popular engines now being used. Table 4.3 provides the age distribution of the towboats in the various horsepower ranges. Figure 4.1 provides a graph of the above data [4,10].

The increasing size of the engines requires the use of large propeller systems. This was made possible by the development of the tunnel stern. This is an indentation in the boat's stern which enables the propellers to operate with about 25 percent of their diameter above the waterline. The vacuum created by propeller action in the tunnel draws water up into it. All modern towboats are also equipped with kort nozzels which help to increase the thrust available to the towboat by concentrating and directing the flow of water to and from the propeller. In addition, the adoption of
flanking rudders located forward of the propellers greatly increases the turning ability of the boats. The use of a hydrodynamic hull and reversing-reduction gear allows the use of smaller, lighter, yet more powerful engines.

The crew size of a towboat ranges from 7 to 14 for line-haul service. The crew work in six hours shifts with six hours off between shifts. They generally work 20 days and are off for 20 days, being paid for both on and off duty days. Recent developments in propulsion control includes a system which allows monitoring of engine pressure and temperature by a fleet engineer at a central land office. This may ultimately allow improved instrumentation and monitoring of performance and the elimination of on-board engineers by the large barge lines, with a significant saving in crew costs [1,p.45]. As seen below, for dedicated integrated tows, crew sizes could also be reduced as well as barge haul time decreased. The towboat itself, except for the time-off needed for maintenance, generally operates year-round and 24 hours a day.

4.2.2 Barques

Open hopper barges are commonly used for the transportation of coal. The hopper barge is basically a double-skinned steel box; the inner shell forming a long open cargo hold. The bottom, sides and ends of the hold are free of any obstructions and adapted for unloading with clamshell buckets, pallets or continuous belt buckets and are therefore suitable for dry bulk-loading commodities such as coal. There has been very little standardization of size but, because of the restrictions imposed by the dimensions of existing lock facilities and channel conditions on various waterways, some uniformity in barge design has been established. Table 4.4 shows the most popular sizes for open hopper barges. The 175' barges may be used on almost all waterways but are required on those with small, typically old, locking facilities. The 195' barges may be used in tows operating through 600' or larger locks. Larger barges may operate, with a smaller number per tow, on rivers with 600' locks but are more efficiently placed on open channel rivers or those with 1200' locks. It should be noted that a capacity loading of the 290' barges may lead to exceeding a 9'
channel depth.

The capacity of a barge is limited by the channel depth of the individual waterway. For example a 35' by 195' barge has an empty draft of 1 1/2 feet and requires an additional foot of draft for each 200 net tons of cargo it carries.

In recent years the cost of barge construction has been increasing steadily due mainly to the rising cost of plate steel and labor. Aluminum and fiberglass have been experimented with as substitutes, but with little success.
<table>
<thead>
<tr>
<th>Length</th>
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<th>Horsepower</th>
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<td>90-120 ft</td>
<td>26-30 ft</td>
<td>7.5-8 ft</td>
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<td>140-150 ft</td>
<td>35-40 ft</td>
<td>8-9 ft</td>
<td>2000-4000</td>
</tr>
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<td>155-160 ft</td>
<td>40-45 ft</td>
<td>9 ft</td>
<td>4000-6000</td>
</tr>
<tr>
<td>160-180 ft</td>
<td>45-50 ft</td>
<td>9 ft</td>
<td>6000-8000</td>
</tr>
<tr>
<td>195-200 ft</td>
<td>54 ft</td>
<td>9 ft</td>
<td>10,000</td>
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<tr>
<th>GM</th>
<th>CATERPILLER</th>
<th>CUMMINS</th>
<th>ALCO</th>
<th>STORKS-WERKSPoop</th>
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<tr>
<td>V-12-71</td>
<td>D 353</td>
<td>VT12-700M</td>
<td>12-251F</td>
<td>DRO-16K</td>
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<td>6-110</td>
<td>D 398</td>
<td>NH 250</td>
<td>16-251B</td>
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<td>NT-335</td>
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Source: [4]
TABLE 4.3: Number of Currently Operating Towboats (Year of Construction)

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<td>100-999</td>
<td>229</td>
<td>371</td>
<td>493</td>
<td>344</td>
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<td>1000-1999</td>
<td>63</td>
<td>106</td>
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<td>2000-2999</td>
<td>17</td>
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<td>14</td>
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<td>9000-10500</td>
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<td>7</td>
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Source: [4]
### TABLE 4.4: Typical Barge Sizes

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<th>Length (ft)</th>
<th>Width (ft)</th>
<th>Draft (ft)</th>
<th>Capacity (net tons)</th>
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<tbody>
<tr>
<td>175</td>
<td>26</td>
<td>9</td>
<td>1000</td>
</tr>
<tr>
<td>195</td>
<td>35</td>
<td>9</td>
<td>1500</td>
</tr>
<tr>
<td>290</td>
<td>50</td>
<td>9</td>
<td>3000</td>
</tr>
</tbody>
</table>

Source: [4]
FIGURE 4.1: Horsepower Range

Source: [4]
4.3 TOWING OPERATIONS

The push-towing method is used in all line-haul operations on the inland waterway system. In push-towing operations, barges in the tow are lashed together by a complex system of cables to form a single unit. This unit is lashed solidly against the towboat's towing knees. The assembling, breaking and reassembling of a tow consumes costly time and manpower. It is a major source of injuries. Constant readjustment of the towing cables is necessary during a voyage. Equipment failures are expensive and potentially dangerous. Given the number of lockages and double lockages required on some of the waterways with their attendant delays, it would seem that a moderate expenditure of research time and money spent on alternatives to lashing would produce major time and cost savings.

A towboat may push one barge or any multiple of barges ranging upwards of 45 barges when the tow is operating in open water. For passage through locks, barges are grouped four wide and three long or three wide and three or four long, depending on the size of the barges and the size of the locks to be transited. For maximum efficiency, tows are arranged as much as possible as dedicated tows.

4.3.1 Integrated Towing Operations

In the past, barges were constructed with a slope at both ends. This resulted in a loss of performance when multiple units were formed into a single tow due to the cumulative drag of water-breaking rakes. In order to obtain greater towing performance, barges are now designed to be assembled into integrated tows having an underwater shape equivalent to a single vessel. An integrated tow has a lead barge with a slope at the bow to minimize water resistance and a square stern for joining with the square end of another barge, thus eliminating underwater surface break. The barges at the rear end of the assembly have a short rake on the stern with double square-ended barges inserted in the middle. Such a formation provides water resistance nearly equivalent to a single vessel of equivalent total dimensions.

Integrated tows are generally more efficient for the carriage of large tonnages, on a continuing basis, over a long distance to a single destination.
This is evident in Table 4.5.

The fully integrated tow concept has the disadvantage that it is of little value unless it is in dedicated service where the barge position never changes. Where barges must be dropped off, it becomes difficult to retain an integrated configuration. The reason is that barges designed for an intermediate position in a tow are square on both ends and are extremely difficult to handle when separated from the other units of the tow.

4.3.2 Dedicated Tows

In this type of tow, the towboat remains with the barges during loading, unloading, and round trip transit. The towboat is generally owned by the shipper or contracted for exclusive use over a stipulated period of time. The advantages of this form of service are the ability to utilize an integrated towing operation, since all barges will be carrying one type of bulk commodity to a common destination; fast turn around time resulting in reduced inventory cost; insurance; and reduced leasing cost or ownership cost of the barges per ton of shipment handled.

Where tows are both fully integrated and dedicated, it would appear that significant cost savings could be made by the use of larger (and fewer) barges in a tow and/or by a different means of joining the barges. If, for example, the barges were connected by hydraulic clamps, the current system of lashing and ratcheting would be unnecessary. This would result in a reduction of crew size. More important it would save time during double locking operations. Not only would this reduce costs, it would increase river capacity.

This study assumes that all shipments of coal are made by a dedicated tow service using a fully integrated towing operation. This is based on the study assumption that provision must be made for anticipated multifold increases in coal movement. If the waterways are to be used for a part of this, efficiency requires the use of this form of service.
### Table 4.5: Tow Configuration and Performance

<table>
<thead>
<tr>
<th>Type of towing</th>
<th>Cargo Capacity (%)</th>
<th>Towing Speed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-integrated</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Semi-integrated</td>
<td>103.2</td>
<td>105</td>
</tr>
<tr>
<td>Fully-integrated</td>
<td>104.8</td>
<td>110</td>
</tr>
</tbody>
</table>

Source: [5, p. 7]
4.4 CHARACTERISTICS OF THE INLAND WATERWAY SYSTEM

4.4.1 Introduction

The size and shape of a tow, the size of the towboat, the cargo capacity of a barge, and the capacity of a waterway are largely determined by the physical dimensions of the waterway as well as by the locks located on them. On most of the waterways in the system, dams are constructed to provide adequate channel depth for barge navigation by creating a stepped series of lakes, at least 9 feet deep in most cases, in place of the flowing river. To pass a dam, a tow must use a facility constructed alongside the dam called a lock. Locks consist of two parallel walls with end-gates. The tow enters through one end-gate, the gate is closed, and the water level within the structure is adjusted between the upstream and the downstream levels by gravity feed permitting the tow to pass out through the other end-gate at the appropriate water level. A lock will pass a vessel through in about 30 minutes. Sizes of the lock chamber control the dimensions of the vessels using the waterways. For example a 110' by 600' lock allows a group of nine 35' by 195' barges to pass through in one lockage operation and a tow of 15 barges and a towboat to pass through using a double lockage operation. The following standard lock dimensions were established by the Corps of Engineers:

1) Lock width of 66 feet with length of either 400 feet or 600 feet.

2) Lock width of 84 feet with length of 600, 800, or 1200 feet.

3) Lock width of 110 feet with length of 600, 800 or 1200 feet.

Lock chambers of adequate size to accommodate different types of tows are important to the economics of barge transportation for two reasons. First, the size of the locks determines the capacity of a particular section of a waterway. Assuming 30-40 minutes for a single lockage (the newer locks are close to 30 minutes, the older ones closer to 40) and 90 minutes for a double lockage, the maximum number of double lockages per day results in an
average waiting time of 3 hours [6, p. 55]. Furthermore, in practice the maximum number of double lockages possible is about 3,650 per year [6, p. 55]. For a 600' by 110' lock chamber the average capacity for double lockage is 15 barges while a 110' by 1200' lock chamber can process 30 barges per double lockage. Second, smaller lock chambers require the breakup of large tows. This breakup and reassembly of tows requires additional time which, together with two lockage operations, imposes an additional cost on barge transportation.

River capacity in a system that includes locks is bounded by the efficiency of the locks and of the barge crews. By way of illustration, a single example may suffice. Assume a 110' x 600' lock and barge operation with 15 barge tows. If the double lockage requires 90 minutes, 16 transits per day each way is the maximum usage. At 1500 tons/barge, if all were loaded, a total of 720,000 tons could transit daily. If the route were navigable all year and maintenance time allows a 330 day year, river capacity could be a maximum of 237.6 million tons.

Actual totals are considerably smaller. First, navigation may not be possible year round. Second, many tows are not optimally sized; lock capacity is wasted. Third, pleasure craft may not be denied a lockage for more than two lockings; every third lockage could be non-cargo. Fourth, all barges are not loaded. Perhaps as many as 40 percent are returning empty. Fifth, many barges are not in the 1500 ton class. If, for the purposes of this example, we simply assume some numbers for the first five non-decision variables, total capacity is greatly reduced: (1) the river is closed by ice, low water, and/or flood for one month during which maintenance cannot be accomplished, (2) the average of all tows is 12 barges and a tow boat, (3) every sixth lockage is for pleasure craft, (4) 60 percent of all barges are loaded and (5) the average tonnage of all barges is 1200 net tons, total lock capacity is reduced to 68.95 million tons per year. If a 110' x 1200' lock is postulated and the scenario remains the same, the theoretical limit is 712.8 million tons per year while the adjusted limit is 207.36 million tons per year.

Further discretionary adjustments are necessary however. If the maximum practicable number of double lockages is only 3650 per year, this implies a total of 10-12 lockages per day, not 16.
Additionally, the example above assumes smooth operations. Not only are tows always available for locking but they must move smoothly in and out of the chambers. Traffic surges and delays at individual locks produce the same type of local traffic jams and delays on waterways that are observed on highways. More importantly, in a double lockage the tows are assumed to be reassembled and broken in such a manner that they do not block waiting tows from the lock entry. Lockages are assumed to take the minimum time for each size lock. Even in the theoretical example recalculation indicates that an increase of lock time of ten minutes due to older locks or lack of trained crews would reduce the number of daily transits by ten percent. Finally, to the extent that integrated dedicated tows are used, while capacity use of the locks per tow and average tons per tow would both increase, the percentage of empty returning tows transiting the system would increase.

Comparisons between the numerical examples given above and actual commodity flow data indicate that river traffic is significantly lower than the general discussion presented here. If the rivers are to be successfully used for greatly enlarged traffic, a great deal more study is needed in the ways in which existing traffic flows can be augmented even under existing conditions.

The following is a summary of the characteristics of each of the individual rivers included in this study as well as the locks and dams located on each of the rivers. They are included here for general information, as a basis for some of the costing, and because some of the specific data are needed for those wishing to estimate barge costs between intermediate points on a given waterway.

4.4.2 Illinois Waterway

The Illinois River is formed by the confluence of the Kankakee and Des Plaines Rivers. It flows southwesterly and enters the Mississippi River at Grafton, Illinois, about 38 miles above St. Louis. The Illinois Waterway comprises the Illinois River from its mouth at Grafton 273 miles to the confluence of the Kankakee and Des Plaines Rivers; 18.1 miles on the Des Plaines River to Lockport and 34.5 miles on the Chicago Sanitary and Ship Canal
and the South Branch of the Chicago River to Lake Street, Chicago. From a point 12.4 miles above Lockport, the waterway also comprises 23.8 miles of the Calumet-Sag Channel and Little Calumet and Calumet Rivers to turning basin 5, near the entrance to Lake Calumet; and the Grand Calumet River from the junction, 9 miles to 141st Street and 4.2 miles to Clark Street, Gary, Indiana. The total mileage of the entire waterway is 353.6 miles [7,p.30-6].

Channel Dimension:

Channel depth is maintained at a minimum of 9 feet at all times. From Lockport to Chicago Harbor the minimum depth is approximately 17 feet. The channel is 300' wide from Grafton to Lockport; 160' wide from Lockport to Chicago Harbor and 60' wide from Lockport to Calumet Harbor [7,p.30-6].

Navigation Season:

The navigation season can be regarded as year round although traffic can experience some delays in January and February when parts of the river may ice up, especially during extremely cold weather.

Locks:

Table 4.6 shows the existing locks on the Illinois Waterway together with their estimated original cost [7,p.30-37].

Navigation Constraints:

Navigation on the waterway is limited by the size of the existing locks which limit the size of tows to 15 barges for a tow that requires double lockage. The 1962 Authorization Bill which provided for the construction of auxiliary locks at LaGrange, Peoria, Starved Rock, Marseilles, Dresden Island, Brandon Road and Lockport, and which would have reduced congestion to a large degree, has not yet been implemented. Construction has not begun on any of these locks. The new locks were to have cost $629.8 million in 1973 dollars [33,p.1-12]. However, detailed engineering costs estimated by the
Corps of Engineers, suggest that the first two alone will cost almost one-half of the amount quoted for all seven [33,p.6-28]. Inflating the 1973 figures to 1976 levels and adjusting on the basis of the two detailed studies suggests that projected costs may be as much as $1.2 billion [7,p.30-6]. Another limiting factor is the many bridges on the waterway. In 1973, limiting horizontal clearances were as follows: 118 feet at a bridge in the reach from Grafton to Utica, Illinois; 110 feet at bridges between Utica and Lockport and the Saq Junction; 80 feet at mile 293.1 between Lockport and the Saq Junction; 80 feet at a bridge between the Saq Junction and Lake Michigan via the Chicago Sanitary Canal and Chicago River; and 67.0 feet at a bridge between the Saq Junction and turning basin 5 in the Calumet River [7,p.30-6]. The narrow channel upstream of Lockport is a major capacity constraint for shipments to and from Chicago.

On the average, towboats are of the 2,600 horsepower class and tows average about eight barges. They average four in the Chicago area due to congestion and horizontal restrictions [8,p.IV-15]. Maximum tow size is 15 barges. According to the Corps of Engineers, the average tow speed is about 4.1 mph loaded, 4.8 mph empty and 4.0 mph at all times in the Chicago area. The maximum towboat size that can be used efficiently is about 4000 horsepower [8,p.IV-15].

4.4.3 Ohio River

The Ohio River is formed by the junction of the Allegheny and Monogahela Rivers at Pittsburgh, Pennsylvania, and flows generally southwesterly for 981 miles to join the Mississippi River near Cairo, Illinois [7,p.22-1].

Channel depth is maintained at 9 feet for the entire length. Channel width varies from 100 feet to 600 feet [7,p.22-1].

Navigation Season:

Navigation is possible year-round.

4-18
Locks:

The 1909 Act provided for a lock with usable dimensions of 110' by 600' at each of the dams located on the river with an auxiliary lock 56' by 360' at the Emsworth, Dashields, Montgomery, and McAlpine locks and dams and with a 110' by 360' auxiliary lock at Galipolis. Modifications to the 1909 Act provided for fixed dams with movable crests and with two locks (110' by 1,200' and 110' by 600') at New Cumberland, Pike Island, Hannibal, Willow Island, Belleville, Racine, Greenup, Meldahl, Markland, Cannelton, Newburgh, Uniontown, and Mound City; two locks 110' by 1200' at Smithland; 100' by 1200' temporary locks in addition to the existing locks at locks and dams 52 and 53; and reconstruction to provide a 110' by 1200' lock in addition to existing locks [7, p.22-1]. Table 4.7 is a listing of the locks and their status at the end of 1976 [7,p.22-8,9, as adjusted].

Navigation Constraints:

On stretches where the 110' by 1200' locks exist, tow size is limited to the size that can double lock (i.e., thirty 195' by 35' barges). In the lower reaches of the Ohio between 776 miles below Pittsburgh to Cairo, where construction of 110' by 1200' locks intended to replace smaller locks has been delayed, tow size is still limited to the size that can double lock a 110' by 600' lock, that is, fifteen 195' by 35' barges. According to the Corps of Engineers, average tow speed on the river is 4.8 mph loaded and 6.2 mph empty. Low water occasionally delays tows or causes them to be loaded to less than full capacity. Anticipated future industrial and other developments in the Ohio River drainage basin may put temporary pressure on water use for navigation. Recycling water for lockages by pumping has been suggested, but it is costly.

4.4.4 Missouri River

The Jefferson, Madison and Gallatin Rivers meet at Three Forks, Montana to form the Missouri River, which flows southeasterly 2,315 miles across or along seven states to the Mississippi River at a point 17 miles above St. Louis [7,p.20-2].
Channel Dimensions:

The existing project is to provide a channel of 9-foot depth and a width of not less than 300 feet [7,p.20-2]. Between Rulo, Nebraska and the confluence with the Mississippi, a channel with a minimum depth of 7.5 feet is currently available. Between Rulo and Sioux City, Iowa a channel with a minimum depth of 8.5 feet is now available [11,p.10].

Navigation Season:

From Sioux City to Omaha the river is navigable from late March to late November. Between Omaha and Kansas City the navigation season is from late March to early December. Finally, between Kansas City and the mouth of the river, it is navigable between early April and early December [8,p.IV-25]. The average navigation season for the entire river is about 7.5 months [11,p.10].

Navigation Constraints:

The major constraints on this river are channel depth variability and channel curvature. The Corps is attempting to develop a 9 foot channel by dredging, bank stabilization, and water flow releases. However, sedimentation and hydraulic conditions often reduce controlling depth to 7.5 feet thus reducing the carrying capacity of a 195' barge from 1500 net tons to 1100 net tons. With a controlling bend radius of 6000', the size of a tow is limited to ten 195' barges between the mouth and Booneville, Missouri. Between Booneville and Sioux City, Iowa, the controlling bend radius is 3000 feet which limits the tow size to six 195' barges [11,p.10]. The average tow speed on the river, according to the Corps of Engineers, is 3.5 mph upstream and 10.0 mph downstream.

The availability of water is crucial to the maintenance of channel depth in the Missouri River. Future use of the water in this river basin for irrigation and other purposes is anticipated to deplete river flows to the point at which navigation will be seriously impaired. By the year 2020, it may not be viable for navigation [34,p.141]. The Corps of Engineers has forseen three alternatives for navigation on the Missouri River over the next
forty years: abandon the development project, reduce service, or canalize [35]. If we assume that the locks and dams would have a completed cost of $150-$200 million each, and if 20 are needed, the projected costs would range from $3-4 billion.

4.4.5 The McClellan-Kerr Arkansas River System

The system provides a channel 9 feet deep and 441.0 miles long. It begins at the mouth of the White River which starts at the Mississippi River; 10 miles upstream to the Arkansas Post Canal, 9 miles on the canal to mile 42 on the Arkansas River; 372.3 miles along the river to the mouth of the Verdigris River at mile 391.3; 49.7 miles up the Verdigris River to the head of navigation at Catoosa, Oklahoma. The system is canalized throughout its length by 17 locks and dams [7,p.18-2].

Channel Dimensions:

From the mouth to Chouteau lock and dam, the channel is about 150 feet wide. Between Chouteau lock and dam and Catoosa, the channel is about 250 feet wide. The depth for the entire system is 9 feet [11,p.10].

Navigation Season:

The channel is open to navigation year-round.

Locks:

There are 17 locks and dams on the waterway, all of which are now in operation. Table 4.8 shows their location and original cost of construction [7,p.17-18].

Navigation Constraints:

The major constraints on this waterway, which opened for navigation in 1971, are the size of the locks and the curvature of the channel. Although the size of the locks limit the maximum tow size to 15 barges, the maximum number to double lock a 110'
by 600' lock, the actual tow size that can operate on this river is much smaller. Between the mouth and Chouteau lock and dam, the controlling bend radius of 3000' to 4500' limits the maximum tow size to nine 195' barges. Between Chouteau lock and New Graham lock the controlling bend radius of 3500' limits the tow size to only four 195' barges [11,p.10].

4.4.6 Upper Mississippi River

This section of the Mississippi extends from the Soo Line Bridge in Minneapolis, 857.6 miles to the confluence of the Mississippi and Ohio Rivers, at Cairo, Illinois. Between Minneapolis and the Chain of Rocks lock and dam, about 185 miles above Cairo, the river is controlled by a series of locks and dams. Between the Chain of Rocks lock and Cairo the river is lock free and permits larger, more powerful towboats to be used [7,p.29-1]. However, bridge abutments constrict traffic between lock 27 and Cairo.

Channel Dimensions:

The waterway is maintained at a minimum depth of 9 feet. Navigation on the Mississippi is hampered in spring by high flow velocities and floods. In the winter a low flow condition occurs which, when combined with a shortage of rain, reduces the channel depth to less than 9 feet. A channel width of 300' to 400' is available throughout the entire length with the exception of the Minneapolis area where the width is about 200 ft. [7,p.20-1]

Navigation Season:

Between Minneapolis and Rock Island, the navigation season is from April 10 to December 1. From Rock Island to Grafton, the season extends from March 1 to December 1. Below Grafton, the navigation season is year-round although some delays may be experienced due to ice formation in January and February. The average navigation season for this section of the river is about 9 months.
Locks:

All of the locks on the waterway are 110' by 600' or smaller with the exception of locks 19 and 27 where 1200' chambers are in service. The proposal by the Corps of Engineers to replace lock and dam 26 at Alton with two 110' by 1200' locks is pending before Congress. Table 4.9 is a list of existing locks and dams [7,p.29-6,7].

Navigation Constraints:

For the section above Grafton, Illinois, the major navigation constraints are the size and capacity of the locks, the curvature of the channel, and the water volume. Because nearly all of the locks in the system are 110' by 600' this, together with the curvature of the channel, limits the maximum size of a tow to fifteen 195' barges. In addition, during the winter months the river is closed to most navigation due to ice. The reduction in water volume in drought years makes it difficult to maintain the 9 foot channel depth. In turn this reduces the amount of cargo a barge can carry. Significant future increases in traffic between the upper and lower Mississippi will require enlargement of the upper river locks. Further viability of the nine foot navigation project between lock 27 and the Ohio River (sometimes called the middle Mississippi) may be threatened by periods of low water on the upper Mississippi and anticipated depletions of Missouri River flows as described above.

Substantially increased coal traffic on the upper Mississippi would require enlargement of some or all of the locks even after an Alton replacement. An early estimate of the cost of replacing the current lock dimensions with 110' x 1200' locks was made by the Corps of Engineers in 1968 [37]. Then it was estimated that replacing locks 14-27 (but excluding lock 26) would entail a first cost of $521,876,000. As lock 27 alone was estimated at $105,460,000, the remaining 12 locks would average $34.7 million each. Assuming a minimum three year building period and a 5 percent interest rate on costs during construction raises the ante significantly. There is some evidence that these costs are understated. The 1974 "Mudd memorandum" [35, exhibit 12] estimates the cost of these same locks at about $100 million each. If this is added to the cost for lock 27, and about $500 million more
is added for lock 26, total prospective costs for the upper river to Davenport - Rock Island (lock 14) are about $1.8 billion. To make full use of the river, particularly with reference to coal shipments from the northern great plains, locks 1-13 would also have to be enlarged. This would allow major coal access to the river as far north as Minneapolis - St. Paul. The cost for the addition, based on the above, is another $1.3 billion or $3.1 billion for the upper Mississippi. Even if amortized over 50 years, if the annual charges had to be paid by users, it is worth a study to see if the costs would allow users to remain competitive with other modes of transportation.

Since the introduction of steel-hulled towboats the navigation season below Grafton has become year-round despite the presence of ice. Some delays may still be encountered as a result of large ice formations during extreme cold weather in January and February. Below the Chain of Rocks locks there is open channel navigation. However, the size of a tow is limited to about fifteen 195' barges due to the controlling bend radius of 3100' to 6000' and low water volume during the dry season [11,p.10].

According to the Corps of Engineers, average tow speed on the Upper Mississippi above Dam 27 is approximately 5.0 mph loaded and 7.0 mph empty. Between dam 27 and Cairo, the average tow speed is about 8.0 mph downstream and 5.0 mph upstream.

4.4.7 Lower Mississippi River

This section of the Mississippi River begins at the confluence of the Mississippi River and the Ohio River at Cairo, extends for 954 miles and enters the Gulf of Mexico at Head of Passes, Louisiana. There are no locks on the lower Mississippi River. The entire length is open channel navigation.

Channel Dimensions:

Between Cairo and Baton Rouge a minimum nine foot channel is maintained. Between Baton Rouge and Head of Passes a minimum depth of 40 feet is maintained [11,p.10].
Between Cairo and Baton Rouge the channel is between 400' and 550' wide. Between Baton Rouge and New Orleans the width is 530'. Between New Orleans and Head of Passes the width is about 1000' [11,p.10].

Navigation Season:

Year-round navigation is possible over the entire section of the river [11,p.10].

Navigation Constraints:

Because of its width, depth and open channel characteristics, this section of the Mississippi River is suitable for the use of large size tows. It is the only place where the large 8000 to 10,500 horsepower towboats can operate efficiently. As a result, below Cairo, tows with upward of 45 barges operate on the waterway. On occasion, low water requires that barges be loaded to less than full capacity.

According to the Corps of Engineers, the average tow speed on the lower Mississippi is 5.0 mph upstream and 12.0 mph downstream.

4.4.8 Tennessee River

The river extends from its navigation head at Knoxville, Tennessee, for 650 miles to its mouth on the Ohio River near Paducah, Kentucky. The river is made navigable by a series of nine locks and one on the tributary Clinch River. With the exception of the lock at Wheeler dam and the Wilson locks and dams, all the other locks and dams were constructed by the Tennessee Valley Authority [7,p.23-4].

Channel Dimensions:

The entire length of the river is maintained at a channel depth of 9 feet and a width of 300 feet [11,p.10].
Navigation Season:

The entire length is open for navigation year-round.

Locks:

There are nine locks and dams on the river and one, Melton Hill, on the tributary Clinch River near Knoxville, Tennessee. All but one of the locks are 110' by 600' or smaller. Table 4.10 is a list of the locks.

Navigation Constraints:

The major constraint on this river is the size of the locks. From Chattanooga to Paducah, all of the locks are of 110' by 600' with the exception of the main lock at Nickajack which is 110' by 800'. As a result, the maximum tow size is limited to fifteen 195' barges for double lockage. Between Chattanooga and Knoxville, the locks are 60' by 360' which limits tow size to two 195' barges or seven 175' barges for double lockage. Because of the limitation on the size of the tows, it is not economic to use towboats exceeding 2000 horsepower beyond Chattanooga.

According to the Corps of Engineers, the average tow speed on this river is 5.8 mph loaded and 7.0 mph empty.

4.4.9 Tennessee - Tombigbee - Warrior Rivers

The Warrior River flows generally southwesterly from northern Alabama above Birmingham to unite with the Tombigbee River at Demopolis, Alabama. The Tombigbee then flows south, uniting with the Alabama River to form the Mobile River which flows into the Gulf of Mexico at Mobile Bay, 45 miles south [7,p.10-5].

The canal connecting the Tombigbee and Tennessee Rivers is in the construction stage. The project, when completed, would allow river traffic on the Tennessee River to go all the way to the Gulf of Mexico. The project provides for a waterway 253 miles in length with a minimum depth of 9 feet and a
width of 280 feet. There will be ten locks each having chamber dimensions of 110' by 600'. The total estimated cost of the project in 1976 was $1.58 billion [36,p.44].

Channel Dimensions:

The Warrior - Tombigbee waterway has a minimum depth of 9 feet and a width of 200 feet for the entire 408 miles of the waterway [7,p.10-5].

Navigation Season:

Navigation on this waterway is available year-round.

Locks:

On the Warrior - Tombigbee Waterway, the original 17 dams completed in 1915 were replaced by five new locks and dams and the reconstruction of the Bankhead lock and dam. Table 4.11 lists the locks on the Tombigbee - Warrior Waterway [7,p.10-45].

Navigation Constraints:

The major constraints on this waterway are the size of the locks and channel curvature. After the rehabilitation of Bankhead lock and dam, the lock which sets the limits on the size of tows going up to Birmingham is the Oliver lock which is 95' by 460'. This limits the maximum tow size to eight 195' barges for double lockage. Below Bankhead lock the maximum tow size is fifteen 195' barges, the maximum size to double lock a 110' by 600' lock. In addition to the limitation set by the dimensions of the locks, the sharp curvature of the channel imposes further limitations; normal tow size on this waterway seldom exceeds four to six barges [11,p.10].

According to the Corps of Engineers, average tow speed on the waterway is about 5.2 mph loaded and 6.8 mph empty.
4.4.10 Gulf Intracoastal Waterway - East

This section of the waterway extends from the junction of the Inner Harbor Navigation Canal and the Mississippi River, east along the Gulf coast 427 miles to St. Marks, Florida [7,p.10-9,10].

Channel Dimensions:

The channel is maintained at a depth of 12 feet and a width of 125 feet [11,p.10].

Navigation Season:

The waterway is open for traffic year-round.

Locks:

There is only one lock on this section of the waterway: the Inner Harbor Navigation Canal lock 2.9 miles below New Orleans with a dimension of 75' by 640' built in 1923 at a cost of $8,648,492 [7,p.11-50].

Navigation Constraints:

The major constraints are the narrowness and curvature of the channel. With a width of only 125 feet and a bend radius of 500 feet, tows are limited to a maximum of five 195' barges [6,p.57].

According to the Corps of Engineers, the average tow speed on the waterway is 5.5 mph loaded and 7.2 mph empty.

4.4.11 Gulf Intracoastal Waterway - West

This section of the waterway extends from the junction of the Inner Harbor Navigation Canal and the Mississippi River, west along the Gulf coast 650 miles to Brownsville, on the Mexican border [7,p.11-10].
Channel Dimensions:

The channel is maintained at a depth of 12 feet and a width of 125 feet [11,p.10].

Navigation Season:

The waterway is open for traffic year-round.

Locks:

Table 4.12 shows the locks in operation on the waterway.

Navigation Constraints:

The major constraints are the narrowness and curvature of the channel. With a width of only 125 feet and bend radius of 5000 feet, tows are limited to a maximum of five 195' barges [11,p.10]. Two way traffic is possible only when flotilla width is restricted to one barge. Two locks on this section of the waterway are nearing capacity: the Vermillion lock and the Bayou Sorrel lock. Average delays for each tow reach 6 hours indicating a 75 percent utilization rate. Any further increase in waiting time is considered intolerable by barge operators [6,p.57].

According to the Corps of Engineers, the average tow speed on the waterway is 5.5 mph loaded and 7.2 mph empty.
**TABLE 4.6: Illinois Waterway Locks and Dams**

<table>
<thead>
<tr>
<th>Lock</th>
<th>Miles Above Mouth</th>
<th>Width of Chamber (ft)</th>
<th>Chamber Length (ft)</th>
<th>Year Completed</th>
<th>Estimated Federal Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LaGrange</td>
<td>80.2</td>
<td>110</td>
<td>600</td>
<td>1939</td>
<td>2,774,592</td>
</tr>
<tr>
<td>Aux.</td>
<td>80.2</td>
<td>110</td>
<td>1200</td>
<td></td>
<td>55,328,000</td>
</tr>
<tr>
<td>Peoria</td>
<td>157.7</td>
<td>110</td>
<td>600</td>
<td>1939</td>
<td>3,381,030</td>
</tr>
<tr>
<td>Aux.</td>
<td>157.7</td>
<td>110</td>
<td>1200</td>
<td></td>
<td>55,982,000</td>
</tr>
<tr>
<td>Starved Rock</td>
<td>231.0</td>
<td>110</td>
<td>600</td>
<td>1933</td>
<td>885,315</td>
</tr>
<tr>
<td>Aux.</td>
<td>231.0</td>
<td>110</td>
<td>1200</td>
<td></td>
<td>57,569,000</td>
</tr>
<tr>
<td>Marseilles</td>
<td>244.6</td>
<td>110</td>
<td>600</td>
<td>1933</td>
<td>57,569,000</td>
</tr>
<tr>
<td>Aux.</td>
<td>244.6</td>
<td>110</td>
<td>1200</td>
<td></td>
<td>1,853,725</td>
</tr>
<tr>
<td>Dresden Is.</td>
<td>271.5</td>
<td>110</td>
<td>600</td>
<td>1933</td>
<td>2,503,376</td>
</tr>
<tr>
<td>Aux.</td>
<td>271.5</td>
<td>110</td>
<td>1200</td>
<td></td>
<td>46,956,800</td>
</tr>
<tr>
<td>Brandon Rd.</td>
<td>286.0</td>
<td>110</td>
<td>600</td>
<td>1933</td>
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Source: [7,p.30-37]

Note: Construction on none of the auxiliary locks has been started.
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<th>Lock</th>
<th>Miles Below Pittsburgh</th>
<th>Width of Chambers (ft)</th>
<th>Length (ft)</th>
<th>Year Completed</th>
<th>Estimated Federal Cost (S)</th>
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<td>1959</td>
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<td>Meldahl</td>
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<td>1200</td>
<td>1962</td>
<td>74,164,520</td>
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<td>1963</td>
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TABLE 4.7: Ohio River Locks and Dams (Continued)

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<th>Lock</th>
<th>Miles Below Pittsburgh</th>
<th>Width of Chambers (ft)</th>
<th>Length (ft)</th>
<th>Year Completed</th>
<th>Estimated Federal Cost ($)</th>
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<td>McAlpine</td>
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<td>110</td>
<td>600</td>
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<td></td>
<td>56</td>
<td>360</td>
<td></td>
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<tr>
<td>Cannelton</td>
<td>720.7</td>
<td>110</td>
<td>1200</td>
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<td></td>
<td>97,300,000</td>
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<tr>
<td>Newburgh</td>
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<td>110</td>
<td>1200</td>
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<tr>
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<td>600</td>
<td>1929</td>
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<td></td>
<td></td>
<td>110</td>
<td>600</td>
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<td>1,539,470</td>
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</table>

(1) 94% completed in 1976  
(2) 96% completed in 1976  
(3) 96% completed in 1976  
(4) 94% completed in 1976  
(5) 57% completed in 1976  
(6) construction not yet started in 1973.

Source: [7,p.22-8,9] and adjusted by later data.

Note: Lock No. 53; the temporary 110' x 1200' lock was 48% complete in 1976. It is due for completion in early 1978 at an estimated federal cost of $37.1 million. As the named locks are completed, the preceding numbered locks are eliminated.
**TABLE 4.8: McClellan - Kerr - Arkansas River System Locks and Dams**

<table>
<thead>
<tr>
<th>Lock</th>
<th>Miles Upstream from mouth</th>
<th>Width of Chamber</th>
<th>Chamber Length</th>
<th>Year Completed</th>
<th>Cost ($)</th>
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<tr>
<td>Norrell</td>
<td>10.4</td>
<td>110</td>
<td>600</td>
<td>1967</td>
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<tr>
<td>No. 2</td>
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<td>110</td>
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<td>No. 3</td>
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<td>110</td>
<td>600</td>
<td>1968</td>
<td>33,140,000</td>
</tr>
<tr>
<td>No. 4</td>
<td>65.0</td>
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<td>600</td>
<td>1968</td>
<td>40,150,000</td>
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<tr>
<td>No. 5</td>
<td>85.0</td>
<td>110</td>
<td>600</td>
<td>1968</td>
<td>28,810,000</td>
</tr>
<tr>
<td>Terry</td>
<td>106.3</td>
<td>110</td>
<td>600</td>
<td>1968</td>
<td>60,040,000</td>
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<tr>
<td>Murray</td>
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<td>110</td>
<td>600</td>
<td>1969</td>
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<tr>
<td>Toad Suck Ferry</td>
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<td>600</td>
<td>1969</td>
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<td>1969</td>
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<td>110</td>
<td>600</td>
<td>1970</td>
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Source: [7,p.17-18]
### TABLE 4.9: Upper Mississippi River Locks and Dams

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<th>Lock</th>
<th>Miles Above the Ohio River</th>
<th>Width of Chamber (ft)</th>
<th>Chamber Length (ft)</th>
<th>Year Completed</th>
<th>Estimated Cost ($)</th>
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<td>St. Anthony lower</td>
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<td>400</td>
<td>1917</td>
<td>2,358,000</td>
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<td>110</td>
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<td>796.9</td>
<td>110</td>
<td>600</td>
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<td>600</td>
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<td>600</td>
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<tr>
<td>Le Claire (Canal)</td>
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<td>320</td>
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TABLE 4.9: Upper Mississippi River Locks and Dams  
(Continued)

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<th>Lock No.</th>
<th>Miles Above the Ohio River</th>
<th>Width of Chamber (ft)</th>
<th>Chamber Length (ft)</th>
<th>Year Completed</th>
<th>Estimated Cost ($)</th>
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Source: [17,p.29-6,7]
<table>
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<th>Lock</th>
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<th>Chamber Length (ft)</th>
<th>Year Completed</th>
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<td>Kentucky</td>
<td>22.4</td>
<td>110</td>
<td>600</td>
<td>1942</td>
</tr>
<tr>
<td>Pickwick Landing</td>
<td>206.7</td>
<td>110</td>
<td>600</td>
<td>1937</td>
</tr>
<tr>
<td>Wilson</td>
<td>259.4</td>
<td>60</td>
<td>292</td>
<td>1927</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110</td>
<td>300</td>
<td>1959</td>
</tr>
<tr>
<td>Wheeler</td>
<td>274.9</td>
<td>60</td>
<td>400</td>
<td>1934</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110</td>
<td>600</td>
<td>1963</td>
</tr>
<tr>
<td>Guntersville</td>
<td>349.0</td>
<td>60</td>
<td>360</td>
<td>1937</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110</td>
<td>600</td>
<td>1965</td>
</tr>
<tr>
<td>Nickajack</td>
<td>424.7</td>
<td>110</td>
<td>600</td>
<td>1967</td>
</tr>
<tr>
<td>Chickamauga</td>
<td>471.0</td>
<td>60</td>
<td>360</td>
<td>1939</td>
</tr>
<tr>
<td>Watts Bar</td>
<td>529.9</td>
<td>60</td>
<td>360</td>
<td>1941</td>
</tr>
<tr>
<td>Fort Loudon</td>
<td>602.3</td>
<td>60</td>
<td>360</td>
<td>1943</td>
</tr>
<tr>
<td>Melton Hill (Clinch River)</td>
<td>23.1</td>
<td>75</td>
<td>400</td>
<td>1963</td>
</tr>
</tbody>
</table>

Source: [7,p.23-15]
<table>
<thead>
<tr>
<th>Lock</th>
<th>Miles Above Mobile</th>
<th>Width of Chamber (ft)</th>
<th>Chamber Length (ft)</th>
<th>Year Opened to Navigation</th>
<th>Estimated Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffeeville</td>
<td>116.7</td>
<td>110</td>
<td>600</td>
<td>1960</td>
<td>21,597,264</td>
</tr>
<tr>
<td>Demopolis</td>
<td>213.2</td>
<td>110</td>
<td>600</td>
<td>1954</td>
<td>19,774,583</td>
</tr>
<tr>
<td>Warrior</td>
<td>261.1</td>
<td>110</td>
<td>600</td>
<td>1957</td>
<td>13,295,553</td>
</tr>
<tr>
<td>Bacon Oliver</td>
<td>336.15</td>
<td>95</td>
<td>460</td>
<td>1939</td>
<td>4,450,874</td>
</tr>
<tr>
<td>Holt</td>
<td>347.0</td>
<td>110</td>
<td>600</td>
<td>1966</td>
<td>28,100,000</td>
</tr>
<tr>
<td>Bankhead</td>
<td>365.5</td>
<td>110</td>
<td>600</td>
<td>1976</td>
<td>46,000,000</td>
</tr>
</tbody>
</table>

Source: [7, p.10-45] updated
TABLE 4.12: Gulf Intracoastal Waterway - West
Locks and Dams

<table>
<thead>
<tr>
<th>Lock Name</th>
<th>Miles from New Orleans:</th>
<th>Lock dimensions:</th>
<th>Year completed:</th>
<th>Cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algiers Lock:</td>
<td>7 miles</td>
<td>75' by 800'</td>
<td>1956</td>
<td>$5,215,700</td>
</tr>
<tr>
<td>Bayou Boeuf Lock:</td>
<td>96.6 miles</td>
<td>75' by 1156'</td>
<td>1954</td>
<td>$2,754,000</td>
</tr>
<tr>
<td>Bayou Sorrel Lock:</td>
<td>135 miles</td>
<td>56' by 797'</td>
<td>1951</td>
<td>$4,700,948</td>
</tr>
<tr>
<td>Calcasieu Lock:</td>
<td>16.6 miles</td>
<td>75' by 1206'</td>
<td>1950</td>
<td>$2,133,527</td>
</tr>
<tr>
<td>Harvey Lock:</td>
<td>3.3 miles</td>
<td>75' by 425'</td>
<td>1935</td>
<td>$1,775,132</td>
</tr>
<tr>
<td>Port Allen Lock:</td>
<td>132.5 miles</td>
<td>84' by 1202'</td>
<td>1961</td>
<td>$13,902,222</td>
</tr>
<tr>
<td>Vermillion Lock:</td>
<td>26 miles</td>
<td>56' by 1182'</td>
<td>1934</td>
<td>$330,765</td>
</tr>
</tbody>
</table>

(Replacement approved in 1967, but not yet completed)

Source: [7, p. 11-49, 50]
FIGURE 4.2: Upper Mississippi, Missouri and Illinois Waterways
FIGURE 4.3: Ohio, Tennessee, Tombigbee and Warrior Rivers
FIGURE 4.4: Lower Mississippi, McClellan - Kerr - Arkansas Rivers, and the Intracoastal Waterway - West
FIGURE 4.5: Gulf Intracoastal Waterway - East, Tennessee, Tombigbee, Warrior and Mobile Rivers
4.5 DETERMINATION OF LINE-HAUL COSTS

4.5.1 Introduction

Efforts to determine line-haul costs from original and recent data are difficult because the barge industry is largely unregulated. As a result, very little published information is available. Even efforts by the Research Division of the Transportation System Center of the U.S. Department of Transportation to obtain operating and ownership cost information directly from individual barge companies for a study on water transportation requirements for coal movement in the 1980's were largely futile due to the reluctance of the barge companies to provide such information [9,p.VIII].

As a result, we have relied on estimates obtained from two earlier studies on the estimation of ownership and operating costs. The first set of estimates examined was developed by A.T. Kearney & Co. for the Maritime Administration for its Domestic Waterborne Shipping Market Analysis [1]. The report does not provide detailed ownership or operating estimates but merely a set of costs representing average costs for inland waterway equipment operating on specific waterways. For example, according to the report, the variable line-haul cost for operations on the Upper Mississippi River is 0.40 cents/ton-mile upstream and 0.22 cents/ton-mile downstream. The fully allocated line-haul cost is 0.46 cents/ton-mile upstream and 0.26 cents/ton-mile downstream [1,app.G]. The problem with this set of cost figures is that they reflect 1973 (or earlier) prices and, since the raw data which produced the set of cost figures are unavailable, it is difficult to obtain cost distributions or update them to reflect 1976 prices. Simple inflation of the data is possible, but would result in a loss of costing detail.

A second study which examined line-haul costs was done by the Market Research Department of the Illinois Central Railroad [8]. Unlike the Kearney study, the Illinois Central study developed an hourly ownership and operating cost for towboats of various horsepower classes and barges of different sizes. By using the average tow speed data provided by the Corps of Engineers, the time needed
to cover two points on a waterway can be determined. The line-haul cost between two points on a river can be determined by multiplying the ownership and operating costs per hour for a specific tow by the number of hours needed to cover the distance. As a detailed set of data was included in the final report, it is possible to inflate the estimates to reflect 1976 prices.

Due to the difficulty of obtaining more recent estimates from the barge companies and our inability to break down the cost figures provided in the Kearney study, we have adopted the approach used by Illinois Central in the determination of line-haul costs. The data used by Illinois Central (I.C.) to derive ownership and operating costs can be inflated at various rates to reflect 1976 prices. Other adjustments can be made to reflect current financial conditions.

In costing studies it is generally preferable to rely in the first instance on the industry under consideration for the data. Where such data are unavailable, data derived from competitors' costing estimates are "second best." Where competitors must meet rates in order to obtain business, they must be substantially aware of their opponents' cost structures in order to be able to set their own rates successfully. In using the I.C. study we have relied on this argument.

Because the data provided in the I.C. study included towboats only up to the 6500 hp. class, attempts were made to derive costs for towboats in the larger horsepower classes from existing data by using graphical extrapolation. The resulting costs are an estimate of ownership and operating costs for towboats between 6500 hp. and 10,500 hp. and may not accurately reflect actual costs. Given efficiencies, it is probable that these last are overstated.
4.5.2 Methods of Updating Data

4.5.2.1 Average replacement costs for towboats and barges. According to the I.C. study, the cost for a new 4800 hp. towboat was $1,231,200 [8, Chart V-10] in 1971 and the cost for a new 195' open hopper barge was $92,340. In 1976, according to a study by the staff of the Iowa Department of Transportation, a towboat in the 4000-5000 hp. class cost approximately $2,250,000 and a 1500 ton capacity barge cost $195,000 [15, p.14]. At the same time, according to the U.S. Department of Transportation study on water transportation, "Requirements for Coal Movement in the 1980's," the average cost for hopper barges, both covered and open, was $199,000 in 1976, while the cost of an open hopper barge was about $163,000. Based on these figures it is apparent that in the past five years the cost for a new open hopper barge has increased 76.5 percent and the cost of a new towboat has increased by 82.7 percent. Using these assumptions we developed the 1976 costs for towboats in the various horsepower classes and barges of various sizes.

Between the 7200 hp. class and the 10,500 hp. class, where data are unavailable, a rough estimate of the replacement costs for towboats was determined by graphical extrapolation involving plotting the cost against the towboats of various horsepower classes [Figure 4.6].

4.5.2.2 Fixed charges. Instead of using 5 percent on half value for interest [8,Chart V-10], 7 percent on full value was used. Depreciation is based on a 5 percent salvage value and a 20 year life as indicated in the I.C. study.
4.5.2.3 Administration and supervision costs. The estimates provided in the I.C. study [8, Chart V-10] were inflated at 7 percent per year for 5 years to reflect 1976 prices. Costs for the larger horsepower classes, between 7200 hp. and 10,500 hp., were extrapolated [Figure 4.7].

4.5.2.4 Operating expenses and taxes. The various categories of operating expenses and taxes were inflated at the rate of 7 percent per year for 5 years to reflect 1976 prices with the exception of fuel oil which was assumed to have doubled in cost. For estimates between 7200 hp. and 10,500 hp. where 1971 data are unavailable, an estimate was made using the graphical method [Figures 4.8-4.13]. For costing purposes, the data in Figure 4.8 was inflated to obtain 1976 costs. In the case of wages, fringe benefits, subsistence and miscellaneous items, where no graphical relationship can be established, a graph for total operating expenses was plotted and the result extrapolated. Combined with the items which can be estimated from the graphical method, a rough estimate for them was determined.

4.5.2.5 Return on investment. Instead of using 10 percent on half value [8, Chart V-10] for the return on investment, 10 percent on full value was used.

4.5.2.6 Ownership and operating costs for barges. All costs were based on a percentage of investment. Depreciation was based on a 5 percent salvage value and a 20 year life, interest at 7 percent declining balance or 3.7 percent of investment, insurance at 2 percent of investment and taxes at 0.5 percent of investment. In the I.C. study, maintenance and repairs were estimated at 3 percent of investment. Because replacement costs have increased about 76.5 percent for barges, it was decided to reduce the figure for maintenance to 2 percent as this cost
probably did not increase as fast as replacement cost. For the same reason, 0.5 percent of investment was used for administrative costs instead of the 0.75 percent of investment used in the I.C. study [8,Chart V-10].

4.5.3 Determination of Hourly Ownership and Operating Costs

In order to determine the hourly ownership and operating costs for towboats and barges, yearly costs were developed. Tables 4.13 and 4.14 show the yearly costs for towboats of various classes and open hopper barges of various sizes derived from the I.C. data including the adjustments described above.

Because the concern of this study is coal transportation, the only type of barge examined was the open hopper barge.

To obtain hourly operating and ownership costs for towboats and barges operating on the various rivers, the yearly costs were divided by the length of the navigation season for each waterway. Where the navigation season is year-round, towboats and barges are assumed to operate for 355 days allowing 10 days for maintenance and repairs. All craft are assumed to operate on a 24 hour basis. The only towboats considered for each waterway were those that could operate on that waterway. Table 4.15 shows the hourly ownership and operating costs of towboats and barges for each waterway examined in this study.

4.5.4 Determination of Line-haul Costs

With the determination of hourly ownership and operating costs for towboats and barges on the various waterways, line-haul costs can be determined based on the following equations derived from the I.C. study [8,p.V-2]. Back-haul time is included in the total number of hours.

Total barge cost per net tons delivered = (Hourly ownership-operating cost of barge) x (Total number of hours used per trip)/(Total net tons delivered per barge trip)
Total towboat cost per net ton delivered = (Hourly ownership-operating cost of towboat) x (Total number of hours per trip)/(Total net tons delivered per towboat trip)

The sum of these two equations is the estimated line-haul cost for a tow between two specific points per net ton delivered.

For the purpose of this study, dedicated integrated towing was assumed in all cases for the movement of coal. Therefore, the back haul to the point of origin was assumed to be empty.

Two kinds of time must be considered in determining the total number of hours used per trip. The first is the amount of time needed to cover a specific distance between two points. Knowing the specific distance between two points, the time needed to cover the distance is determined by dividing the distance by the average tow speed on the specific waterway as determined by the Corps of Engineers. This tow speed takes into account both average delays encountered at locks and weather conditions. Table 4.16 reviews the tow speeds on the various rivers.

The second factor to be considered is terminal time. According to the I.C. study [8,Chart V-3], based on Corps of Engineers' data, the average terminal time for loading coal is 72 hours, for unloading it is 120 hours. The basis is not given, however. We have used estimated times for loading from unit trains and apportioned the unloading time in the ratio implied above.

In determining the total net tons per barge trip it is important to take the constraints on the various rivers into account. Some rivers restrict the number of barges, or the size of the barges, on others the capacity load a barge can carry is limited.

From data derived above and in the previous sections, we obtain an estimate of the line-haul cost for the movement of a coal flotilla from point A to point B within the waterway system examined.
### TABLE 4.13: Towboats: Ownership and Operating Costs ($)

<table>
<thead>
<tr>
<th>TOWBOATS</th>
<th>800 HP</th>
<th>1200 HP</th>
<th>1400 HP</th>
<th>1600 HP</th>
<th>1800 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INVESTMENT</strong> (average new cost)</td>
<td>432,000</td>
<td>648,000</td>
<td>756,000</td>
<td>864,000</td>
<td>972,000</td>
</tr>
<tr>
<td><strong>FIXED CHARGES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest (7% on full value)</td>
<td>30,240</td>
<td>45,360</td>
<td>52,920</td>
<td>60,480</td>
<td>68,040</td>
</tr>
<tr>
<td>Depreciation (5% 20 yr. life)</td>
<td>20,520</td>
<td>30,780</td>
<td>35,910</td>
<td>41,040</td>
<td>46,170</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td>50,760</td>
<td>76,140</td>
<td>88,830</td>
<td>101,520</td>
<td>114,210</td>
</tr>
<tr>
<td><strong>ADMINISTRATION &amp; SUPERVISION</strong></td>
<td>37,589</td>
<td>48,154</td>
<td>50,441</td>
<td>56,731</td>
<td>58,982</td>
</tr>
<tr>
<td><strong>OPERATING EXPENSES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>146,059</td>
<td>178,756</td>
<td>178,756</td>
<td>200,048</td>
<td>200,204</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>21,909</td>
<td>26,616</td>
<td>26,616</td>
<td>30,029</td>
<td>30,029</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>54,476</td>
<td>81,324</td>
<td>94,672</td>
<td>107,936</td>
<td>121,132</td>
</tr>
<tr>
<td>Maint. &amp; Repairs</td>
<td>15,120</td>
<td>22,680</td>
<td>26,480</td>
<td>30,240</td>
<td>34,020</td>
</tr>
<tr>
<td>Supplies</td>
<td>8,694</td>
<td>9,828</td>
<td>10,395</td>
<td>10,962</td>
<td>11,529</td>
</tr>
<tr>
<td>Subsistence</td>
<td>10,955</td>
<td>12,519</td>
<td>12,519</td>
<td>14,084</td>
<td>15,649</td>
</tr>
<tr>
<td>Insurance</td>
<td>6,048</td>
<td>9,072</td>
<td>10,584</td>
<td>12,096</td>
<td>13,609</td>
</tr>
<tr>
<td>Misc.</td>
<td>3,651</td>
<td>4,467</td>
<td>4,467</td>
<td>5,005</td>
<td>5,005</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td>266,912</td>
<td>345,462</td>
<td>364,669</td>
<td>410,556</td>
<td>431,177</td>
</tr>
<tr>
<td>Taxes</td>
<td>1,512</td>
<td>2,266</td>
<td>2,646</td>
<td>3,024</td>
<td>3,402</td>
</tr>
<tr>
<td><strong>TOTAL CHARGES &amp; EXPENSES</strong></td>
<td>356,773</td>
<td>472,024</td>
<td>506,586</td>
<td>571,831</td>
<td>607,771</td>
</tr>
<tr>
<td><strong>RETURN ON INVESTMENT</strong> (10% on Full Value)</td>
<td>43,200</td>
<td>64,800</td>
<td>75,600</td>
<td>86,400</td>
<td>97,200</td>
</tr>
<tr>
<td><strong>TOTAL CHARGES &amp; RETURN ON INVESTMENT</strong></td>
<td>399,973</td>
<td>536,824</td>
<td>582,186</td>
<td>658,231</td>
<td>704,971</td>
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</table>
TABLE 4.13: Towboats: Ownership and Operating Costs
(Continued)

<table>
<thead>
<tr>
<th>TOWBOATS</th>
<th>2000 HP</th>
<th>2200 HP</th>
<th>2400 HP</th>
<th>3200 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>INVESTMENT (average new cost)</td>
<td>1,080,000</td>
<td>1,188,000</td>
<td>1,296,000</td>
<td>1,728,000</td>
</tr>
<tr>
<td>FIXED CHARGES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest (7% on full value)</td>
<td>75,600</td>
<td>83,160</td>
<td>90,720</td>
<td>120,960</td>
</tr>
<tr>
<td>Depreciation (5% 20 yr. life)</td>
<td>51,300</td>
<td>56,430</td>
<td>61,560</td>
<td>82,080</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>126,900</td>
<td>139,590</td>
<td>152,280</td>
<td>203,040</td>
</tr>
<tr>
<td>ADMINISTRATION &amp; SUPERVISION</td>
<td>65,349</td>
<td>67,586</td>
<td>69,839</td>
<td>86,895</td>
</tr>
<tr>
<td>OPERATING EXPENSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>222,082</td>
<td>222,082</td>
<td>222,082</td>
<td>265,009</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>33,309</td>
<td>33,309</td>
<td>33,309</td>
<td>39,750</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>134,288</td>
<td>147,356</td>
<td>160,380</td>
<td>212,824</td>
</tr>
<tr>
<td>Maint. &amp; Repairs</td>
<td>37,800</td>
<td>41,580</td>
<td>45,360</td>
<td>60,480</td>
</tr>
<tr>
<td>Supplies</td>
<td>12,096</td>
<td>12,663</td>
<td>13,230</td>
<td>15,498</td>
</tr>
<tr>
<td>Subsistence</td>
<td>15,649</td>
<td>15,649</td>
<td>15,649</td>
<td>18,780</td>
</tr>
<tr>
<td>Insurance</td>
<td>15,120</td>
<td>16,632</td>
<td>18,144</td>
<td>24,192</td>
</tr>
<tr>
<td>Misc.</td>
<td>5,550</td>
<td>5,550</td>
<td>5,550</td>
<td>6,622</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>475,894</td>
<td>494,821</td>
<td>513,704</td>
<td>643,155</td>
</tr>
<tr>
<td>Taxes</td>
<td>3,780</td>
<td>4,158</td>
<td>4,536</td>
<td>6,048</td>
</tr>
<tr>
<td>TOTAL CHARGES &amp; EXPENSES</td>
<td>671,923</td>
<td>706,155</td>
<td>740,359</td>
<td>939,138</td>
</tr>
<tr>
<td>RETURN ON INVESTMENT 10% on Full Value</td>
<td>108,000</td>
<td>118,800</td>
<td>129,600</td>
<td>172,800</td>
</tr>
<tr>
<td>TOTAL CHARGES EXPENSES &amp; RETURN ON INVESTMENT</td>
<td>779,923</td>
<td>824,955</td>
<td>869,959</td>
<td>1,111,938</td>
</tr>
</tbody>
</table>

4-50
<table>
<thead>
<tr>
<th>TOWBOATS</th>
<th>4800 HP</th>
<th>5600 HP</th>
<th>6000 HP</th>
<th>6500 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>INVESTMENT (average new cost)</td>
<td>2,462,000</td>
<td>2,829,600</td>
<td>3,013,200</td>
<td>3,240,000</td>
</tr>
<tr>
<td>FIXED CHARGES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest (7% on full value)</td>
<td>172,340</td>
<td>198,072</td>
<td>210,924</td>
<td>226,800</td>
</tr>
<tr>
<td>Depreciation (5% 20 yr. life)</td>
<td>116,945</td>
<td>134,406</td>
<td>143,127</td>
<td>153,900</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>289,285</td>
<td>332,478</td>
<td>354,041</td>
<td>380,700</td>
</tr>
<tr>
<td>ADMINISTRATION &amp; SUPERVISION</td>
<td>111,495</td>
<td>120,037</td>
<td>127,568</td>
<td>132,829</td>
</tr>
<tr>
<td>OPERATING EXPENSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>305,364</td>
<td>305,364</td>
<td>322,638</td>
<td>322,638</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>45,807</td>
<td>45,807</td>
<td>48,400</td>
<td>48,400</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>316,958</td>
<td>369,338</td>
<td>395,258</td>
<td>427,658</td>
</tr>
<tr>
<td>Maint. &amp; Repairs</td>
<td>86,184</td>
<td>99,036</td>
<td>105,538</td>
<td>113,400</td>
</tr>
<tr>
<td>Supplies</td>
<td>20,034</td>
<td>22,302</td>
<td>23,438</td>
<td>24,872</td>
</tr>
<tr>
<td>Subsistence</td>
<td>21,848</td>
<td>21,848</td>
<td>23,474</td>
<td>23,474</td>
</tr>
<tr>
<td>Insurance</td>
<td>34,474</td>
<td>39,614</td>
<td>42,185</td>
<td>45,360</td>
</tr>
<tr>
<td>Misc.</td>
<td>7,636</td>
<td>7,634</td>
<td>8,067</td>
<td>8,067</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>838,305</td>
<td>910,945</td>
<td>968,996</td>
<td>1,013,867</td>
</tr>
<tr>
<td>Taxes</td>
<td>8,618</td>
<td>9,904</td>
<td>10,546</td>
<td>11,340</td>
</tr>
<tr>
<td>TOTAL CHARGES &amp; EXPENSES</td>
<td>1,247,703</td>
<td>1,373,364</td>
<td>1,461,151</td>
<td>1,538,736</td>
</tr>
<tr>
<td>RETURN ON INVESTMENT 10% on Full Value</td>
<td>246,200</td>
<td>282,960</td>
<td>301,320</td>
<td>324,000</td>
</tr>
<tr>
<td>TOTAL CHARGES EXPENSES &amp; RETURN ON INVESTMENT</td>
<td>1,493,903</td>
<td>1,656,324</td>
<td>1,762,471</td>
<td>1,862,735</td>
</tr>
</tbody>
</table>
## TABLE 4.13: Towboats: Ownership and Operating Costs (Continued)

<table>
<thead>
<tr>
<th>TOWBOATS</th>
<th>7200 HP</th>
<th>8400 HP</th>
<th>9000 HP</th>
<th>10500 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INVESTMENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(average new cost)</td>
<td>3,564,300</td>
<td>4,114,000</td>
<td>4,536,000</td>
<td>5,021,000</td>
</tr>
<tr>
<td><strong>FIXED CHARGES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest (7% on full value)</td>
<td>249,501</td>
<td>287,980</td>
<td>317,520</td>
<td>351,470</td>
</tr>
<tr>
<td>Depreciation (5% 20 yr. life)</td>
<td>169,304</td>
<td>195,415</td>
<td>215,460</td>
<td>238,498</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>418,805</td>
<td>483,395</td>
<td>532,980</td>
<td>589,968</td>
</tr>
<tr>
<td><strong>ADMINISTRATION &amp; SUPERVISION</strong></td>
<td>140,000</td>
<td>147,000</td>
<td>152,600</td>
<td>158,900</td>
</tr>
<tr>
<td><strong>OPERATING EXPENSES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>3,228,826</td>
<td>330,669</td>
<td>330,669</td>
<td>330,669</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>49,328</td>
<td>49,605</td>
<td>49,605</td>
<td>49,605</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>473,000</td>
<td>551,000</td>
<td>589,000</td>
<td>655,000</td>
</tr>
<tr>
<td>Maint. &amp; Repairs</td>
<td>128,500</td>
<td>149,500</td>
<td>159,500</td>
<td>178,500</td>
</tr>
<tr>
<td>Supplies</td>
<td>27,500</td>
<td>31,200</td>
<td>33,050</td>
<td>36,400</td>
</tr>
<tr>
<td>Subsistence</td>
<td>23,924</td>
<td>24,058</td>
<td>24,058</td>
<td>24,050</td>
</tr>
<tr>
<td>Insurance</td>
<td>49,700</td>
<td>57,700</td>
<td>62,500</td>
<td>79,000</td>
</tr>
<tr>
<td>Misc.</td>
<td>8,222</td>
<td>8,268</td>
<td>8,269</td>
<td>8,269</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>1,089,000</td>
<td>1,202,000</td>
<td>1,240,000</td>
<td>1,361,493</td>
</tr>
<tr>
<td>Taxes</td>
<td>12,450</td>
<td>14,350</td>
<td>15,300</td>
<td>17,000</td>
</tr>
<tr>
<td><strong>TOTAL CHARGES &amp; EXPENSES</strong></td>
<td>1,660,255</td>
<td>1,846,745</td>
<td>1,940,880</td>
<td>2,127,361</td>
</tr>
<tr>
<td>RETURN ON INVESTMENT 10% on Full Value</td>
<td>356,430</td>
<td>411,400</td>
<td>453,600</td>
<td>502,100</td>
</tr>
<tr>
<td><strong>TOTAL CHARGES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EXPENSES &amp; RETURN ON INVESTMENT</strong></td>
<td>2,016,685</td>
<td>2,258,145</td>
<td>2,394,480</td>
<td>2,629,461</td>
</tr>
</tbody>
</table>

4-52
### Table 4.14: Open Hopper Barges: Ownership and Operating Costs ($)

<table>
<thead>
<tr>
<th>CAPACITY</th>
<th>1000 NT</th>
<th>1500 NT</th>
<th>3000 NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>INVESTMENT (Average New Cost)</td>
<td>108,653</td>
<td>163,000</td>
<td>325,960</td>
</tr>
</tbody>
</table>

#### Annual Ownership & Operating Costs

- **Depreciation** (20 yr. life, 5% salvage):
  - 1000 NT: $5,161
  - 1500 NT: $7,743
  - 3000 NT: $15,483

- **Interest** (7% declining balance):
  - 1000 NT: $4,020
  - 1500 NT: $6,031
  - 3000 NT: $12,061

- **Maint. & Repairs** (2% investment):
  - 1000 NT: $2,173
  - 1500 NT: $3,260
  - 3000 NT: $6,519

- **Insurance** (2% investment):
  - 1000 NT: $2,173
  - 1500 NT: $3,260
  - 3000 NT: $6,519

- **Administration** (5% investment):
  - 1000 NT: $543
  - 1500 NT: $815
  - 3000 NT: $1,630

- **Taxes** (5% investment):
  - 1000 NT: $543
  - 1500 NT: $815
  - 3000 NT: $1,630

**TOTAL CHARGES EXPENSES & RETURN ON INVESTMENT**

- 1000 NT: $14,613
- 1500 NT: $21,924
- 3000 NT: $43,842

4-53
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway

1) Illinois Waterway

Navigation Season: approximately 325 days taking into account delays tows encountered in January and February. Approximately 7800 hours

Ownership and operating cost for towboats ($/hour):

<table>
<thead>
<tr>
<th>HP</th>
<th>Ownership and operating cost ($/hour)</th>
<th>HP</th>
<th>Ownership and operating cost ($/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>$51.28</td>
<td>1400</td>
<td>$74.64</td>
</tr>
<tr>
<td>1200</td>
<td>$68.82</td>
<td>1600</td>
<td>$84.4</td>
</tr>
<tr>
<td>1400</td>
<td>$74.64</td>
<td>1800</td>
<td>$90.38</td>
</tr>
<tr>
<td>1600</td>
<td>$84.4</td>
<td>2000</td>
<td>$100</td>
</tr>
<tr>
<td>1800</td>
<td>$90.38</td>
<td>2200</td>
<td>$105.76</td>
</tr>
<tr>
<td>2000</td>
<td>$100</td>
<td>2400</td>
<td>$111.53</td>
</tr>
<tr>
<td>2200</td>
<td>$105.76</td>
<td>3200</td>
<td>$142.55</td>
</tr>
<tr>
<td>2400</td>
<td>$111.53</td>
<td>4800</td>
<td>$191.53</td>
</tr>
</tbody>
</table>

Ownership and operating cost for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>NT</th>
<th>Ownership and operating cost ($/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>$1.87</td>
</tr>
<tr>
<td>1500</td>
<td>$2.81</td>
</tr>
<tr>
<td>3000</td>
<td>$5.62</td>
</tr>
</tbody>
</table>
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

2) Ohio River

Navigation Season: 355 days or 8520 hours

Ownership and operating costs for towboats ($/hour):

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$46.94</td>
<td>$63</td>
<td>$68.33</td>
<td>$77.26</td>
<td>$82.74</td>
<td>$91.54</td>
<td>$96.83</td>
<td>$102.1</td>
<td>$130.51</td>
<td>$175.34</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>Large</th>
<th>1000 NT</th>
<th>1500 NT</th>
<th>3000 NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$1.71</td>
<td>$2.57</td>
<td>$5.15</td>
</tr>
</tbody>
</table>
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

3) Missouri River

Navigation season - approximately 240 days or 5760 hours

Ownership and operating cost for towboats ($/hour):

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$69.44</td>
<td>$93.2</td>
<td>$101.07</td>
<td>$114.28</td>
<td>$122.39</td>
<td>$135.4</td>
<td>$143.22</td>
<td>$151.03</td>
<td>$193.04</td>
<td>$259.36</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>NT</th>
<th>1000 NT</th>
<th>1500 NT</th>
<th>3000 NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$2.54</td>
<td>$3.81</td>
<td>$7.61</td>
</tr>
</tbody>
</table>
### TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

4) The McClellan-Kerr Arkansas River System

**Navigation Season - 355 days or 8520 hours**

Ownership and operating costs for towboats ($/hour):

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Ownership and operating costs for towboats ($/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 hp.</td>
<td>$46.94</td>
</tr>
<tr>
<td>1200 hp.</td>
<td>$63.00</td>
</tr>
<tr>
<td>1400 hp.</td>
<td>$68.33</td>
</tr>
<tr>
<td>1600 hp.</td>
<td>$77.26</td>
</tr>
<tr>
<td>1800 hp.</td>
<td>$82.74</td>
</tr>
<tr>
<td>2000 hp.</td>
<td>$91.54</td>
</tr>
<tr>
<td>2200 hp.</td>
<td>$96.83</td>
</tr>
<tr>
<td>2400 hp.</td>
<td>$102.1</td>
</tr>
<tr>
<td>3200 hp.</td>
<td>$130.51</td>
</tr>
<tr>
<td>4800 hp.</td>
<td>$175.34</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>NT</th>
<th>Ownership and operating costs for open hopper barges ($/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>$1.71</td>
</tr>
<tr>
<td>1500</td>
<td>$2.57</td>
</tr>
<tr>
<td>3000</td>
<td>$5.15</td>
</tr>
<tr>
<td>Size (hp.)</td>
<td>Ownership and Operating Costs for Towboats ($/hour)</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>800</td>
<td>$69.44</td>
</tr>
<tr>
<td>1200</td>
<td>$93.20</td>
</tr>
<tr>
<td>1400</td>
<td>$101.07</td>
</tr>
<tr>
<td>1600</td>
<td>$114.28</td>
</tr>
<tr>
<td>1800</td>
<td>$122.39</td>
</tr>
<tr>
<td>2000</td>
<td>$135.40</td>
</tr>
<tr>
<td>2200</td>
<td>$143.22</td>
</tr>
<tr>
<td>2400</td>
<td>$151.03</td>
</tr>
<tr>
<td>3200</td>
<td>$193.04</td>
</tr>
<tr>
<td>4800</td>
<td>$259.36</td>
</tr>
<tr>
<td>5600</td>
<td>$287.56</td>
</tr>
<tr>
<td>6000</td>
<td>$305.98</td>
</tr>
<tr>
<td>6500</td>
<td>$323.39</td>
</tr>
<tr>
<td>1000 NT</td>
<td>$2.54</td>
</tr>
<tr>
<td>1500 NT</td>
<td>$3.81</td>
</tr>
<tr>
<td>3000 NT</td>
<td>$7.61</td>
</tr>
</tbody>
</table>
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

6) Lower Mississippi River

Navigation Season: 355 days or 8520 hours

Ownership and operating costs for towboats ($/hour):

<table>
<thead>
<tr>
<th>Size</th>
<th>Ownership and operating costs for towboats ($/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 hp</td>
<td>$46.94</td>
</tr>
<tr>
<td>1200 hp</td>
<td>$63.00</td>
</tr>
<tr>
<td>1400 hp</td>
<td>$68.33</td>
</tr>
<tr>
<td>1600 hp</td>
<td>$77.26</td>
</tr>
<tr>
<td>1800 hp</td>
<td>$82.74</td>
</tr>
<tr>
<td>2000 hp</td>
<td>$91.54</td>
</tr>
<tr>
<td>2200 hp</td>
<td>$96.83</td>
</tr>
<tr>
<td>2400 hp</td>
<td>$102.10</td>
</tr>
<tr>
<td>3200 hp</td>
<td>$130.51</td>
</tr>
<tr>
<td>4800 hp</td>
<td>$175.34</td>
</tr>
<tr>
<td>5600 hp</td>
<td>$194.40</td>
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<tr>
<td>6000 hp</td>
<td>$206.86</td>
</tr>
<tr>
<td>6500 hp</td>
<td>$218.63</td>
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<tr>
<td>7200 hp</td>
<td>$236.70</td>
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<tr>
<td>8400 hp</td>
<td>$265.04</td>
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<tr>
<td>9000 hp</td>
<td>$281.04</td>
</tr>
<tr>
<td>10,500 hp</td>
<td>$308.62</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>Size</th>
<th>Ownership and operating costs for open hopper barges ($/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 NT</td>
<td>$1.71</td>
</tr>
<tr>
<td>1500 NT</td>
<td>$2.57</td>
</tr>
<tr>
<td>3000 NT</td>
<td>$5.15</td>
</tr>
</tbody>
</table>

4-59
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

7) Tennessee River

Navigation Season: 355 days or 8520 hours

Ownership and operating costs for towboats ($/hour):

<table>
<thead>
<tr>
<th>HP</th>
<th>800 hp.</th>
<th>1200 hp.</th>
<th>1400 hp.</th>
<th>1600 hp.</th>
<th>1800 hp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$46.94</td>
<td>$63.00</td>
<td>$68.33</td>
<td>$77.26</td>
<td>$82.74</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HP</th>
<th>2000 hp.</th>
<th>2200 hp.</th>
<th>2400 hp.</th>
<th>3200 hp.</th>
<th>4800 hp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$91.54</td>
<td>$96.83</td>
<td>$102.10</td>
<td>$130.51</td>
<td>$175.34</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>NT</th>
<th>1000 NT</th>
<th>1500 NT</th>
<th>3000 NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$1.71</td>
<td>$2.57</td>
<td>$5.15</td>
</tr>
</tbody>
</table>
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

8) Tennessee-Tombigbee-Warrior Rivers

Navigation Season: 355 days or 8520 hours

Ownership and operating cost for towboats ($/hour):

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>800 hp.</th>
<th>1200 hp.</th>
<th>1400 hp.</th>
<th>1600 hp.</th>
<th>1800 hp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$46.94</td>
<td>$63.00</td>
<td>$68.33</td>
<td>$77.26</td>
<td>$82.74</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>2000 hp.</th>
<th>2200 hp.</th>
<th>2400 hp.</th>
<th>3200 hp.</th>
<th>4800 hp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$91.54</td>
<td>$96.83</td>
<td>$102.10</td>
<td>$130.51</td>
<td>$175.34</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>1000 NT</th>
<th>1500 NT</th>
<th>3000 NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$1.71</td>
<td>$2.57</td>
<td>$5.15</td>
</tr>
</tbody>
</table>
TABLE 4.15: Hourly Ownership and Operating Costs, Towboats and Barges by Size and Waterway (Continued)

9) Gulf Intracoastal Waterway - East and West

Navigation season: 355 days or 8520 hours

Ownership and operating costs for towboats ($/hour):

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>800 hp.</th>
<th>1200 hp.</th>
<th>1400 hp.</th>
<th>1600 hp.</th>
<th>1800 hp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$46.94</td>
<td>$63.00</td>
<td>$68.33</td>
<td>$77.26</td>
<td>$82.74</td>
</tr>
<tr>
<td></td>
<td>$91.54</td>
<td>$96.83</td>
<td>$102.10</td>
<td>$130.51</td>
<td>$175.34</td>
</tr>
</tbody>
</table>

Ownership and operating costs for open hopper barges ($/hour):

<table>
<thead>
<tr>
<th>Net Tons</th>
<th>1000 NT</th>
<th>1500 NT</th>
<th>3000 NT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$1.71</td>
<td>$2.57</td>
<td>$5.15</td>
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</tbody>
</table>
### TABLE 4.16: Average Tow Speeds by Water (mph)

<table>
<thead>
<tr>
<th>Waterway</th>
<th>Loaded</th>
<th>Empty</th>
<th>Upstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas</td>
<td>4.0</td>
<td>5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warrior &amp; Tombigbee</td>
<td>5.2</td>
<td>6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gulf Intracoastal Waterway, West</td>
<td>5.2</td>
<td>6.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois</td>
<td>4.1</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Mississippi</td>
<td>-</td>
<td>-</td>
<td>5.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Upper Mississippi</td>
<td>5.0</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missouri</td>
<td>-</td>
<td>-</td>
<td>3.5</td>
<td>10.0</td>
</tr>
<tr>
<td>Ohio</td>
<td>4.8</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennessee</td>
<td>5.8</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 4.6: Replacement Costs - Towboats

Source: [8, as extrapolated]
FIGURE 4.7: Administration and Supervision ($ 000)

1976 ANNUAL COST

Source: [8, extrapolated and inflated]
FIGURE 4.8: Fuel Oil Cost Based on 1971 Data

Source: [8, extrapolated]
FIGURE 4.9: Maintenance & Repairs ($000)

1976 ANNUAL COST

Source: [8, extrapolated and inflated]
FIGURE 4.10: Supplies ($ 000)

1976 ANNUAL COST

Source: [8, extrapolated and inflated]
FIGURE 4.11: Insurance ($ 000)

Source: [8, extrapolated and inflated]
FIGURE 4.12: Taxes
($ 000)

1976 ANNUAL COST

Source: [8, extrapolated and inflated]
FIGURE 4.13: Operating Expenses ($ million)

Source: [8, extrapolated and inflated]
4.6.1 Facilities Description

Major requirements include [31] a car dumper, a system for conveying coal to either storage piles or directly to the barges for loading, equipment for storing coal and subsequently reclaiming it for barge loadout, and a barge loading system. The dumping system may be a rotary dump or designed for cars with bottom discharge. Conveyors are used to move the coal, but a tunnel system may be provided for alternative loading capability under certain conditions. A typical stacking/reclaiming unit is a rotary bucket wheel mounted on a gantry that travels on rails along the piles. The barge loading system is simply a conveyor on a structural boom with head level adjustable to the level of the river. Terminal equipment also includes sprays and dust hoods on the conveyors to minimize dust generation, a thawing facility for incoming rail cars, and maintenance and administration buildings.

A terminal designed for an annual throughput of 10MMTY would require coal storage capacity for about 500,000 tons. It would handle approximately three 100 car unit trains per day over a 350 day working year. Normal processing time is 40 cars per hour (30 if the coal requires thawing). Barge loading can be accomplished at the rate of 6000 tons/hour. However, if the barges are loaded directly from the unit train, the loading rate is 4000 tons/hr. On a daily basis, the throughput of 30,000 tons amounts to loading 1.3 tows, of 15 barges each, per day.

The hours required to break up an incoming tow for loading ($T_b$) and to make up a tow after loading ($T_m$) may be, respectively, expressed as [32]:

$$T_b = 0.34 + 0.2 \times \text{(number of barges)}$$
$$T_m = 0.21 + 0.44 \times \text{(number of barges)}$$

4.6.2 Facility Costs

The approximate capital cost for a 10 million ton/year facility, including equipment, material, contract services and labor is $16.05 million (1976) [31]. Operation requires approximately 40
people including supervisors, equipment operators, mechanics, clerks, electricians and general labor. While no estimates were available, operating costs are a function of throughput. However, the relationship is not linear. There are economies of scale. The limits to these economies depend on the time required to dump a train, maximum conveyor belt carrying capacity, barge arrival time irregularities and dock space for barges (five barges in the description above). The facility described above may be optimal for a large facility with a single loading boom.

Based on the above, admittedly sketchy data, it is possible to make a gross estimate of per ton terminal costs. Adding contingencies and working capital to the $16.05 million, a total capital cost of $19.41 million is estimated. Given a 25 year life, annual fixed charges including depreciation, taxes and insurance, may be estimated at $2.193 million. Operation and maintenance costs are estimated at $1.866 million. This includes: $600,000 for labor, $281,000 for fuel, $607,000 for maintenance and supplies, and $378,000 for overhead. The above is consistent with the costing parameters used for rail and slurry pipelines. Total annual costs are therefore $4,059,000 or 40.6 cents/ton at the receiving end. Assuming that the delivery end, assumed to be an electric utility, requires only one-fifth the throughput capacity, total terminal costs are estimated at 48.7 cents/ton.
Unlike rail or pipeline transport, barge traffic does not pay right of way costs or for the operation and maintenance of the waterways. While no position is taken in this study, a rough estimate of these costs is presented so that cost comparisons with competing modes may be placed on a similar basis.

Waterway costs include navigational aids, channel maintenance and improvements, and operation and maintenance costs associated with locks and dams. River dams may provide both flood control and navigation. Flood control alone, however, may be accomplished with levees and/or by a different number of dams of different size, shape and location. Few, if any, non-commercial craft using the inland waterways require either a channel depth of 9 feet or an elaborate system of navigational aids.

In this section of the cost analysis, we have not included the remaining depreciable value of locks and dams or other capital improvements on facilities already in existence. The river system has been taken as is. Therefore, only operation and maintenance costs have been included. This is consistent with the view that sunk costs are dead costs. However, it is consistent with this view that future locks and dams, those currently under construction, replacements, extensions, and improvements should be considered on the basis of their remaining depreciable value.

If this view is accepted, then the use value of a waterway could be assigned on a mile by mile basis from an exhaustive review of Corps of Engineers data. Different stretches of a river would require different "tolls." More important, each lock and dam would have a different toll base to be used in ascertaining each lockage "toll." In general, this would be akin to a toll road, with irregularly spaced toll booths, each collecting a different per mile toll based on the cost of the road travelled since the previous toll booth. This would be cost efficient with respect to the rivers. It would also enter into the calculations of shippers pondering which mode or mixed mode of transport to use and the precise least cost routing.

To determine the portion of operation and maintenance costs attributable to coal traffic on each river, the total cost for each river was first determined. As only 1973 estimates were available for each river [7], these were inflated at the rate of 7 percent per year for 3 years to provide a 1976 estimate. The amount of coal traffic and
the amount of total commodities traffic on each river was then determined [2]. Although only 1974 estimates were readily available, it was assumed that the percentage of coal to total commodities traffic remained stable. The percentage of coal to total commodities traffic is the percentage of operation and maintenance cost attributed to coal traffic for the specific river. Dividing this cost by the amount of coal traffic on the river determined the average river cost per net ton of coal for that river.

Table 4.17 shows the reported 1973 operation and maintenance costs, the 1976 estimate, the coal traffic in 1974, total commodities traffic, the percentage of coal to commodities and the portion of the 1976 cost estimate which can be attributed to coal traffic. For the Missouri River, where no coal transport is shown, using the category for all commodities yields a cost of $1.90/net ton or 0.257 cents/ton/mile.

The U.S. Coast Guard is responsible for navigation aid and safety on the inland waterway system. It spent a total of $10,422,000 in 1974 on the system covered in this study [12, p.23]. At an inflation rate of 7 percent per year, 1976 expenditures by the Coast Guard are estimated at $11,881,080. As a breakdown of expenditures, river by river, is unavailable we estimate the proportion attributable to coal based on the percentage of coal traffic to the total commodities traffic within the system.

Total amount of coal traffic within region = 120,549,000 net tons

Total amount of commodities traffic within region = 528,930,000 net tons

Percent of coal to commodities = 22.8 percent

Navigation cost attributed to coal based on 1976 estimate = $2,709,000

Navigation cost per ton of coal based on 1974 traffic figure = 2.2 cents/ton

Total ton-miles of coal traffic in the waterway system = 102,605,000,000 ton-miles

Navigation cost per ton-mile of coal based on 1974 traffic estimates = $0.0026 cents/ton-mile

A comparison between our user costs and those derived by the U.S. Department of Transportation [38, Table III-2] and the Association of American Railroads [39, Table V] can
be found in Table 4.18. Some caution must be used. The AAR estimates of operation and maintenance costs are based on average annual expenditures for FY 1970-1974 while their ton-miles are for CY 1972. The DOT estimate of recovery tolls is for 1968. Our data are based on 1973 costs and coal movements.
<table>
<thead>
<tr>
<th>Waterway</th>
<th>1973 Cost ($)</th>
<th>Estimated 1976 Cost ($)</th>
<th>Amount of Coal Transported (net tons) 1974</th>
<th>Amount of Commodities Transported (net tons) 1974</th>
<th>Percent of Coal to Commodities (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1). Illinois (353.6 miles)</td>
<td>6,976,030</td>
<td>8,373,636</td>
<td>6,997,890</td>
<td>45,301,607</td>
<td>15.4</td>
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<tr>
<td>2). Ohio (981 miles)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locks &amp; Dams</td>
<td>12,188,625</td>
<td>14,626,350</td>
<td>67,293,171</td>
<td>139,258,864</td>
<td>48.4</td>
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<tr>
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<td>2,024,315</td>
<td>14,429,178</td>
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</tr>
<tr>
<td>3). Missouri (732 miles)</td>
<td>12,024,315</td>
<td>14,429,178</td>
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<td>7,673,084</td>
<td>0</td>
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<td>4). Arkansas (448 miles)</td>
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<td></td>
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<tr>
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<td>3,106,791</td>
<td>3,728,149</td>
<td>198,080,000</td>
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<td>18,327,095</td>
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<tr>
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<td>14,476,098</td>
<td>17,371,317</td>
<td>7,598,695</td>
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<tr>
<td>(between Missouri &amp; Minneapolis)</td>
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<td>6). Lower (1174 miles)</td>
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<tr>
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<td>15,402,460</td>
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<tr>
<td>7). Tennessee</td>
<td>2,503,293</td>
<td>3,003,952</td>
<td>9,162,073</td>
<td>27,123,623</td>
<td>33.8</td>
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<tr>
<td>8). Tombigbee-Warrior (408 miles)</td>
<td>2,918,989</td>
<td>3,502,789</td>
<td>6,243,303</td>
<td>15,548,253</td>
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<td>Waterway</td>
<td>1973 Cost ($)</td>
<td>Estimated 1976 Cost ($)</td>
<td>Amount of Coal Transported (net tons) 1974</td>
<td>Amount of Commodities Transported (net tons) 1974</td>
<td>Percent of Coal to Commodities (%)</td>
</tr>
<tr>
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<td>---------------</td>
<td>------------------------</td>
<td>------------------------------------------</td>
<td>---------------------------------------------------</td>
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<tr>
<td>9). Gulf (443 miles) Intracoastal Waterway (St. Marks, Fla. to New Orleans)</td>
<td>811,391</td>
<td>973,669</td>
<td>7,236,276</td>
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<td>10). Gulf (266 miles) Intracoastal Waterway (New Orleans to Sabine River)</td>
<td>4,269,457</td>
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<td>208,572</td>
<td>60,742,405</td>
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<td>4,915,316</td>
<td>208,572</td>
<td>66,055,628</td>
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<tr>
<td>1). Illinois</td>
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<td>(981 miles)</td>
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<td></td>
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<tr>
<td>Locks &amp; Dams</td>
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<tr>
<td>3). Missouri</td>
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<td>(732 miles)</td>
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<td>4). Arkansas</td>
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<td></td>
<td>1,015,336</td>
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<td>5,973,700</td>
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<tr>
<td>(408 miles)</td>
<td>1,408,121</td>
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<td>9</td>
<td>Gulf (443 miles) Intracoastal Waterway (St. Marks, Fla. to New Orleans)</td>
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<td>0.03</td>
<td>3,205,700</td>
<td>0.006</td>
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<td>Gulf (266 miles) Intracoastal Waterway (New Orleans to Sabine River)</td>
<td>17,419</td>
<td>0.08</td>
<td>55,500</td>
<td>0.03</td>
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<td>11</td>
<td>Gulf (400 miles) Intracoastal Waterway (Sabine River to Mexican border)</td>
<td>14,746</td>
<td>0.07</td>
<td>83,430</td>
<td>0.018</td>
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<tr>
<td>Waterway (Data Set)</td>
<td>AAR (1970-1974)</td>
<td>U.S. DOT (1968)</td>
<td>This Study (1973)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------</td>
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<td>--------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arkansas River</td>
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<td>.96</td>
<td></td>
<td></td>
</tr>
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<td>Gulf Intracoastal</td>
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<td>.15</td>
<td>.027</td>
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</tr>
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<td>.052</td>
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<td>.01</td>
<td>.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mississippi - Upper</td>
<td>.045</td>
<td>.079</td>
<td>.042</td>
<td></td>
<td></td>
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<tr>
<td>Missouri River</td>
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<td>.90</td>
<td>-</td>
<td></td>
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</tr>
<tr>
<td>Mobile-Tombigbee-Warrior</td>
<td>.055</td>
<td>.05</td>
<td>.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohio River</td>
<td>.041</td>
<td>.04</td>
<td>.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennessee River</td>
<td>.058</td>
<td>.07</td>
<td>.017</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: [38,39]

*1973 data inflated at 7 percent to 1976.


15. River Transportation Division, Iowa DOT Staff Waterway User Charge Proposal, Iowa Department of Transportation, 1976.


4-83


31. Department of the Army, Corps of Engineers, St. Louis District, Rail-to-barge Coal Transfer Facility, St. Louis, Missouri, Final Environmental Statement, July 1976.


CAC Document No. 223

COMPARATIVE COAL TRANSPORTATION COSTS:
AN ECONOMIC AND ENGINEERING ANALYSIS

CONVEYOR BELTS
Volume 5

by
Michael Rieber and Shao Lee Soo

Center for Advanced Computation
University of Illinois at Urbana-Champaign

August 1977
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**Title and Subtitle:** Comparative Coal Transportation Costs: An Economic and Engineering Analysis of Truck, Belt, Rail, Barge and Coal Slurry and Pneumatic Pipelines; Volume 5 - Conveyor Belts

**Author(s):** Michael Rieber and Shao Lee Soo

**Performing Organization Name and Address:**
Center for Advanced Computation
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

**Sponsoring Organization Name and Address:**
Office of the Assistant Director, Mining
Bureau of Mines
Department of the Interior
Washington, D.C. 20241

**Abstracts:**
Costing of coal transport by conveyor belt, for a range of tonnages and distances, is based on an heuristic model of an optimal system for each case. Cost factors are industry based. The model and format are open to provide user manipulation. A specific case is presented as an example.

**Key Words and Document Analysis:**
- Coal transport
- Conveyor belts
- Conveyor belt costs
- Conveyor belt facilities

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FOREWARD

This report was prepared by the Center for Advanced Computation of the University of Illinois at Urbana-Champaign under USBM Contract No. J0166163. The contract was initiated under the Office of University Relations. It was administered under the technical direction of the Division of Interindustry Analysis with Mr. Ronald Balazik acting as the Technical Project Officer. Mr. Robert Carpenter was the contract specialist for the Bureau of Mines.

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This is to certify that, to the best of my knowledge and belief, there were no Subject Inventions made or have resulted from the performance of this contract.

August 1977

Michael Rieber
Principal Investigator
final report

comparative coal transportation costs: an economic and engineering analysis of truck, belt, rail, barge and coal slurry and pneumatic pipelines

volume 5
conveyor belts

by

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with
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5. CONVEYOR BELTS

5.1 INTRODUCTION

In this study a generalized specification and costing model for high tonnage coal carrying conveyor belts of 3.5 to 100 miles is presented. These belt systems, in modular units or flights, of up to 9 miles in length can be considered in terms of gathering systems. The study format is sufficiently open to allow users to insert their own requirements and parameters. A specific case study is provided.

Because conveyor belts are feasible almost anywhere, this study has not investigated any specific route or geographic location. Rather, it has concentrated on setting up an heuristic programming model for conveyor belt facility optimization and cost minimization. The analysis starts with the principle factors involved in the design of the system and their optimization for various cases. This is followed, in Section 5.4, with a factor by factor cost analysis based on industry data and the preceding optimization. The next step is the development of both facility and costing models suitable for computer analysis. Logic flow diagrams are presented at each major analytic step.

Table 1.21 in Volume 1, presents a listing of the input values for each of the cases. Belt capacities were chosen to reflect both small and large mines. Mileages portray short, medium, and "long" distances but exclude in-house operations. An assumption was made concerning coal lump size. This was set at a maximum of 8 inches for a maximum of 10 percent of the coal transported. This standardization also set the belt width (to avoid spillage) at 30 inches. Finally, it has been assumed that the belt movement is over level terrain. If it is assumed that the terrain is hilly, both construction and operating costs increase. Right-or-way costs may decrease if the land value is decreased due to terrain. Operating costs rise due to increased belt tension. The program can be used, as needed, to provide the operating costs for any feasible terrain.
Because the belt optimization and cost minimization modelling was prepared for a computer, it was desirable to adopt some conventions. In general, it was assumed that, for costing purposes, the belt was in modular units of 3000 feet. Thus, for "long" distances over level terrain, the costing was merely repetitive. Where uneven terrain was assumed, the procedure (see text and program at 04900 to 06600) was to average the increases and decreases in belt height with changing terrain, estimate the needed horsepower, etc, and again calculate on a modular basis over the distance required. Finally, because the belt system is optimized, continuous load is inherent.

A conveyor system is versatile and easy to operate. It is generally reliable and, once installed, has low maintenance and operating costs. As tonnages increase, fixed and operating costs become even more favorable.

Over the last decade, conveyor systems have usually been considered best for the movement of bulk materials under conditions of adverse terrain and continuous throughput. Earlier, due to problems connected with the materials used for the belt carcass and the need for special techniques, conveyor belts were not usually considered suitable for movements of large tonnages over distances of several miles. In recent years, however, significant advances have taken place in the conveyor belt industry: a monofilament rayon material for the carcass belt was developed which had desirable elongation and elastic properties. However, wet strength and other limitations restricted its use and the conveyor belt industry turned to nylon. This had been considered suitable only for the cross and filler threads of the belt carcass. Technical advancement in heat setting and fabric weave created a major change by allowing full tension strength. Nylon resists moisture, acid and mildew. It also has excellent resistance to impact and can be produced with controlled elongation and elastic properties that work to advantage in reduced- ply belt construction. Another technical breakthrough produced a significant increase in chemical bond adhesion. Steel cable belts may be used but, with a friable material such as coal, undue grinding and production of fines may result during travel. The conveyor belt has been considered one of the most important pieces of equipment used in the transportation of coal underground. The improved interface between an underground hauling system and a surface hauling system has been an important cost reducing factor in coal mining.
5.2 SPECIFICATION

The important factors in the design of a belt conveyor are:

5.2.1 Material Characteristics

Bulk density: Because the conveyor is a volumetric transporting medium, the density of material being handled governs the tonnage rating and belt material.

Maximum lump size: Material lump size may dictate the selection of a belt width greater than other factors suggest in order to convey the required tonnage.

Lump size consist: This affects belt width, belt speed, and the gradient over which the material can be loaded and conveyed.

Condition of the material: This affects the operating speed. Friable materials should be handled at reduced speeds if size degradation and dusting are to be avoided.

5.2.2 Operating Conditions

Rate of transport: The successful operation and economic design of a belt conveyor depends upon such factors as average rate, peak rate, and frequency of peak rates.

Climatic conditions: Due to the increase in the grease viscosity in bearings and seals at low ambient temperature, resistance to idler rotation increases. Therefore the horsepower requirement for operation increases.
5.3 CONVEYOR BELT DESIGN – DISCUSSION

5.3.1 Determine the Angle of Surcharge

The angle of surcharge determines the cross-section of the material load which can be safely carried on a belt. It is also an index of the safe angle of incline or decline of the belt conveyor.

5.3.2 Determine the General Belt Width

The belt width increases with increases in the lump size consist, the maximum lump size and the angle of surcharge. Conveyor belt manufacturers in the United States produce the following sizes, expressed in inches: 12-14-16-18-20-24-30-36-42-48-54---72.

5.3.3 Belt Speed Considerations

Maximum belt speed limitation: After the required width of the conveyor belt has been generally considered, belt speed depends directly upon material characteristics such as the condition of the material, maximum lump size, and lump consist. For example, fine dry material will tend to dust on high speed conveyors. There is a maximum speed for given material characteristics.

Economic belt speed: Given the required capacity of the conveyor system and the characteristics of the material, a suitable combination of belt width and speed may be selected. The best combination of belt width and speed is the maximum and minimum width at which the material can be handled without creating operating or maintenance problems.

For a given material, the volumetric capacity of a belt conveyor depends on the belt speed and the cross-sectional area of the material load carried by the conveyor belt. The cross-sectional area of the material on a horizontal conveyor belt is measured in a plane normal to the belt. On an inclined conveyor belt, gravity considerations
require that the actual cross-section of the load be considered in a vertical plane.

5.3.4 Determine Idler Space

The best spacing for carrying idlers depends upon: (1) The weight of the belt plus the weight of the material load that it carries, and (2) on the catenary sag of the belt between the idlers. If too much catenary sag of a loaded belt is permitted between the roughing idlers, the material may spill over the edges of the belt. Therefore, there is an economic trade-off between a small catenary sag to prevent the spilling and the lower cost required if a given spillage risk is assumed. An industry based standard table for idler spacing is presented in Table 5.4.

5.3.5 Determination of Idler Class

The type of service, type of material handled, and belt speed are the three important factors governing the selection of the idler class. The type of service includes the hours of operation per day. The overall life expectancy of the belt material governs the idler load and spacing. The transport material lump size modifies the direct effect of weight by introducing an impact factor. The proper selection of return belt idlers is as important as selection of the carrying idlers. The return belt idler contacts the "dirty" side of the belt, resulting in abrasive wear of the idler roll surface. Material build up on the roll increases its effective diameter. Because the build-up is never uniform, and usually is less at the belt edges, the clean sections of the return roll travel at a surface speed less than that of the belt. This results in relative slippage, thereby accelerating wear of both the belt cover and the surface of the roll. Thus, the life of the roll shell is usually less on return belt idlers than on carrying idlers. Finally, the belt speed determines the rate of rotation of the idler roll and the rate of surface contact between the belt and roll. Belt speed also has a direct relation to the wear life of the idler roll.
5.3.6 Horsepower Calculation and Belt Tension

The power needed to drive a belt conveyor requires consideration of (1) the power needed to lift or lower the load (0.1% - 1%), (2) the power needed to overcome the frictional resistance to the movement of the conveyor parts, the drive parts, and any other accessories (95%) and (3) the power needed to accelerate the material load to belt speed (0.1% - 1%). Because items (1) and (3) are negligible, the power needed to overcome the frictional resistance is the only factor considered here. It is composed of four parts: (1) resistance of the idler rolls to rotation, (2) resistance of the belt to flexure as it moves over the idlers, (3) resistance of the load to flexure as the belt and load move over the idler and (4) resistance of the terminal and bend pulleys to rotation.

5.3.7. Conveyor Belt Material

Generally the belt represents a substantial part of the initial cost of the conveyor system. Consideration of the belt carcass and covers are the most important factors in the selection process. The primary purpose of the belt carcass is to carry the tension necessary to move the loaded belt and to absorb the impact energy released by the material as it is loaded onto the belt. Table 5.1 shows the maximum allowable working tension for various belt carcass constructions. For example, five plies of RMA43 fabric can carry a tension of about 200 lbs. per inch of width. The primary purpose of the cover is to protect the belt carcass against damage from the material being conveyed. Therefore, the top cover normally will have a greater thickness than the bottom cover because of the concentration of wear on the top or carrying side. The materials typically used for covers are natural or synthetic rubber, or a blend of the two. Evaluation of the quality of the cover should be based on the physical attributes of each cover grade, rather than the specific material.
TABLE 5.1: Tension Rating of Conveyor Belts: 
Ratings 70 or Under, lbs per inch per ply

<table>
<thead>
<tr>
<th>Fabric identification</th>
<th>Normal mechanical fastener splice</th>
<th>Normal vulcanized splice</th>
</tr>
</thead>
<tbody>
<tr>
<td>*RMA 35</td>
<td>27</td>
<td>35</td>
</tr>
<tr>
<td>*RMA 43</td>
<td>33</td>
<td>43</td>
</tr>
<tr>
<td>*RMA 50</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>*RMA 60</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>*RMA 70</td>
<td>55</td>
<td>70</td>
</tr>
</tbody>
</table>

Source: [2]
5.4 COST ANALYSIS

Total costs include installation, operating maintenance and ownership.

5.4.1 **Installation Cost**

Installation cost includes the complete inventory of conveyor equipment, including the supporting structural steel, foundations, and erection and assembly into a unit. The following costs cover a wide range of conveyor belt applications and components [7]. Costs are expressed in 1973 dollars.

**Elevated conveyor structures**
- Open truss: $25/ft
- Enclosed gallery: $100/ft

Conveyor belt cost: Figure 5.3 $/ft
Conveyor idlers cost: Figure 5.3 $/ft
Mechanical drive, pulleys, bearings: Figure 5.2 $/each (or $10,000/max. h.p.)
Motor and starter: Figure 5.2 $/h.p. (or $27/h.p.)
Conveyor deck: Figure 5.3 $/ft
Structure cost for conveyor terminals: Figure 5.1 $/belt in.

Feeder cost: 10 percent of equipment cost
Land & improvement cost: 5 percent of equipment cost
Building cost: 6 percent of total equipment cost
Working capital: 10 percent of total equipment cost
Installation
(engineering, supervision & contingencies)

Finally, the costs were adjusted by using the ratio of the Monthly Labor Review wholesale price index, 1976/1973.

5.4.2 Operating and Maintenance Cost

It is generally expected that the original conveyor belt will be replaced at least once during the life of the installation. As the carrying surface of the conveyor increases in length, the expected life also increases as the belt cover is less frequently exposed to wear at the loading point. Conveyor maintenance, the nature of the material handled, and the construction of the belt, are all critical longevity factors. Generally, the life span of a relatively short conveyor belt operating in a plant is short.

<table>
<thead>
<tr>
<th>Cost</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair and maintenance cost</td>
<td>2 percent of equipment cost per year plus 5 percent of belt per year [7]</td>
</tr>
<tr>
<td>Power cost</td>
<td>2.0 - 2.5 cents/kw-hr [9]</td>
</tr>
<tr>
<td>Labor cost (operator)</td>
<td>$8/hr [9]</td>
</tr>
<tr>
<td>Belt replacement cost</td>
<td>(calculated below)</td>
</tr>
<tr>
<td>Supervision cost</td>
<td>20 percent of total labor cost</td>
</tr>
<tr>
<td>Administration and engineering cost</td>
<td>30 percent of total labor cost</td>
</tr>
<tr>
<td>Overhead cost</td>
<td>30 percent of supervisory, administrative and labor cost</td>
</tr>
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5.4.3. Ownership Cost

This includes depreciation of fixed assets and interest on the initial investment.
FIGURE 5.1: Structure Cost for Conveyor Terminals

Source: [2]
FIGURE 5.2: Cost Estimate for Belt & Belt Conveyor Equipment

Source: [2]
FIGURE 5.3: Cost Estimate for Belt & Belt Conveyor Equipment

Source: [2]
5.5 MODEL DESIGN

The following diagram indicates the flow of model design.
5.5.1 Model for Conveyor Belt Design

Determine the Surcharge Angle

Material Characteristics \rightarrow Table 5.2 \rightarrow Surcharge Angle

Determine the belt width for coal transport

Width of Belt Conveyor [2]

for Surcharge Angle of 20 degrees = WOB = (3+2.22(POL-0.1)*SOL)
for Surcharge Angle of 25 degrees = WOB = (4+2.89(POL-0.1)*SOL)
for Surcharge Angle of 30 degrees = WOB = (6+4.4(POL-0.1)*SOL)

WOB = width of conveyor belt
POL = percentage of maximum lump size
SOL = maximum size of lump

Practical modification:

WOBS: The width of belt made by U.S. manufacturing companies. (12,14,16,18,20,22,24,30,36---72) The following diagram indicates the flow of model design:
Determine belt speed based on:

1. Material characteristics
2. Maximum capacity
3. Angle of troughing idler and belt width

Maximum speed limitation for coal

Belt width

Table 5.3

Material characteristics

Economic belt speed

A) Determine belt cross-sectional load area [2]

\[
A = (0.37 \times b + 0.25 + \cos \beta (0.26 \times b - 1.03)) \\
\times \sin \beta (0.26 \times b - 1.03) \\
+ (0.19 \times b + 0.13 + \cos \beta (0.26 \times b - 1.03))^2 \\
\left(\frac{\pi \times \alpha}{180} - \frac{\sin 2 \alpha}{2}\right)
\]

B) Modification "A" due to incline

\[
MA = A \times \cos \theta
\]

C) Belt speed Calculation

\[
V = \frac{C_p}{MA}
\]

For a flat belt use the following equation [2].
\[ A = \left( \frac{\alpha}{180} - \frac{\sin 2\alpha}{2} \right) \left( \frac{b-1.6-0.11b}{2\sin \alpha} \right)^2 \]

- \( A \): WOBS
- \( \alpha \): Surcharge Angle
- \( \beta \): Trough Idler Angle
- \( \theta \): Inclining Angle
- \( C_p \): Maximum Capacity Required
- \( \beta_b \): Maximum \( \beta \)

The following flow diagram indicates the flow for economic belt speed:

1. **Input**
2. Determine VOM
3. Calculate \( A, M_A, V \)
4. Check if \( \beta - \beta_m < \)
5. If yes, go to step 6; if no, return to step 4
6. Check if \( V^* = V \)
7. If yes, stop; if no, increase \( \beta \) and go back to step 3
8. Increase \( b \)

5-16
Determine idler space

Belt Width
Material Density

Table 5.4

Idler Space

Carry
Return

Determine idler class:

(1) Find FA and FB in Table 5.5

Type of Service
Maximum Lump Size
Material Density

Table 5.5

FA, FB

(2) Find average belt weight

Belt Width
Material Weights

Table 5.6

Wb

(3) Determine idler class

Belt Speed

CI
CII

Figure 5.4

Figure 5.5

Carrying Idler Class
Returning Idler Class

CI = FA * FB
CII = FA * Wb

CI: Carry idle selection coefficient
CII: Return idle selection coefficient
FA: Idle service factor
FB: Material weight and lump factor
Wb: Average weight of belt
(4) Determine roll diameter and shaft diameter

The composite flow chart for the above follows

Determine and Roll Diameter
Idler Class Table 5.7 Shaft Diameter

Table 5.5
Determine FA, FB

Calculate
CI = FA*FB
CII = FA * \( \bar{w}_b \)

Figure 5.4 & 5.5

Determine Idler Class

Table 5.7

Determine Wb

Table 5.6
Determine Wb
Conveyor tension calculation

(1) Calculate Factor $K_x$

$$K_x = 0.00068 (W_b + W_m) + \frac{a_i}{S_i} \quad [2]$$

$$W_m = \frac{33.3 \times C_p}{V^*}$$

$W_b =$ Belt weight

$C_p =$ Operating capacity

$V^* =$ Economic belt speed

$W_m =$ Weight of material

$a_i = 0.90$, for 6-inch dia.

with $\frac{3}{4}$-inch shaft idler rolls

$a_i = 1.08$, for 5-inch dia.

with $\frac{3}{4}$-inch shaft idler rolls

$a_i = 1.26$, for 4-inch dia.

with $\frac{3}{4}$-inch shaft idler rolls

$a_i = 1.80$, for 7-inch dia.

with $1\frac{1}{4}$-inch shaft idler rolls

$a_i = 2.13$, for 6-inch dia.

with $1\frac{1}{4}$-inch shaft idler rolls

$S_i =$ Carry idler space
(2) Determine $K_y$ (resistance of the belt to flexure)

<table>
<thead>
<tr>
<th>The Length of Belt</th>
<th>Table 5.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_b + W_m$</td>
<td>IF $l &gt; 3000$</td>
</tr>
<tr>
<td>The Degree of Incline</td>
<td>USE 3000</td>
</tr>
</tbody>
</table>

(3) Determine $K_t$ (resistance due to temperature)

Operating temperature—Figure 5.6—$K_t$

(4) Calculate tension ($T_e$)

\[
T_e = L \times [K_t (K_y + K_y W_b \times 0.015 W_b)] + K_y L W_m \times H W_m + \text{Accessory [2]}
\]

$L$ = length of belt
$H$ = rise from horizontal level

(5) Calculate slack side tension ($T_2$)

\[
T_2 = T_o + T_b - T_f = T_o + HW_b - 0.015LW_b K_t
\]

$T_o$ = minimum belt tension
$T_b$ = tension due to gradient
$T_f$ = average tension on horizontal
(6) Calculate minimum belt tension ($T_o$)

$$T_o = 6.25 \times S_i \times (W_b + W_m) \quad 2\% \text{ Sag}$$

$$T_o = 4.20 \times S_i \times (W_b + W_m) \quad 3\% \text{ Sag} [2]$$

$$T_o = 8.4 \times S_i \times (W_b + W_m) \quad 1\frac{1}{2}\% \text{ Sag}$$

(7) Total tension ($T_1$)

$$T_1 = T_e + T_2$$

(8) Determine horsepower and belt tension

$$\text{H.P.} = \frac{(T_e)(V)}{33000}$$

$$\text{Belt tension} = \frac{T_1}{\text{Belt Width}}$$

$$\text{Motor H.P.} = \frac{\text{H.P.} \times 150}{100}$$

Identify grade and fabric required

A. Material Characteristics ——— Table 5.9 ——— Grade

Belt Tension ——— Table 5.1

B. Determine conveyor belt top-cover and bottom-cover thickness:
(1) Calculate belt frequency factor = \( \frac{2L}{V} \)

(2) Determine top cover thickness

Frequency factor
Cover grade
Material characteristics
Lump size

Table 5.10
Top-Cover Thickness

(3) Determine bottom cover thickness:

Cover grade
Material characteristics

Table 5.11
Bottom-Cover Thickness

5.5.2 Cost Analysis Model

- \( C_1 \) = cost of conveyor belt, \$/ft
- \( C_2 \) = cost of conveyor idler, \$/ft
- \( C_3 \) = cost of mechanical drive, pulleys, bearings, \$/each
- \( C_4 \) = cost of motor and starter, \$/h.p.
- \( C_5 \) = cost of conveyor deck, \$/ft
- \( C_6 \) = cost of conveyor terminals, \$/each
- \( C_7 \) = cost of conveyor structure, \$/ft

\( BL \) = total length of belt conveyor
\( HP \) = total horsepower required
\( CRB \) = cost of belt replacement
\( SFR \) = sinking fund return factor
\( CHP \) = cost of horsepower, \$/kw-hr
TOY = total operating time per year, hours
CLA = cost of labor

Total Equipment Cost ($C_e$)

\[ C_a = (C_1 + C_2 + C_5 + C_7) \times BL \]
\[ C_b = C_4 \times HP \]
\[ CES = C_a + C_b + C_3 + C_6 \]
\[ C_8 = 0.1 \times CES \]
\[ C_e = (C_a + C_b + C_3 + C_6 + C_8) \times FD_1 \]
\[ C_8 = \text{Cost of feeder} \]

Installation Costs ($C_i$);
Engineering, Supervision and Contingencies

\[ C_i = 0.3 \times C_e \]
\[ C_{it} = C_e + C_i \]

Cost of Capital Investment

\[ CL = 0.05 \times C_e \]
\[ CB = 0.06 \times C_e \]
\[ CC = (C_e + C_i + CL + CB) \times 1.1 \]
\[(10\% \text{ for working capital})\]
\[ CL = \text{cost of right of way and land improvement} \]
\[ CB = \text{cost of buildings} \]
\[ CC = \text{cost of capital investment} \]
SFR = RF/((RF + 1.) ** BF - 1.)
CRB = BL * SFR * C₁ * FD
CME = 0.02 * (Cₑ - C₁ * BL * FD₁)
CMB = 0.05 * (C₁ * BL * FD₁)
CM = CME + CMB + CRB
CME = equipment maintenance cost
CMB = belt maintenance cost

Total Cost of Operation (CO)
CTHP = HP * 0.746 * CHP * TOY
CLB = CLH * TOY * NLB
   CLH = hourly wage labor
   CLB = total labor cost
   CTHP = total power cost
   NLB = number of laborers
CS = 0.2 * CLB
CAE = 0.3 * CLB
COV = 0.3 * (CLB + CS + CM)
CO = CLB + CS + CAE + COV

CS = cost of supervision
CAE = cost of administration and engineering
COV = overhead cost
Annual Cost of Belt System and Conveyor Belt (COWS)

\[ CBS = CC - C_1 \times BL \times FD_1 \]

\[ COWS = (CBS - 0.1 \times (C_1 + C_l + CL + CB))/SLF \]
\[ + CBS \times INT \times (SLF+1)/SLF/2 \]

\[ COWB = (C_1 \times \frac{BL}{BF} + C_1 \times BL \times INT \times \frac{(BF+1)/BF/2}{FD_l} \]

\[ SLF = \text{life of belt system} \]
\[ CBS = \text{cost of belt system} \]
\[ INT = \text{interest rate} \]
\[ COWB = \text{annual cost of conveyor belt} \]

Total Annual Fixed Cost (CAF)

\[ CIS = 0.008 \times CC \]
\[ CTA = 0.01 \times CC \]

\[ CAF = COWB + COWS + CTA + CIS \]

\[ CIS = \text{annual insurance cost} \]
\[ CTA = \text{annual taxes} \]

Cost Per Ton (CT)

\[ CT = (CAF + CO + CM)/TOY/CP \]

\[ CTM = \frac{CT}{BL} \times 5280 \]

\[ CP = \text{total capacity} \]
### Table 2-1 FLOWABILITY — ANGLE OF SURCHARGE — ANGLE OF REPOSE

<table>
<thead>
<tr>
<th>Material Characteristics</th>
<th>Flowability</th>
<th>Angle of Surcharge</th>
<th>Angle of Repose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform size, very small rounded particle, either very wet or very dry, such as dry silica sand, cement, wet concrete, etc.</td>
<td>Very free flowing 1°</td>
<td>5° Angle of Surcharge</td>
<td>0°-20° Angle of Repose</td>
</tr>
<tr>
<td></td>
<td>Free flowing 2°</td>
<td>10° Angle of Surcharge</td>
<td>20°-30° Angle of Repose</td>
</tr>
<tr>
<td></td>
<td>Average flowing 3°</td>
<td>20° Angle of Surcharge</td>
<td>30°-35° Angle of Repose</td>
</tr>
<tr>
<td></td>
<td>Sluggish 4°</td>
<td>25° Angle of Surcharge</td>
<td>35°-40° Angle of Repose</td>
</tr>
<tr>
<td></td>
<td>Profile on flat belt</td>
<td>30° Angle of Surcharge</td>
<td>40°-Up Angle of Repose</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>Angle of Surcharge</td>
<td>Other Angles of Repose</td>
</tr>
</tbody>
</table>

**Source:** [2]

---

**TABLE 5.2: Flowability — Angle of Surcharge — Angle of Repose**
TABLE 5.3: Maximum Recommended Belt Speeds (Fpm) for Standard Service

<table>
<thead>
<tr>
<th>Belt Width, In.</th>
<th>Max. Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Recommended Speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>To Reduce Breakage:</strong></td>
<td></td>
</tr>
<tr>
<td>Friable ores</td>
<td>500 250 300 350 350 400 450 500 500 500 500</td>
</tr>
<tr>
<td>Coal</td>
<td>400 250 250 300 300 350 400 400 400 400 400</td>
</tr>
<tr>
<td>Coke</td>
<td>300 250 250 250 250 250 300 300 300 300 300</td>
</tr>
</tbody>
</table>

Source: [7]
TABLE 5.4: Suggested Normal Spacing of Belt Idlers

<table>
<thead>
<tr>
<th>b, Belt width (inches)</th>
<th>Troughing idlers</th>
<th>Return idlers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight of material handled, lbs per cu. ft.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>14</td>
<td>5.0 ft</td>
<td>4.5 ft</td>
</tr>
<tr>
<td>16</td>
<td>5.0 ft</td>
<td>4.5 ft</td>
</tr>
<tr>
<td>18</td>
<td>5.0 ft</td>
<td>4.5 ft</td>
</tr>
<tr>
<td>20</td>
<td>4.5 ft</td>
<td>4.0 ft</td>
</tr>
<tr>
<td>24</td>
<td>4.0 ft</td>
<td>4.0 ft</td>
</tr>
<tr>
<td>30</td>
<td>4.0 ft</td>
<td>4.0 ft</td>
</tr>
<tr>
<td>36</td>
<td>4.0 ft</td>
<td>3.5 ft</td>
</tr>
<tr>
<td>42</td>
<td>3.5 ft</td>
<td>3.0 ft</td>
</tr>
<tr>
<td>48</td>
<td>3.5 ft</td>
<td>3.0 ft</td>
</tr>
<tr>
<td>54</td>
<td>3.5 ft</td>
<td>3.0 ft</td>
</tr>
<tr>
<td>60</td>
<td>3.0 ft</td>
<td>3.0 ft</td>
</tr>
<tr>
<td>66</td>
<td>3.0 ft</td>
<td>3.0 ft</td>
</tr>
<tr>
<td>72</td>
<td>3.0 ft</td>
<td>2.5 ft</td>
</tr>
</tbody>
</table>

Source: [2]
TABLE 5.5: Idler Service Factor A & Material Weight and Lump Factor B

<table>
<thead>
<tr>
<th>Types of service</th>
<th>Factor A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-shift operation</td>
<td></td>
</tr>
<tr>
<td>Operation 10 to 16 hours per day</td>
<td>12</td>
</tr>
<tr>
<td>Unsized material up to and including 100 lbs per cu ft</td>
<td>12</td>
</tr>
<tr>
<td>Sized material, over 100 lbs per cu ft</td>
<td>15</td>
</tr>
<tr>
<td>Unsized material, limited in lump size only by belt width</td>
<td>15</td>
</tr>
<tr>
<td>Continuous operation</td>
<td></td>
</tr>
<tr>
<td>Over 16 hours per day, all material</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum lump size (inches)</th>
<th>Factor B</th>
<th>Material weight, lbs per cu ft</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>48</td>
<td>60</td>
<td>72</td>
<td>84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>80</td>
<td>96</td>
<td>112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>96</td>
<td>120</td>
<td>144</td>
<td>168</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>112</td>
<td>140</td>
<td>168</td>
<td>196</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>128</td>
<td>160</td>
<td>192</td>
<td>224</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>144</td>
<td>180</td>
<td>216</td>
<td>252</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>160</td>
<td>200</td>
<td>240</td>
<td>280</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [2]
### TABLE 5.6: Estimated Average Belt Weights, Lbs Per Ft Length

<table>
<thead>
<tr>
<th>Belt width (inches)</th>
<th>75 to 129 (Medium duty)</th>
<th>130 to 200 (Heavy duty)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>16</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td>18</td>
<td>4.0</td>
<td>4.1</td>
</tr>
<tr>
<td>20</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>24</td>
<td>5.7</td>
<td>6.2</td>
</tr>
<tr>
<td>30</td>
<td>7.2</td>
<td>8.0</td>
</tr>
<tr>
<td>36</td>
<td>9.6</td>
<td>11.5</td>
</tr>
<tr>
<td>42</td>
<td>11.5</td>
<td>13.8</td>
</tr>
<tr>
<td>48</td>
<td>14.2</td>
<td>16.6</td>
</tr>
<tr>
<td>54</td>
<td>16.9</td>
<td>19.3</td>
</tr>
<tr>
<td>60</td>
<td>19.4</td>
<td>21.4</td>
</tr>
<tr>
<td>66</td>
<td>21.8</td>
<td>23.6</td>
</tr>
<tr>
<td>72</td>
<td>24.3</td>
<td>25.7</td>
</tr>
</tbody>
</table>

These values are for the term $W_b$

Source: [2]
<table>
<thead>
<tr>
<th>Series number</th>
<th>Roll diameter (inches)</th>
<th>Shaft diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>4&amp;5</td>
<td>5/8</td>
</tr>
<tr>
<td>II</td>
<td>4&amp;5</td>
<td>0.669 thru 3/4</td>
</tr>
<tr>
<td>III</td>
<td>4&amp;5</td>
<td>3/4</td>
</tr>
<tr>
<td>IV</td>
<td>6</td>
<td>3/4</td>
</tr>
<tr>
<td>V</td>
<td>6</td>
<td>1 3/16 or 1 1/4</td>
</tr>
<tr>
<td>VI</td>
<td>7</td>
<td>1 3/16 or 1 1/4</td>
</tr>
</tbody>
</table>

Source: [2]
<table>
<thead>
<tr>
<th>Conveyor Length (ft)</th>
<th>( W_p + W_m ) (lbs per ft)</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>24</th>
<th>33</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>100</td>
<td>0.030</td>
<td>0.026</td>
<td>0.022</td>
<td>0.019</td>
<td>0.017</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>0.033</td>
<td>0.024</td>
<td>0.019</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.032</td>
<td>0.023</td>
<td>0.017</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>1400</td>
<td>100</td>
<td>0.028</td>
<td>0.023</td>
<td>0.019</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>0.029</td>
<td>0.020</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.030</td>
<td>0.021</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>2000</td>
<td>100</td>
<td>0.025</td>
<td>0.020</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>0.026</td>
<td>0.017</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.024</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
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<tr>
<td>2400</td>
<td>100</td>
<td>0.024</td>
<td>0.019</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>0.024</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.021</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>3000</td>
<td>100</td>
<td>0.022</td>
<td>0.017</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>0.022</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.019</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Source: [2]
<table>
<thead>
<tr>
<th>Cover grade</th>
<th>Major advantages</th>
<th>General applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cut &amp; tear resistance</td>
<td>Abrasion resistance</td>
</tr>
<tr>
<td>General Service</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 3</td>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [2]
TABLE 5.10: Conveyor Belt Top-Cover Thickness and Grade: Recommendations For Cold Bulk Materials With Normal Loading Conditions

<table>
<thead>
<tr>
<th>Abrasive Material Class 6</th>
<th>Very abrasive Material Class 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust to 1/4</td>
<td>1/2</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3/16</td>
<td>3/8</td>
</tr>
<tr>
<td>1/8</td>
<td>1/4</td>
</tr>
<tr>
<td>3/32</td>
<td>—</td>
</tr>
<tr>
<td>1/32</td>
<td>1/16</td>
</tr>
<tr>
<td>1/16</td>
<td>1/32</td>
</tr>
<tr>
<td>1/8</td>
<td>1/32</td>
</tr>
<tr>
<td>1/8</td>
<td>1/16</td>
</tr>
<tr>
<td>3/16</td>
<td>3/32</td>
</tr>
<tr>
<td>1/8</td>
<td>1/16</td>
</tr>
<tr>
<td>3/16</td>
<td>3/32</td>
</tr>
<tr>
<td>1/8</td>
<td>1/16</td>
</tr>
<tr>
<td>3/16</td>
<td>3/32</td>
</tr>
<tr>
<td>1/8</td>
<td>1/16</td>
</tr>
</tbody>
</table>

Source: [2]
### TABLE 5.11: Conveyor Belt Bottom Covers

Minimum requirements for bottom cover selection, cover thickness in inches

<table>
<thead>
<tr>
<th>Cover quality grade</th>
<th>Non-abrasive material Class 5</th>
<th>Abrasive material Class 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal good</td>
<td>Normal</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>1/32</td>
<td>1/16</td>
</tr>
<tr>
<td>2</td>
<td>1/32</td>
<td>1/16</td>
</tr>
<tr>
<td>1</td>
<td>1/32</td>
<td>1/16</td>
</tr>
</tbody>
</table>

Source: [2]
FIGURE 5.4: Troughing Idler Selection Chart
(for belt widths through 60 inches)

Source: [2]
FIGURE 5.5: Return Idler Selection Chart
(for belt widths through 60 inches)

Source: [2]
FIGURE 5.6: Factor $K_t$ Value

Source: [2]
5.6 COMPUTER PROGRAM FOR CONVEYOR BELT

5.6.1 Input Data for Belt Width and Operating Speed

<table>
<thead>
<tr>
<th>*</th>
<th>ITEM</th>
<th>UNIT</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>Demand Capacity</td>
<td>ton/hr.</td>
<td>F</td>
</tr>
<tr>
<td>A1</td>
<td>Incline Angle (Decline)</td>
<td>degree</td>
<td>F</td>
</tr>
<tr>
<td>A2</td>
<td>Surcharge Angle</td>
<td>degree</td>
<td>F</td>
</tr>
<tr>
<td>A3</td>
<td>Idler Angle</td>
<td>degree</td>
<td>F</td>
</tr>
<tr>
<td>A3M</td>
<td>Maxi Idler Angle</td>
<td>degree</td>
<td>F</td>
</tr>
<tr>
<td>POL</td>
<td>Percentage of Maxi Lump</td>
<td>×</td>
<td>F</td>
</tr>
<tr>
<td>SOL</td>
<td>Size of Maximum Lump</td>
<td>inch</td>
<td>F</td>
</tr>
<tr>
<td>DM</td>
<td>Density of Material</td>
<td>lb/in^3</td>
<td>F</td>
</tr>
<tr>
<td>T</td>
<td>Ambient Temperature</td>
<td>°F</td>
<td>F</td>
</tr>
<tr>
<td>MT</td>
<td>Mileage Between Plant and Mine</td>
<td>miles</td>
<td>F</td>
</tr>
</tbody>
</table>

5.6.2 Input Data for Belt Tension

| WB| Weight of Belt                   | lb/in           | F      |
| AI| Coefficient for Frac tion        | ×               | F      |
| SI| Carry Idler Space                | inch            | F      |
| BL| Length of Belt Conveyor          | ft              | F      |
| AY| Flurxe Resistance Footer         | ×               | F      |
| T | Ambient Temperature              | degree          | F      |
| H | Height from Level                | ft              | F      |
| SAG| Percentage Sag of Belt           | ×               | F      |
| WB| Belt Weight                      | lb/in           | F      |
| CP| Belt Capacity                    | T/hr            | F      |
| VO| Economic Speed                   | ft/hr           | F      |
| DM| Material Density                 | lb/in^3         | F      |
| BW| Width of Belt                    | in              | F      |
| FA| Service Factor                   | ×               | F      |
| FB| Material and Lump Factor         | ×               | F      |
| N | Number of Segments               | ×               | I2     |
| BLS| Segment Length                   | ft              | F      |
| H | Segment Height                   | ft              | F      |
### 5.6.3 Input Data for Conveyor Belt Program - Cost

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Belt Cost</td>
<td>$/ft</td>
<td>F</td>
</tr>
<tr>
<td>C2 Idler Cost</td>
<td>$/ft</td>
<td>F</td>
</tr>
<tr>
<td>C5 Deck Cost</td>
<td>$/ft</td>
<td>F</td>
</tr>
<tr>
<td>C6 Terminal Cost</td>
<td>$/each</td>
<td>F</td>
</tr>
<tr>
<td>C7 Structure Cost</td>
<td>$/ft</td>
<td>F</td>
</tr>
<tr>
<td>INT Sinking Fund Return Interest</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>BF Belt Life</td>
<td>Year</td>
<td>F</td>
</tr>
<tr>
<td>CHP Cost of Horse Power</td>
<td>$/h.p.</td>
<td>F</td>
</tr>
<tr>
<td>TOY Total Operating Time</td>
<td>hr.</td>
<td>F</td>
</tr>
<tr>
<td>CLH Lab Cost</td>
<td>$/hr</td>
<td>F</td>
</tr>
<tr>
<td>SLF Belt Equipment Life</td>
<td>Year</td>
<td>F</td>
</tr>
<tr>
<td>FD1 Inflation Factor</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>RF Belt Replacement - Sinking Fund</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>NLB Number of Workers</td>
<td>*</td>
<td>F</td>
</tr>
</tbody>
</table>
References


2. Conveyor Equipment Manufacturers' Association, Belt Conveyor for Bulk Material, Washington, D.C.


**SUBPROGRAM TO DETERMINE BELT WIDTH AND OPERATING SPEED**

02000   CP: QUANTITY OF MATERIAL TRANSPORTED
02200   A1: DEGREE OF DECLINE AND INCLINE ANGLE
02400   A2: DEGREE OF SURCHARGE ANGLE
02600   A3: DEGREE OF IDLER ANGLE
02800   A3H: MAXIMUM DEGREE OF THE IDLER ANGLE
03000   FCL: PERCENTAGE OF MAXIMUM LUMP
03200   SL: SIZE OF MAXIMUM LUMP
03400   D1: DENSITY OF MATERIAL
03600   FA: IDLER SERVICE FACTOR
03800   FB: MATERIAL WEIGHT AND LUMP FACTOR
04000   W: WIDTH OF BELT CONVEYOR
04200   BO: ECONOMIC BELT WIDTH
04400   VM: MAXIMUM OPERATING SPEED
04600   H1: FLUX OF MATERIAL TRANSPORT
04800   X1: MODIFIED FLUX OF MATERIAL TRANSPORT
05000   HT: TOTAL MILEAGE
05200   VQ: ECONOMIC OPERATING SPEED
05400   K1: CARRY IDLER SELECTION FACTOR
05600   K2: RETURN IDLER SELECTION FACTOR
05800   B: COEFFICIENT

**DATA INPUT**

06000   REAL M
06100   OPEN(UNIT=5,DEVICE='DSK',FILE='bell',ACCESS='SEQIN')
06200   OPEN(UNIT=5,DEVICE='DSK',FILE='bell',ACCESS='SEQOUT')
06300   READ(5,1) CF,Al,A2,A3,FCL,SL,HB,VM,HT
06400   формат(6X,10F)
06500   TYPE999,CF,Al,A2,A3,FCL,SL,HB,VM,HT
06600   формат(10F)
06700   999 формат(10F)
06800   999 формат(10F)
06900   999 формат(10F)
07000

**CALCULATE WIDTH OF BELT CONVEYOR**
CP=CPY/24.330.
07000 IF(A2-25) 101, 102, 103
07100 A2=20.
07200 B=3.
07300 D=2.22
07400 GO TO 11
07500 102
07600 A2=25.
07700 B=4.
07800 D=2.89
07900 GO TO 11
08000 103
08100 A2=30.
08200 B=6.
08300 D=4.4
08400 IF(WOBI=24) 104, 105, 106
08500 104
08600 C1=WOB/2.
08700 L1=C1
08800 F1-C1-L1
08900 IF(F1) 108, 109, 109
09000 106
09100 WOB=WOB/L1
09200 GO TO 12
09300 109
09400 WOB=WOB(L1+1)
09500 GO TO 12
09600 100
09700 WOB=WOB
09800 GO TO 12
09900 100
10000 C1=(WOB-24)/6.
10100 L1=C1
10200 F1-C1-L1
10300 IF(F1=0.5) 110, 110, 111
10400 110
10500 WOB=WOB/L1
10600 GO TO 12
10700 111
10800 WOB=WOB+6,*(L1+1)
10900 12
11000 *CALCULATE MAXIMUM OPERATING BELT CONVEYOR SPEED
11100
11200 14
11300 IF(BW=20) 112, 112, 113
11400 112
11500 VOB=400.
11600 GO TO 13
11700 113
11800 IF(BW=30) 114, 114, 115
11900 114
12000 VOB=600.
12100 GO TO 13
12200 115
12300 VOB=700.
12400 *CALCULATE ECONOMIC OPERATING BELT CONVEYOR SPEED
12500
B2 = A2 * 3.1416 / 180,
B3 = A3 * 3.1416 / 180,
AAA1 = (0.37 * BW + 0.25 * COS(B3) * (0.26 * BW - 1.03)) * SIN(B3)
AAA2 = 0.26 * BW - 1.03
AAA = AAA1 + AAA2
AAAB = ((0.19 * BW + 0.13 * COS(B3) * (0.26 * BW - 1.03)) / SIN(B2)) ** 2
A22 = 2 * B2
AAC = (B2 - SIN(A22) / 2)

A = AAA + AAAB * AAC
A = A / 144,
MA = A * COS(A1)
V = CP * 2000 * 60 / MA / DM
F2 = V / VDM

IF (F2) 116, 116, 117
F3 = A3 - ASM
IF (F3) 118, 119, 119
A3 = A3 + 5
GO TO 13
IF (BW - 24) 120, 121, 121
BW = BW + 2
GO TO 14
BW = BW + 6
GO TO 14
V0 = V

TYPE64
WRITE(6, 64)

FORMAT(// // 40X, 'BELT CONVEYOR SPECIFICATION')
WRITE(6, 65)
FORMAT(10X, 'BELT WIDTH OF BELT CONVEYOR = ', F10.3)

WRITE(6, 66)
FORMAT(10X, 'DETERMINE THE BELT CONVEYOR PARAMETER')

WRITE(6, 67)
FORMAT(10X, 'DEMAND CAPACITY OF MATERIAL TRANSPORTED = ', F10.2)

WRITE(6, 68)
FORMAT(10X, 'DEGREE OF IDLER ANGLE = ', F10.3)

END
***SUBPROGRAM TO DETERMINE CONVEYOR BELT OPERATING HORSEPOWER***

02300 02400 02500 02600 02700 02800 02900 03000 03100 03200 03300 03400 03500 03600 03700 03800 03900 04000 04100 04200 04300 04400 04500 04600 04700 04800 04900 05000 05100 05200 05300 05400 05500 05600 05700 05800 05900 06000 06100 06200 06300 06400 06500 06600 06700 06800 06900 07000 07100 07200 07300 07400 07500 07600 07700 07800

**AI**: COEFFICIENT FOR FRICTIONAL RESISTANCE

**SI**: CARRY IDLER SPACE

**BL**: LENGTH OF BELT CONVEYOR

**AY**: RESISTANCE FACTOR TO FLUXURE

**T**: DEGREE OF AMBIENT TEMPERATURE

**H**: HEIGHT FROM HORIZONTAL LEVEL

**SAG**: PERCENTAGE SAG OF BELT

**WB**: WIDTH OF BELT CONVEYOR

**CP**: OPERATING CAPACITY

**VO**: ECONOMIC OPERATING SPEED

**BW**: WIDTH OF BELT CONVEYOR

**AX**: FRICTIONAL RESISTANCE FACTOR DUE TO ROLLING & SLIDING

**AT**: AMBIENT TEMPERATURE FACTOR

**WM**: THE WEIGHT OF LOADED MATERIAL

**TE**: BELT TENSION

**TO**: MINIMUM BELT TENSION

**T1**: TOTAL BELT TENSION

**T2**: SLACK SIDE TENSION

**HP**: HORSEPOWER

**BT**: BELT TENSION PER PLY

**HPM**: MOTOR HORSEPOWER SPECIFICATION

---

**DATA INPUT**

**SUM OF FRICTIONAL RESISTANCE OF THE IDLER ROLLS AND SLIDING ROLL**

REAL INT

OPEN UNIT=5, DEVICE='DSK', FILE='belta.dat', ACCESS='SEQIN')

OPEN UNIT=6, DEVICE='DSK', FILE='belta0.dat', ACCESS='SEQOUT')

READ(5) AI, SI, BL, AY, T, H, SAG, WB, CP, VO, WM, BW, FA, FB

FORMAT(6X,14F)

READ(6) N

FORMAT(6X,12)

WRITE(6,152) CP=CP/330.724.

TET = 0.

TIT = 0.

DO 200 I=1,N

READ(5,152) BL, H

FORMAT(6X,2F)

WM = 33.3*CP/VO

AX = 0.00066*(WB+WM)*FA/5

**DETERMINE AT, THERMAL RESISTANCE**

**CALCULATE BELT TENSION**
07900 31  TE=BL*S*(C*(A+AY*WB+0.015*WB)+AY*BL*WM+H*WM
08000  IF(SAG=2.) 205,206,207
08100 ********DETERMINE MINIMUM BELT TENSION FOR SPECIFIC SAG
08200
08300
08400  205  T0=0.4*SI*(WB+WM)
08500  GO TO 32
08600  206  T0=0.25*SI*(WB+WM)
08700  GO TO 32
08800  207  T0=4.2*SI*(WB+WM)
08900  32  T2=T0+H*WB-0.015*BL*WM*AT
09000 ********CALCULATE TOTAL TENSION REQUIRED
09100
09200
09300
09400  T1=TE+T2
09500 ********CALCULATE TOTAL HORSEPOWER
09600
09700
09800  T1=T1+T1
09900  TET=TET+TE
10000  HP=(TET)*(Vo)/33000.
10100
10200
10300
10400  BT=T1/8W
10500 ********DETERMINE MOTOR HORSEPOWER SPECIFICATION
10600
10700
10800
10900
11000
11100
11200
11300
11400
11500
11600
11700
11800
11900
12000
12100
12200
12300
12400
12500
12600
12700
12800
12900
13000
13100
13200
13300
13400
13500
13600
13700
13800
13900
14000
14100
14200
14300
14400
14500
14600
14700
14800
14900
15000
15100
15200
15300
15400
15500
15600
15700
15800
15900
16000
16100  C1F=FA*FB
16200  R1F=FA*WB
16300  TYPE161,HP,HT,HPH,C1F,R1F
16400  WRITE(6,161) HP,BT,HPH,C1F*R1F
16500  FORMAT(29X, HORSE POWER='F10.3, BELT TENSION='F10.3
16600  /20X, 'MOTOR HORSE POWER='F10.3
16700  /20X, 'THE CARRY IDLER SELECTION FACTOR='F10.3
16800  /20X, 'THE RETURN IDLER SELECTION FACTOR='F10.3)
the subprogram for cost analysis
******DATA INPUT******

REAL NLB
READ(5,73) C1,C2,C5,C6,C7,INT,BF,CHP,TOY,CLH,SLF,FD1,RF
FORMAT(6X,1F)
TYPE73,C1,C2,C5,C6,C7,INT,BF,CHP,TOY,CLH,SLF,FD1,RF
READ(5,75) NLB
FORMAT(6X,1F)

******CALCULATE INSTALLATION COST OF BELT CONVEYOR******

******CALCULATE COST OF EQUIPMENT******

C3=10000.*HP/100.
C4=2B.
CA=(C1+C2+C5+C7)*BL
CB=C4*HP
CES=CA+CB+C3+C6
CB=0.1*CES
CE=(CES+C8)*FD1

******CALCULATE COST OF INSTALLATION******

CI=0.3*CE
CIT=CE+CI

******CALCULATE COST OF CAPITAL INVESTMENT******

CL=0.05*CE
CB=0.06*CE
CC=(CE+CI+CL+CB)*1.1

******CALCULATE MAINTENANCE & OPERATING COST******

******CALCULATE MAINTENANCE COST OF EQUIPMENT & BELT******
CALCULATE THE COST OF OPERATION

CHP = HP * 0.746 * CHP * TOY
CLB = CLH * TOY * NLB
CS = 0.2 * CLB
CAE = 0.3 * CLB
COV = 0.5 * (CLB * CS) + 0.3 * CM
CD = CLB * CS * CM + CO + CHP

CALCULATE OWNERSHIP COST

CBS = CC - C1 * BL * FD1
COWS = (CBS - 0.1 * (CE + EI + CL + CB)) / SLF + CBS * INT / 2. / SLF * (1. + SLF)

COWB = C1 * BL * FD1 * (1. / BF + INT / 2. / BF * (1. + BF))

ANNUAL TOTAL FIXED COST

CIS = 0.008 * CC
CTA = 0.01 * CC
CAF = COWB + COWS + CTA + CIS

CALCULATE TOTAL COST PER TON

CT = (CAF + CO + CM) / TOY / CP
CTM = CT / BL * 5280.

TYPE71
TYF=70, CE, CI, CIT, CC, CM, CO, COWS, COWB, CAF, CT, CTM
WRITE(6,71)

FORMAT(////40X, 'THE COST ANALYSIS FOR BELT CONVEYOR')
WRITE(6,70) CE, CI, CIT, CC, CM, CO, COWS, COWB, CAF, CT, CTM

FORMAT(////20X, 'THE COST OF EQUIPMENT=', F15.1)
/20X, 'COST OF ERECTION=', F15.1
/20X, 'COST OF INSTALLATION & EQUIPMENT=', F15.1
/20X, 'COST OF CAPITAL INVESTMENT=', F15.1
/20X, 'COST OF MAINTENANCE=', F10.1
/20X, 'COST OF OPERATION=', F10.1
/20X, 'COST OF OWNERSHIP FOR BELT SYSTEM=', F10.1
/20X, 'COST OF OWNERSHIP FOR BELT =', F10.1
/20X, 'ANNUAL TOTAL FIXED COST=', F10.1
/20X, 'TOTAL COST PER TON =', F10.3
/20X, 'TOTAL COST PER TON PER MILE =', F10.3)
BELT CONVEYOR SPECIFICATION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRASHED COAL WITH MAX SIZE</td>
<td>0.00</td>
</tr>
<tr>
<td>PERCENTAGE OF MAX SIZE</td>
<td>0.10</td>
</tr>
<tr>
<td>DENSITY OF MATERIAL TRANSPORTED</td>
<td>135.00</td>
</tr>
<tr>
<td>DEMAND CAPACITY OF MATERIAL TRANSPORTED</td>
<td>0.10</td>
</tr>
<tr>
<td>OPERATING AMBIENT TEMPERATURE</td>
<td>32.00</td>
</tr>
<tr>
<td>DEGREE OF DECLINE OR INCLINE ANGLE</td>
<td>0.00</td>
</tr>
<tr>
<td>TOTAL MILEAGE BETWEEN PLANT AND MINE</td>
<td>3.5</td>
</tr>
<tr>
<td>DEGREE OF SURCHARGE ANGLE</td>
<td>25.00</td>
</tr>
<tr>
<td>DEGREE OF IDLER ANGLE</td>
<td>20.00</td>
</tr>
</tbody>
</table>

DETERMINE THE BELT CONVEYOR PARAMETER

- BELT WIDTH OF BELT CONVEYOR: 30,000
- ECONOMIC OPERATING SPEED: 5,258

HORSE POWER: 7,531
BELT TENSION: 1371.885
MOTOR HORSE POWER: 11,296
THE CARRY IDLER SELECTION FACTOR: 1800.000
THE RETURN IDLER SELECTION FACTOR: 120,000

THE COST ANALYSIS FOR BELT CONVEYOR

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>THE COST OF EQUIPMENTS</td>
<td>4762293.6</td>
</tr>
<tr>
<td>COST OF MACHINES</td>
<td>1428688.3</td>
</tr>
<tr>
<td>COST OF INSTALATION AND EQUIPMENTS</td>
<td>619081.6</td>
</tr>
<tr>
<td>COST OF CAPITAL INVESTMENT</td>
<td>7386317.3</td>
</tr>
<tr>
<td>COST OF MAINTENANCE</td>
<td>177495.6</td>
</tr>
<tr>
<td>COST OF OPERATION</td>
<td>492237.8</td>
</tr>
<tr>
<td>COST OF OWNERSHIP FOR BELT SYSTEM</td>
<td>514475.7</td>
</tr>
<tr>
<td>ANNUAL TOTAL FIXED COST</td>
<td>747147.7</td>
</tr>
<tr>
<td>TOTAL COST PER TON</td>
<td>13,678</td>
</tr>
<tr>
<td>TOTAL COST PER TON PER MILE</td>
<td>3,988</td>
</tr>
</tbody>
</table>
Belt Conveyor Specification

Crushed coal with max size = 8.00
Percentage of max size = 0.10
Density of material transported = 135.00
Demand capacity of material transported = 0.10
Operating ambient temperature = 32.00
Degree of decline or incline angle = 0.00
Total mileage between plant and mine = 10.00
Degree of surcharge angle = 26.00
Degree of idler angle = 20.00

Determine the Belt Conveyor Parameter

Belt width of belt conveyor = 30.00
Economic operating speed = 5.25

Horse power = 21,517
Belt tension = 379,411
Motor horse power = 32,275
The entry idler selection factor = 160.000
The return idler selection factor = 120.000

The Cost Analysis for Belt Conveyor

The cost of equipment = 11523612.8
Cost of erection = 4557004.8
Cost of installation & equipment = 17580496.5
Cost of capital investment = 20975123.3
Cost of maintenance = 505215.0
Cost of operation = 43841.0
Cost of ownership for belt system = 1459706.4
Cost of ownership for belt = 785109.4
Annual total fixed cost = 2122468.2
Total cost per ton = 31.712
Total cost per ton per mile = 3.171
BELT CONVEYOR SPECIFICATION

CRUSHED COAL WITH MAX SIZE = 0.00
PERCENTAGE OF MAX SIZE = 0.10
DENSITY OF MATERIAL TRANSPORTED = 135.00
DEMAND CAPACITY OF MATERIAL TRANSPORTED = 0.25
OPERATING AMBIENT TEMPERATURE = 32.00
DEGREE OF DECLINE OR INCLINE ANGLE = 0.000
TOTAL MILEAGE BETWEEN PLANT AND MINE = 3.5
DEGREE OF SURCHARGE ANGLE = 25.00
DEGREE OF IDLER ANGLE = 20.00

DETERMINE THE BELT CONVEYOR PARAMETER

BELT WIDTH OF BELT CONVEYOR = 30.00
ECONOMIC OPERATING SPEED = 13.146

HORSE POWER = 18.501
BELT TENSION = 1474.752
MOTOR HORSE POWER = 27.752
THE CARRY IDLER SELECTION FACTOR = 125.000
THE RETURN IDLER SELECTION FACTOR = 125.000

THE COST ANALYSIS FOR BELT CONVEYOR

THE COST OF EQUIPMENT = 4748533.2
COST OF FRATION = 1429359.9
COST OF INSTALLATION & EQUIPMENTS = 619383.1
COST OF CAPITAL INVESTMENT = 7397670.9
COST OF MAINTENANCE = 174459.6
COST OF OPERATION = 14796.7
COST OF OWNERSHIP FOR SYSTEM = 514676.3
COST OF OWNERSHIP FOR BELT = 99788.5
ANNUAL TOTAL FIXED COST = 197980.9
TOTAL COST PER TON = 5,479
TOTAL COST PER TON PER MILE = 1,565
**BELT CONVEYOR SPECIFICATION**

<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crashfin Coal with Max Size</td>
<td>8,00</td>
</tr>
<tr>
<td>Percentage of Max Size</td>
<td>0,10</td>
</tr>
<tr>
<td>Density of Material Transported</td>
<td>135,00</td>
</tr>
<tr>
<td>Demand Capacity of Material Transported</td>
<td>2,00</td>
</tr>
<tr>
<td>Operating Ambient Temperature</td>
<td>32,00</td>
</tr>
<tr>
<td>Degree of Decline or Incline Angle</td>
<td>0,000</td>
</tr>
<tr>
<td>Total Mileage Between Plant and Mine</td>
<td>10,000</td>
</tr>
<tr>
<td>Degree of Surcharge Angle</td>
<td>25,00</td>
</tr>
<tr>
<td>Degree of Idler Angle</td>
<td>20,00</td>
</tr>
</tbody>
</table>

**DETERMINE THE BELT CONVEYOR PARAMETER**

<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse Power</td>
<td>52,861</td>
</tr>
<tr>
<td>Belt Tension</td>
<td>441,392</td>
</tr>
<tr>
<td>Motor Horse Power</td>
<td>79,291</td>
</tr>
<tr>
<td>The Carrying Idler Selection Factor</td>
<td>100,000</td>
</tr>
<tr>
<td>The Return Idler Selection Factor</td>
<td>120,000</td>
</tr>
</tbody>
</table>

**THE COST ANALYSIS FOR BELT CONVEYOR**

<table>
<thead>
<tr>
<th><strong>Cost Item</strong></th>
<th><strong>Cost</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The Cost of Equipment</td>
<td>135,391,12.3</td>
</tr>
<tr>
<td>Cost of Freight</td>
<td>42,590.036</td>
</tr>
<tr>
<td>Cost of Installation &amp; Equipment</td>
<td>17,689,116.0</td>
</tr>
<tr>
<td>Cost of Capital Investment</td>
<td>209,850.48</td>
</tr>
<tr>
<td>Cost of Maintenance</td>
<td>50,534.0</td>
</tr>
<tr>
<td>Cost of Operation</td>
<td>59,314.5</td>
</tr>
<tr>
<td>Cost of Ownership for Belt System</td>
<td>146,948.0</td>
</tr>
<tr>
<td>Annual Total Fixed Cost</td>
<td>212,5320.3</td>
</tr>
<tr>
<td>Total Cost per Ton</td>
<td>107.08</td>
</tr>
<tr>
<td>Total Cost per Ton Per Mile</td>
<td>1,271</td>
</tr>
</tbody>
</table>
BELT CONVEYOR SPECIFICATION

CRASHED COAL WITH MAX SIZE = 8.00
PERCENTAGE OF MAX SIZE = 0.10
DENSITY OF MATERIAL TRANSPORTED = 135.00
DEMAND CAPACITY OF MATERIAL TRANSPORTED = 1.00
OPERATING Ambient TEMPERATURE = 32.00
DEGREE OF DECLINE OR INCLINE ANGLE = 0.00
TOTAL MILEAGE BETWEEN PLANT AND MINE = 3.5
DEGREE OF SURCHARGE ANGLE = 25.00
DEGREE OF IDLER ANGLE = 20.00

DETERMINE THE BELT CONVEYOR PARAMETER

BELT WIDTH OF BELT CONVEYOR = 30.000
ECONOMIC OPERATING SPEED = 52.583

HORSE POWER = 74,289
BELT TENSION = 1494.723
TOTALE HORSE POWER = 111.009
THE CARRY IDLER SELECTION FACTOR = 1800.000
THE RETURN IDLER SELECTION FACTOR = 1200.000

THE COST ANALYSIS FOR BELT CONVEYOR

THE COST OF EQUIPMENT = 4775922.9
COST OF INSTALLATION & EQUIPMENT = 6200699.8
COST OF CAPITAL INVESTMENT = 7407456.3
COST OF MAINTENANCE = 177758.4
COST OF OPERATIONS = 493619.6
COST OF OWNERSHIP FOR BELT SYSTEM = 516052.8
COST OF OWNERSHIP FOR BELT = 99788.3
ANNUAL TOTAL FIXED COST = 749175.4
TOTAL COST PER TON = 1,480
TOTAL COST PER TON PER MILE = 0.394
BELT CONVEYOR SPECIFICATION

CRASHED COAL WITH MAX SIZE = 8.00
PERCENTAGE OF MAX SIZE = 0.10
DENSITY OF MATERIAL TRANSPORTED = 135.00
DEMAND CAPACITY OF MATERIAL TRANSPORTED = 1.00
OPERATING AMBIENT TEMPERATURE = 32.00
DEGREE OF DECLINE OR INCLINE ANGLE = 0.00
TOTAL MILEAGE BETWEEN PLANT AND MINE = 1.0
DEGREE OF SURCHARGE ANGLE = 25.00
DEGREE OF IDLER ANGLE = 20.00

DETERMINE THE BELT CONVEYOR PARAMETER.

BELT WIDTH OF BELT CONVEYOR = 30.000
ECONOMIC OPERATING SPEED = 92.583

MOTOR POWER = 212.254
BELT TENSION = 47.638
MOTOR HORSE POWER = 318.381
THE CARRY IDLER SELECTION FACTOR = 180.000
THE RETURN IDLER SELECTION FACTOR = 120.000

THE COST ANALYSIS FOR BELT CONVEYOR

THE COST OF EQUIPMENT = 13962553.9
COST OF ELECTION = 406427.9
COST OF INSTALLATION & EQUIPMENT = 17631320.0
COST OF CAPITAL INVESTMENTS = 21235521.0
COST OF MAINTENANCE = 572455.9
COST OF OPERATIONS = 572455.9
COST OF OWNERSHIP FOR BELT = 1464412.9
ANNUAL TOTAL FIXED COST = 2123161.7
TOTAL COST PER TON = 9.206
TOTAL COST PER TON PER MILE = 0.321
Belt Conveyor Specification

Crushed Coal with Max Size: 8.00
Percentage of Max Size: 0.10
Density of Material Transported: 155.04
Demand Capacity of Material Transported: 1.00
Operating Ambient Temperature: -32.00
Degree of Decline or Incline Angle: 2.00
Total Mileage Between Plant and Mine: 100
Degree of Surcharge Angle: 25.00
Degree of Inler Angle: 20.00

Determine the Belt Conveyor Parameter

Belt Width of Belt Conveyor: 30.00
Economic Operating Speed: 52.583

Horse Power: 2122.543
Belt Tension: 42013.561
Motor Horse Power: 3183.815
The Carry Inler Selection Factor: 1830.000
The Return Inler Selection Factor: 120.000
### The Cost Analysis for Belt Conveyor

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<td>Total Cost per Ton per Mile</td>
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BELT CONVEYOR SPECIFICATION

CRUSHED COAL WITH MAX SIZE = 8,00
PERCENTAGE OF MAX SIZE = 8,10
MAXIMUM CAPACITY OF MATERIAL TRANSPORTED = 135,00
OPERATING AMBIENT TEMPERATURE = 32,00
DEGREE OF DECLINE OR INCLINE ANGLE = 8,00
TOTAL MILEAGE BETWEEN PLANT AND MINE = 3,50
DEGREE OF SURCHARGE ANGLE = 25,00
DEGREE OF IDLER ANGLE = 20,00

DETERMINE THE BELT CONVEYOR PARAMETER

BELT WIDTH OF BELT CONVEYOR = 30,000
ECONOMIC OPERATING SPEED = 262,914

HORSEPOWER = 357,491
BELT TENSION = 1494,564
"TOP" HORSEPOWER = 536,236
THE CARRY IDLER SELECTION FACTOR = 1800,000
THE RETURN IDLER SELECTION FACTOR = 120,000

THE COST ANALYSIS FOR BELT CONVEYOR

THE COST OF EQUIPMENT = 4833741,3
COST OF FREIGHT = 1450122,4
COST OF INSTALLATION & EQUIPMENT = 6283883,6
COST OF CAPITAL INVESTMENT = 7497132,7
COST OF MAINTENANCE = 178349,8
COST OF OPERATION = 495358,3
COST OF OWNERSHIP FOR BELT SYSTEM = 523040,6
COST OF OWNERSHIP FOR BELT = 99288,3
ANNUAL TOTAL FIXED COST = 757777,3
TOTAL COST PER TON = 0,286
TOTAL COST PER TON PER MILE = 0,082
Belt Conveyor Specification

Crashed coal with max size = 8,00
Percentage of max size = 0.10
Density of material transported = 135,00
Demand capacity of material transported = 5,00
Operating ambient temperature = 32,00
Degree of decline or incline angle = 0.000
Total mileage between plant and mine = 10,000
Degree of surcharge angle = 25.00
Degree of idler angle = 20.00

Determine the belt conveyor parameter

Belt width of belt conveyor = 30,000
Economic operating speed = 242.914

Horse power = 1021.491
Belt tension = 4114.100
Motor power = 1532.192
The carry idler selection factor = 1.002
The return idler selection factor = 1.000

The cost analysis for belt conveyor

The cost of equipment = 13727749.4
Cost of erection = 418524.8
Cost of installation & equipment = 17846074.3
Cost of capital investment = 21291739.3
Cost of maintenance = 589297.8
Cost of operations = 695552.5
Cost of ownership for belt system = 1484377.8
Cost of ownership for belt = 285109.4
Annual total fixed cost = 2152738.6
Total cost per ton = 6.671
Total cost per ton per mile = 0.067
BELT CONVEYOR SPECIFICATION

CRASHED COAL WITH MAX SIZE = 8,00
PERCENTAGE OF MAX SIZE = 0.10
DENSITY OF MATERIAL TRANSPORTED = 135,00
DEMAND CAPACITY OF MATERIAL TRANSPORTED = 5,00
OPERATING AMBIENT TEMPERATURE = 32,00
DEGREE OF DECLINE OR INCLINE ANGLE = 0,000
TOTAL MILEAGE BETWEEN PLANT AND MINE = 100,
DEGREE OF SURCHARGE ANGLE = 25,00
DEGREE OF IDLER ANGLE = 20,000

DETERMINE THE BELT CONVEYOR PARAMETER

BELT WIDTH OF BELT CONVEYOR = 30,000
ECONOMIC OPERATING SPEED = 242,914

MOTOR POWER = 17214.214
BELT TENSION = 40686.491
MOTOR POWER = 15321.021
THE CARRY IDLER SELECTION FACTOR = 1800.000
THE RETURN IDLER SELECTION FACTOR = 1200.000

THE COST ANALYSIS FOR BELT CONVEYOR

THE COST OF EQUIPMENTS = 136875552.0
COST OF ERECTION = 41762685.0
COST OF INSTALLATION & EQUIPMENT = 177938218.0
COST OF CAPITAL INVESTMENTS = 21229392.0
COST OF MAINTENANCE = 5284938.9
COST OF OPERATION = 3623077.0
COST OF OWNERSHIP FOR CONVEYOR = 14795281.0
ANNUAL TOTAL FIXED COST = 1467587.0
TOTAL COST PER TON = 5.995
TOTAL COST PER TON PER MILE = 0.060
Belt Conveyor Specification

Crushed Coal with Max Size = 8.00
Percentage of Max Size = 0.10
Density of Material Transports = 135.00
Demin Capacity of Material Transports = 7.00
Operating Ambient Temperature = 32.00
Degree of Incline or Incl Angle = 0.00
Total Mileage Between Plant and Line = 310.000
Degree of Surcharge Angle = 25.00
Degree of Idler Angle = 20.00

Determine the Belt Conveyor Parameter

Belt Width of Belt Conveyor = 30.000
Economic Operating Speed = 368.000

Horse Power = 14515.012
Belt Tension = 49310.200
Motor Horse Power = 21472.518
The Carry Idler Selection Factor = 180.000
The Return Idler Selection Factor = 120.000

The Cost Analysis for Belt Conveyor

The Cost of Equipment = 137712412.0
Cost of Erection = 41913843.0
Cost of Installation & Equipment = 179926656.0
Cost of Capital Investments = 213592572.0
Cost of Maintenance = 51016884.1
Cost of Operation = 4130850.7
Cost of Ownership for Belt System = 14296387.9
Annual Total Fixed Cost = 21592158.0
Total Cost Per Tons = 4.990
Total Cost Per Ton Per Mile = 0.044
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Contract Report J0166163

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**Title and Subtitle:** Comparative Coal Transportation Costs: An Economic and Engineering Analysis of Truck, Belt, Rail, Barge, and Coal Slurry and Pneumatic Pipelines; Volume 6 - Truck Haulage

**Author(s):** Michael Rieber and Shao Lee Soo

**Performing Organization Name and Address:** Center for Advanced Computation
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

**Sponsoring Organization Name and Address:** Office of the Assistant Director, Mining Bureau of Mines
Department of the Interior
Washington, D.C. 20241

**Abstract:**
An heuristic facility and costing model is developed for over the road coal transport at varying distances and tonnages. Cost data are based on industry sources. Road use costs are estimated. The computer program and an example are presented.

**Keywords:**
- Coal transportation
- Coal gathering systems
- Trucks
- Truck haulage costs
- Road costs

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This report is a summary of the work recently completed as part of this contract during the period May 1976 to August 1977. This report was submitted by the authors on August 1977.

This volume is a part of the eight volume report completed for this contract. The draft final report was submitted in May 1977.

The principal authors, Michael Rieber and Shao Lee Soo, are, respectively, Research Professor, Center for Advanced Computation, the Graduate College; and Professor of Mechanical Engineering, College of Engineering; both at the University of Illinois at Urbana-Champaign.
Subject Inventions

This is to certify that, to the best of my knowledge and belief, there were no Subject Inventions made or have resulted from the performance of this contract.

August 1977

Michael Rieber
Principal Investigator
FINAL REPORT

COMPARATIVE COAL TRANSPORTATION COSTS: AN ECONOMIC AND ENGINEERING ANALYSIS OF TRUCK, BELT, RAIL, BARGE AND COAL SLURRY AND PNEUMATIC PIPELINES

VOLUME 6

TRUCK HAULAGE

by

Michael Rieber and Shao Lee Soo
with
P. King, Y. T. King, T. Leung, H. Wu and J. Wu

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University of Illinois
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August 1977
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6. TRUCK HAULAGE

6.1 INTRODUCTION

Among the principal gathering/distribution systems for coal is over-the-road trucking. Where alternative trunk line modes such as barge or rail links are weak or nonexistent, trucks may, particularly for relatively short line hauls, act as substitutes. Their major application, however, appears to be in connection with smaller mines or coal users particularly where terrain problems are significant.

Truck use has increased as rail lines have been abandoned or suffered neglect. For example, in 1956 about 38 percent of the coal transported in eastern Kentucky and about 8 percent of the coal moved in western Kentucky went by truck. By 1975, the percentages were almost 77 percent and 28 percent, respectively [4,U-11]. While rail route limitations and deterioration played a part in the change, increased emphasis on road building, particularly during the 1950's and 1960's, and improved truck load capacity and efficiency were also important.

Coal haulage costs by truck are relatively high. Other things being equal, variations in these costs are largely a function of road conditions, terrain and weather. In this study estimates are made of capital and operating costs of truck haulage. These include a separable estimate of road use costs. Rather than attempt to determine road deterioration due to coal movements which, at best, would be highly dependent on region, weather, original road type, other users, and maintenance conditions, an alternative was chosen. This involved an estimation of the cost of building and maintaining a road capable of sustaining the traffic, annualizing the costs, and allocating a portion to the coal traffic. The procedure is presented in Section 6.4. A computer model is presented which will enable users to generate their own cost data tailored to their specific needs.

A word of caution is in order. Hard data were found to be sketchy. However, there have been no significant technological advances in recent years. In many cases a simple updating of older material appeared to be adequate.
The data problem arises because most large coal trucking operations appear to be exempt from ICC regulation and rate making. Therefore, cost data presented in support of administered rates are lacking. The exemptions arise because the operations tend to be owned by the mine or receiver, or because they are handled by a for-hire carrier hauling an exempt commodity.

Because of the size of the trucks, industry trends, and the increasing cost of gasoline and, possibly, associated taxes, the cost calculations have been made in terms of diesel fuel rather than gasoline. The analysis excludes all taxes. Fuel taxes differ by state while property taxes differ by state and locality. Both also depend on the size of the operation which is determined only after an optimization calculation. Users may wish to add taxes as a lump, or distributed, sum after completing the costing model. Finally, it will be found that the program assumes that time for hauling coal has been set equal to the time required for the empty return (\(T_R = T_H\) in Section 6.3.8.1). In relatively flat regions this is reportedly true. Where topography makes this convenient assumption untenable, the model can be easily altered either by using \(T_H\), with altered values of the components, to substitute for a new \(T_F\), or by reestimating with a simple empirically derived factor for \(T_H\) (e.g. \(T_H = aT_R; a > 1\)).
Line-haul trucking costs for various vehicle gross weights were based on the procedure used by Stevens [2,5,6] and the Highway Research Bulletin [1]. Figure 6.1 indicates the cost breakdown. (Note: all tables and figures are collected at the end of each major section.) To indicate the trends in vehicle - mile cost, it was expedient to group and accumulate the individual expense accounts under the seven headings: shown in the figure. Because engine oil consumption is primarily for lubricants, engine oil costs were included with repair and servicing costs. The Stevens study was adjusted for price inflation as follows.

In compiling repair and service costs the principal components are mechanics and repair parts. About 33 percent of repair servicing costs accrue to mechanics; repair parts represent 60 percent. Therefore, to update the Stevens' study, and its supplement, the 33 percent due to mechanics was adjusted by the ratio of indexes for 1976/1970 (5.92/3.85 = 1.55), given by the wholesale price index for the annual wage of mechanics. The 67 percent due to parts was adjusted by the ratio of the wholesale price index, 1976/1970 (151.7/111.6 = 1.36), for transportation equipment. Ownership of shop and garage facilities is covered under the cost of depreciation and interest. The cost of tires and tubes was adjusted by using the ratio of the wholesale price index, 1976/1970 (157.1/107.2 = 1.47) published in the Monthly Labor Review. Fuel costs were adjusted in the same way. They were further adjusted for speed and terrain. This is discussed below. Indirect and overhead costs include the subcategories shown in Figure 6.1. Because indirect and overhead costs are broad items, adjustments to indirect and overhead costs were simplified by using percentage of the overhead and indirect cost to total per-mile operating costs excluding overhead and indirect. Therefore, adjustments were first made to the total of the first five items, excluding overhead and indirect cost.

Depreciation and investment costs include those subcategories found in Figure 6.1. As the fleet model garage facility was assumed to be located on industrial property, no separate depreciation was calculated on land investment. Furthermore, as the vehicles are assumed to run out their useful line-haul life, they are salvagable only at scrap values. This is estimated at approximately one percent of original price, and here considered to be zero. From the Stevens' study, it is estimated that 80 percent of the depreciation value and interest charges for
line-haul operating costs accrues to the line-haul truck itself. As depreciation and interest are essentially directly related to the cost of the new vehicle equipment, the ratio of the wholesale price index for trucks for 1976/1970 was used (151.7/111.6 = 1.36). To the 1.36 was added a factor to account for the increase in interest rates from 6.5 percent to 8.5 percent, or 0.095. The total adjustment factor used was 1.455.

6.2.1 Operating Cost Adjusted by Running Speed

Vehicle speed is an important factor in running costs. Therefore adjustment due to running speed is necessary if more precise cost data are required. In practice, total elapsed time, or trip time, is more important than simply driving time. Dividing the trip mileage by driving time gives average running speed. The operating cost as modified by different running speeds was based on the Stevens' investigation [5,6].

6.2.2 Operating Cost Adjusted by Elements of Highway Design

The operating cost of a truck is affected by highway design elements such as distance, grades, curves, speed changes, roadway surfaces, lane width, number of lanes, shoulder width, and traffic control. Therefore some adjustments are necessary to produce a more reliable cost analysis. However, except for grades none of the above factors appeared to be highly significant with respect to costs. Here, an attempt has been made to classify different truck operations for terrain that can be crudely classified as flat and mountainous. A percentage factor is used in our cost analysis program instead of real mileage estimates for each type of terrain. For example, if the total mileage between a plant location and a mine location is 100 miles and includes a mountain section of 10 miles, the percentage factor for grades would be 10%.
6.2.3 Reserve Truck Requirements

In the calculation of truck transport costs, it is also necessary to know the total number of trucks needed with respect to mine output capacity. This depends on total tonnage and truck cycle time. The truck cycle calculation includes waiting time (to load), loading time, hauling time (loaded), waiting time (to dump), dumping time, and return time (unloaded).

After the cycle time estimate has been completed for a given truck, the supply estimate is made and the number of trucks required is determined. Because the number of productive minutes per hour varies, the average minutes per shift hour is used.

Truck down-time for service and repairs is also included when making an estimate of the total fleet required. The availability factor is included in order to determine the actual fleet size needed. There are different ways to determine truck availability. In this study we use a probability factor associated with truck downtime. It can be shown that the probability of having exactly \( n \) units available is:

\[
P_n = P_{nr} \times P_{mnr} \times C^n_r
\]

where \( P_n \) is the probability of \( n \) units being available, \( P_{nr} \) is the probability of a single unit being available, \( P_{mnr} \) is the probability of a single unit not being available, and \( C^n_r \) is the combinations of \( n \) things taken \( r \) at a time. Therefore the total fleet size can be calculated as follows:

\[
\text{Fleet size} = \frac{\text{Trucks required}}{P_n}
\]

Since the fleet size is always greater than the theoretical number of trucks required, the cost of reserve trucks is an important factor and is included with operating costs.
FIGURE 6.1: Truck Cost Elements

- Repair & Servicing
  - Engine Oil
  - Mechanics
  - Repair Parts
- Tire & Tube
- Indirect & Otherhead
  - Maintenance Supervision
  - Maintenance Office & Other Expenses
  - Other Maintenance Expenses
  - Transportation Supervision
  - Transportation Office & Other Expenses
  - Insurance & Safety Supervision
  - Insurance & Safety Office & Other Expenses
  - Salaries -- General Officers
  - Salaries -- General Office
  - Insurance, Safety Other Department Expenses
  - Expenses -- General Office
  - Expenses -- General Office Employees
  - Other General Office Expenses
- Drivers' Pay
  - Wages Paid
  - Vacation Paid
  - Bonuses
- Fuel
- Depreciation & Interest
  - Real Property, (Land & Buildings)
  - Personal Property, (Shop Equipment, Service Equipment Repair Parts and Supplies in Stock)
  - Trucks or Trailers
- Reserve Equipment
  - Reserve Truck
  - Depreciation & Interest
6.3 OPERATING COSTS - MODEL

A generalized description of the costing model is found in Figure 2. The specific relationship, adjustments and sources are described below.

6.3.1 Maintenance Cost

6.3.1.1 Cost adjusted by gross weight. The regressions are based on data derived from [1, pages 121-2].

\[ Y_1 = 7.15 - 0.048X_A + 0.0012X_A^2 \]
\[ Y_{11} = 7.15 - 0.048X_B + 0.0012X_B^2 \]

\( X_A \) = gross weight of truck loaded

\( X_B \) = gross weight of unloaded truck

\( Y_1 \) = $/vehicle mile for repair and service of loaded truck

\( Y_{11} \) = Cost per vehicle mile for repair and service of unloaded truck

6.3.1.2 Data adjusted by wholesale price indexes.

\[ Y_{1M} = 0.33 \times FR1 \times Y_1 + 0.67 \times FR11 \times Y_{11} \]
\[ Y_{11M} = 0.33 \times FR1 \times Y_{11} + 0.67 \times FR11 \times Y_{11} \]

\( Y_{1M} \) = adjusted maintenance cost of PTM for loaded truck

\( Y_{11M} \) = adjusted maintenance cost of PTM for unloaded truck

\( FR1 \) = adjustment factor for mechanics

\( FR11 \) = adjustment factor for repair parts
PTM = per truck-mile

Sources are found in the Monthly Labor Review.

6.3.2 Tires and Tubes Cost

6.3.2.1 Cost adjusted by gross weight.

\[ Y_2 = 1.74 - 0.01X_A + 0.0004X_A^2 \]
\[ Y_{22} = 1.74 - 0.01X_B + 0.0004X_B^2 \]
\[ Y_2 = \text{Cost per vehicle-mile for tires of loaded truck} \]
\[ Y_{22} = \text{Cost per vehicle-mile for tires of unloaded truck} \]

Regressions based on data derived from [1, pages 121-2].

6.3.2.2 Data adjusted by wholesale price indexes.

\[ Y_M = FR2 \times Y_2 \]
\[ Y_{22M} = FR2 \times Y_{22} \]
\[ Y_{2M} = \text{adjusted cost per vehicle-mile for loaded truck} \]
\[ Y_{22M} = \text{adjusted cost per vehicle-mile for unloaded truck} \]
\[ FR2 = \text{adjustment factor for tires and tubes} \]
\[ FR2 = \frac{157.1}{107.2} = 1.47 \]

Sources are found in the Monthly Labor Review.

6.3.3 Cost of Fuel (Diesel)
6.3.3.1 **Cost adjusted by gross weight.**

\[
Y_3 = 2.77 - 0.004X_A + 0.00012X_A^2
\]

\[
Y_{33} = 2.77 - 0.004X_B + 0.00012X_B^2
\]

\[
Y_3 = \text{Cost per vehicle-mile for fuel, loaded truck}
\]

\[
Y_{33} = \text{Cost per vehicle-mile for fuel, unloaded truck}
\]

Regression based on data derived from [1, pages 121-2].

6.3.3.2 **Data adjusted by wholesale price index.**

\[
Y_{3M} = FR3 \times Y_3
\]

\[
Y_{33M} = FR3 \times Y_{33}
\]

\[
Y_{3M} = \text{adjusted cost per vehicle mile, loaded truck}
\]

\[
Y_{33M} = \text{adjusted cost per vehicle mile, unloaded truck}
\]

FR3 = adjustment factor for fuel consumption

Sources are found in the *Monthly Labor Review*.

6.3.4 **Depreciation and Interest**

6.3.4.1 **Cost adjusted by gross weight.**

\[
Y_4 = 0.28 + 0.155X_A - 0.00027X_A^2
\]

\[
Y_{44} = 0.28 + 0.155X_B - 0.00027X_B^2
\]

\[
Y_4 = \text{Cost per vehicle-mile for depreciation of loaded truck}
\]
\(Y_{44}\) = Cost per vehicle-mile for depreciation of unloaded truck

Regression based on data derived from [1, pages 121-2].

6.3.4.2 **Data adjusted by current wholesale price.**

\[Y_{4M} = FR_4 \times Y_4\]
\[Y_{44M} = FR_4 \times Y_{44}\]
\[Y_{4M} = \text{adjusted cost per vehicle-mile for loaded truck}\]
\[Y_{44M} = \text{adjusted cost per vehicle-mile for unloaded truck}\]
\[FR_4 = \text{adjustment factor for depreciation and interest}\]

Sources are found in the *Monthly Labor Review.*

6.3.5 **Driver Costs**

6.3.5.1 **Cost adjusted by gross weight.**

\[Y_5 = 14.1 + 0.027X_A + 0.00005X_A^2\]
\[Y_{55} = Y_5\]
\[Y_5 = \text{Cost per vehicle-mile for drivers' wages and subsistence, loaded truck}\]
\[Y_{55} = \text{Cost per vehicle-mile for drivers' wages and subsistence, unloaded truck}\]

Regression based on data derived from [1, pages 121-2].
6.3.5.2 Data adjusted by current wholesale price.

\[ Y_{5M} = FR5 \times Y_5 \]
\[ Y_{55M} = FR5 \times Y_{55} \]

\( Y_{5M} \) = adjusted cost per vehicle-mile for loaded truck
\( Y_{55M} \) = adjusted cost per vehicle-mile for unloaded truck
\( FR5 \) = adjustment factor for drivers' wages and subsistence

Sources are found in the Monthly Labor Review.

6.3.6 Indirect and Overhead Costs Adjusted by Gross Weight

\[ Y_{15M} = Y_{1M} + Y_{2M} + Y_{3M} + Y_{4M} + Y_{5M} \]
\[ Y_{115M} = Y_{11M} + Y_{22M} + Y_{33M} + Y_{44M} + Y_{55M} \]
\[ Y_{6M} = Y_{15M} \times (0.35 - 0.0012X_A) \]
\[ Y_{66M} = Y_{115M} \times (0.35 - 0.0012X_B) \]

\( Y_{15M} \) = adjusted operating cost per vehicle-mile for loaded truck excluding indirect and overhead costs
\( Y_{115M} \) = adjusted operating cost per vehicle-mile for unloaded truck excluding indirect and overhead costs
\( Y_{6M} \) = adjusted indirect and overhead costs for loaded truck
\( Y_{66M} \) = adjusted indirect and overhead costs for unloaded truck

Regression equations are based on [1, pages 121-2], see Figure 6.3.

Price adjustments were already included in the previous sections.
6.3.7 Operating Cost Adjusted by Running Speed and Grades

Figure 6.4 indicates the cost flow through the model. Tables 6.1 and 6.2 provide the specific factors.

\[ Y_{16M} = Y_{1M} + Y_{2M} + Y_{3M} + Y_{4M} + Y_{5M} + Y_{6M} \]

\[ Y_{116M} = Y_{11M} + Y_{22M} + Y_{33M} + Y_{44M} + Y_{55M} + Y_{66M} \]

\[ Y_{16M} = \text{total updated operating cost per vehicle-mile for loaded truck} \]

\[ Y_{116M} = \text{total updated operating cost per vehicle-mile for unloaded truck} \]

\[ \text{COPL} = \text{operating cost on level road} \]

\[ \text{COPB} = \text{operating cost under bottle-neck conditions} \]

\[ \text{COPU} = \text{operating cost on up-grade} \]

\[ \text{COPD} = \text{operating cost on down-grade} \]

\[ \text{FV} = \text{speed adjustment factor} \]

\[ \text{FB} = \text{speed adjustment factor for bottle-necks} \quad (\text{FB} = \text{FV}) \]

\[ \text{FU} = \text{cost adjustment factor for up-grade} \]

\[ \text{FD} = \text{cost adjustment factor for down-grade} \]

\[ \text{COPTM} = \text{operating cost per ton per mile} \]

\[ \text{COPT} = \text{operating cost per ton} \]

\[ \text{YOP} = \text{average operating cost per truck-mile for round trip} \]

\[ \text{PL} = \text{percentage of total mileage on level} \]

\[ \text{PB} = \text{percentage of total mileage at bottle-neck} \]

\[ \text{PU} = \text{percentage of total mileage on up-grade} \]

\[ \text{PD} = \text{percentage of total mileage on down-grade} \]

\[ \text{CPT} = \text{capacity per truck} \]
\[ MT = \text{mileage between mine and plant} \]
\[ YOP = \frac{1}{2} (Y_{16M} + Y_{116M}) \]
\[ COPL = PL \times FV \times YOP \]
\[ COPE = PB \times FE \times YOP \]
\[ COPU = PU \times YOP \times FU \]
\[ COPD = PD \times YOP \times FD \]
\[ COPT = (COPL + COPB + COPU + COPD)/CPT \]

6.3.8 Number of Reserve Trucks Required

6.3.8.1 Calculation of truck cycle time. Figure 6.5 indicates the calculation flow for reserve trucks. Figure 6.6 indicates the flow of the cost calculations.

\[ TH = MT \times (PL/VL + PU/VU + PL/VD) \]
\[ TB = MT \times PB/VB \]
\[ TR = TH \]
\[ CY = 2TH + TB + TWL + TWD + TL + TD \]

\[ TH = \text{time for hauling} \]
\[ TR = \text{time for return} \]
\[ PL = \text{percentage of total mileage on level} \]
\[ PU = \text{percentage of total mileage on up-grades} \]
\[ PD = \text{percentage of total mileage on down-grades} \]
\[ VL = \text{level speed (regular speed)} \]
\[ VU = \text{speed on rising grades} \]
\[ VD = \text{speed on down-grades} \]
NT = mileage between mine and plant
TB = time during bottle-neck
PB = percentage of total mileage at bottle-neck
VB = bottle-neck speed
CY = total cycle time

6.3.8.2 Number of trucks.

\[ \text{NOTE} = \frac{\text{CPY} \times \text{CY}}{\text{OD} \times \text{OH} \times \text{CPT}} \]

NOTE = number of trucks
CPY = demand capacity per year
OD = operating days per year
OH = operating time per day
CPT = capacity per truck

6.3.8.3 Real truck number.

\[ \text{NOT} = \frac{\text{NOTE}}{\text{PY}} \]

NOT = size of fleet
PY = \( (P_d) \) the probability of hauling exactly n units

6.3.9 Cost of Reserved Trucks

6.3.9.1 Depreciation and interest.

\[ \text{CTTK} = (\text{NOTE-NOT}) \times \text{PT} \left( \frac{1}{\text{LOT}} \times \frac{\text{INT}}{\text{LOT}} \times (\text{LOT} + 1) \right) \]
CTTK = total reserved truck cost per year
PT = truck price
LOI = service life of trucks

6.3.9.2 Unit cost ($/ton).

\[
CTT = \frac{CTTK}{CPY}
\]

\[
CTTM = \frac{CTTK}{MT}
\]

CTT = cost of reserved truck per ton

CTTM = cost of reserved truck per ton per mile
<table>
<thead>
<tr>
<th>GROSS WEIGHT (Kips)</th>
<th>SPEED (mph)</th>
<th>FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>15-20</td>
<td>1.245</td>
</tr>
<tr>
<td></td>
<td>20-25</td>
<td>1.117</td>
</tr>
<tr>
<td></td>
<td>25-30</td>
<td>1.064</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>35-45</td>
<td>0.979</td>
</tr>
<tr>
<td></td>
<td>45-55</td>
<td>1.000</td>
</tr>
<tr>
<td>70</td>
<td>15-20</td>
<td>1.200</td>
</tr>
<tr>
<td></td>
<td>20-25</td>
<td>1.130</td>
</tr>
<tr>
<td></td>
<td>25-30</td>
<td>1.060</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>35-45</td>
<td>1.000</td>
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<tr>
<td></td>
<td>45-55</td>
<td>1.000</td>
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<td>1.000</td>
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<td>1.064</td>
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<tr>
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<td>30-35</td>
<td>1.064</td>
</tr>
<tr>
<td></td>
<td>35-45</td>
<td>1.064</td>
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<tr>
<td></td>
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<td>1.000</td>
</tr>
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<td>40</td>
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<td>1.021</td>
</tr>
<tr>
<td></td>
<td>20-25</td>
<td>1.125</td>
</tr>
<tr>
<td></td>
<td>25-30</td>
<td>1.042</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>1.063</td>
</tr>
<tr>
<td></td>
<td>35-45</td>
<td>1.042</td>
</tr>
<tr>
<td></td>
<td>45-55</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Source: [5]
# TABLE 6.2: Grade Adjustment Factors

## Diesel Engine

<table>
<thead>
<tr>
<th>Gross Weight (Kips)</th>
<th>Level</th>
<th>Terrain Rolling</th>
<th>Rising</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>1</td>
<td>1.06</td>
<td>1.10</td>
</tr>
<tr>
<td>70</td>
<td>1</td>
<td>1.05</td>
<td>1.11</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

## Gas Engine

<table>
<thead>
<tr>
<th>Gross Weight (Kips)</th>
<th>Level</th>
<th>Terrain Rolling</th>
<th>Rising</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>70</td>
<td>1</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>1.05</td>
<td></td>
</tr>
</tbody>
</table>

Source: [5]
FIGURE 6.2: Operating Cost Model Flow Chart

Drivers' Wages & Subsistence
- Data Adjustment FR5 = 1.456

Depreciation & Interest
- Data Adjustment FR4 = 1.26

Fuel Cost
- Data Adjustment FR3 = 2.33

Tube & Tube Cost
- Data Adjustment FR2 = 1.47

Maintenance Cost
- Data Adjustment FR1 = 1.55

Cost of Indirect & Overhead
- Y6M = Y15M \times (0.35 - 0.0012X_A)
- Y66M = Y115M \times (0.35 - 0.0012X_B)

Total Operating Cost $/truck-mile

Source: Reference [1]
Note: Regression coefficients derived from data in [1]
FIGURE 6.3: Ratio of Indirect to Operating Costs: Percent Change by Gross Weight

Percentage

Source: [1]

Note: One Kip equals 1000 pounds.
FIGURE 6.4: Adjusted Operating Cost Flow Model

Percentage for each Running Speed

Total Operating Cost  Running Speed

Operating Cost Adjusted by Speed
TABLE 6.1

Operating Cost Adjusted by Grade
TABLE 6.2

Total Operating Cost per Vehicle-mile
Truck Capacity

$/Ton-Mile
FIGURE 6.5: Reserve Truck Quantity Calculation

Cycletime
\[ CY = TWL + TL + TH + TWU + TD + TR \]

Number of trucks
\[ NOTE = \frac{CPY \times CY}{OD \times CH \times CPT} \]

Availability Factor
\[ P_n = P_{nr} \times P_{nrr} \times C_r^n \]

Required number of trucks
\[ NOT = \frac{NOTE}{P_n} \]

- Waiting time (to load) (TWL)
- Loading time (TL)
- Hauling time (TH) Level speed
- Waiting time (to dump) (TWU) Bottleneck
- Dumping time (TD) Grade effect
- Returning time (TR)

- Demand capacity per year (CPY)
- Operating days per year (OD)
- Operating time per day (OH)
- Capacity per truck (CPT)

- The probability of a single unit being available \( P_{nr} \)
- The probability of a single unit not being available \( P_{nrr} \)
- The combinations of \( n \) things taken \( r \) at a time \( C_r^n \)
FIGURE 6.6: Reserved Truck Cost Calculations

Number of Reserved Trucks

Cost of Each Truck

Total Cost of Reserved Trucks

Depreciation

\[
\text{Total Reserved Truck Cost} = \frac{\text{Depreciation}}{\text{Truck Life}(=6)}
\]

Investment

\[
\text{Investment} = \text{Total Reserved Truck Cost} \times \frac{\text{Interest rate}}{2}
\]

\[
\text{(Truck Life +1 = 7)}
\]

\[
\text{Truck Life = 6}
\]

Total Annual Cost of Reserved Truck

\[
\text{Total Annual Cost of Reserved Trucks} = \frac{\text{Total Annual Cost of Reserved Trucks}}{\text{Total Demand per Year}}
\]

Cost per Ton

\[
\frac{\text{Cost per Ton}}{\text{Mileage}} = \frac{\$\text{Ton}}{\$\text{Ton-Mile}}
\]
6.4. CAPITAL COST - DISCUSSION

As used here, capital costs refer to road construction and maintenance including total construction costs, engineering, right of way, earth works and drainage, structures and flexible pavement. Figure 6.7 provides an outline of the principle components. Figure 6.8 shows the costing model.

There have been no great technological changes in road construction, therefore, cost data for road construction taken from Federal-Aid projects for 1964 have been used. These include six different types of roads and ten geographic divisions. The cost data were adjusted for inflation. Road maintenance data are based on the same source.
FIGURE 6.7: Capital Cost Components

Capital Cost
- Road Construction Cost
  - Interstate Rural
  - Interstate Urban
  - Primary Rural
  - Primary Urban
  - Secondary Rural
  - Secondary Urban
  - Engineering
    - Right of Way
    - Earthwork & Drainage
    - Structures
    - Flexible Pavement

- Road Maintenance Cost
  - Interstate Rural
  - Interstate Urban
  - Primary Rural
  - Primary Urban
  - Secondary Rural
  - Secondary Urban
  - Roadside & Drainage
    - Surface and Base
    - Shoulders
    - Structures
    - Traffic Services
    - Snow, Ice and Sand Control
FIGURE 6.8: Construction Cost Flow Chart

\[ \text{CCR} = \sum_{i=1}^{6} (\text{CR}_i \times \text{MR}_i) \]

**TABLE 6.3**

Total Construction Cost

Data Adjustment Factor

- Purchasing Power (1964)
- Update Purchase Power

Depreciation

\[ \frac{\text{Total Construction Cost}}{\text{Road Life (}=30)} \]

\[ \text{Total Construction Cost} \times \text{Interest Rate} \times \frac{(\text{road life} + 1)}{2} = 31 \]

\( \text{road life} = 30 \)

Total Annual Cost of Construction

Total Annual Cost for Construction

Cost per Ton

\$/Ton

Total Demand Per Year

\$/Ton-Mile

Cost per Mileage
6.5 CAPITAL COST - MODEL

6.5.1 Road Construction Cost

6.5.1.1 Total construction cost. This follows the pattern indicated below.

<table>
<thead>
<tr>
<th>Type of Road</th>
<th>TABLE 6.3</th>
<th>Cost/Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
CCR = \sum_{i=1}^{6} \left( CR_i \times MR_i \right)
\]

\[
(CR_1 \times MR_1 + CR_2 \times MR_2 + \ldots + CR_6 \times MR_6)
\]

CR = cost of each type of road per mile

CCR = total construction cost of road

CR = cost of each type of road per mile

MR = mileage of each type of road

xx1 = interstate rural highway

xx2 = interstate urban highway

xx3 = primary rural highway

xx4 = primary urban highway

xx5 = secondary rural highway

xx6 = secondary urban highway

6.5.1.2 Data adjustment factors. This inflation adjustment is based on the relative wholesale prices found in the Survey of Current Business.
\[ FR = \frac{1}{DV} \]

\( FR = \) adjustment factor

\( DV = \) current dollar value compared to base value

6.5.1.3 Annual depreciation and interest on road construction.

\[ CARC = \frac{CCR \times FR}{LOR} + \frac{INT \times (LOR + 1)}{2 \times LOR} \times CCR \times FR \]

\( CACR = \) total construction cost per year

\( INT = \) interest

\( LOR = \) average life of road

6.5.1.4 Unit Cost ($/ton):

\[ C_{ht} = \frac{CARC}{CPY} \]

\[ CTMR = \frac{CTR}{MT} \]

\( CTR = \) cost of road construction per ton

\( CTMR = \) cost of road construction per ton per mile

\( MT = \) mileage between plant and mine

6.5.2 Road Maintenance Cost

Figure 6.9 shows the flow necessary for these calculations.

6.5.2.1 Model of road maintenance costs.
6.5.2.1.1 Total maintenance cost:

The flow of these maintenance costs is seen directly below.

Type of Road ➔ TABLE 6.4 ➔ Cost/Mile

CCM = \sum_{i=1}^{6} CM_i \times MR_i
CCM = total maintenance cost of road
CM = cost of each type of road per mile
MR = mileage of each type of road
i=1 = interstate rural highway
i=2 = interstate urban highway
i=3 = primary rural highway
i=4 = primary urban highway
i=5 = secondary rural highway
i=6 = secondary urban highway

6.5.2.1.2 Data adjustment factors:

FR = \frac{1}{DV}
FR = adjustment factor
DV = current dollar value compared to base value
6.5.2.1.3 Unit costs:

\[ \text{CTRM} = \frac{\text{CCM} \times \text{FR}}{\text{CPY}} \]

\[ \text{CTRMM} = \frac{\text{CTM}}{\text{MT}} \]

CTRM = cost of road maintenance per ton

CTRMM = cost of road maintenance per ton-mile

MT = mileage between plant and mine
TABLE 6.3: Cost of Road Construction

<table>
<thead>
<tr>
<th>Type of Road</th>
<th>Dollars per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate Rural</td>
<td>$751,000</td>
</tr>
<tr>
<td>Interstate Urban</td>
<td>$3,198,000</td>
</tr>
<tr>
<td>Primary Rural</td>
<td>$318,000</td>
</tr>
<tr>
<td>Primary Urban</td>
<td>$600,000</td>
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<tr>
<td>Secondary Rural</td>
<td>$136,000</td>
</tr>
<tr>
<td>Secondary Urban</td>
<td>$175,000</td>
</tr>
</tbody>
</table>

Source: [9]

Includes: engineering, right of way, earthwork and drainage, structures, flexible pavement

Note that dollars/ton/mile are simple averages of the ten geographic areas. For more detailed work, the original source should be used.
**TABLE 6.4: Road Maintenance Costs**

<table>
<thead>
<tr>
<th>Type of Road</th>
<th>Dollars per mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate Rural</td>
<td>$3,233</td>
</tr>
<tr>
<td>Interstate Urban</td>
<td>$6,677</td>
</tr>
<tr>
<td>Primary Road</td>
<td>$2,358</td>
</tr>
<tr>
<td>Primary Urban</td>
<td>$4,484</td>
</tr>
<tr>
<td>Secondary Rural</td>
<td>$850</td>
</tr>
<tr>
<td>Secondary Urban</td>
<td>$1,979</td>
</tr>
</tbody>
</table>

Source: [9]

Includes: Roadside and drainage, surface and base, shoulder, structures, traffic services, snow, ice and sand control.

Note that dollars/ton/mile are simple averages of the ten geographic areas. For more detailed work, the original source should be used.
FIGURE 6.9: Road Maintenance Flow Chart

Table 6.4

Total Maintenance Cost

\[ C_{CM} = \sum_{i=1}^{6} C_{M_i} \times M_{R_i} \]

Data Adjustment Factor Equals

\[ \frac{\text{Wholesale Price Index 1964}}{\text{Wholesale Price Index 1976}} \]

Total Annual Cost of Maintenance

Total Annual Cost for Maintenance

\[ \frac{\text{Total Demand Per Year}}{\text{Cost per ton}} \]

\[ \frac{\text{Total Demand Per Year}}{\text{Mileage}} \]

$/Ton $/Ton-Mile
The total cost model is the aggregation of each of the parts described above. The flow chart (Figure 6.10) indicates the procedure.

Total capital investment cost (CTCI)

\[
CFC1 = \frac{(Y44M + Y4M)}{2} \times MT \times 2 \times \text{NOTE} \times \frac{OH/CY}{OD/100}
\]

CTCI1 = \(CFC1 / \left(1 / OY + \text{INT} \times (OY + 1) / 2 / OY\right)
+ (\text{NOTE} - \text{NOTE}) \times \text{PT} \times \frac{OY/LOT + \text{CCR} \times \text{FR}}{\text{PC}}
\]

CTCI = 1.1 \times CTCI1

CwCA = CTCI1 \times 0.1 \times \text{INT} \times \frac{(OY + 1) / OY}{2}

CFC = CFC1 + CwCA

CwCA = annual working capital cost

CFC = annual depreciation and interest

OY = number of years of operation

Annual operating costs (Section 6.3)

COPT = COPYh \times MT + CTT + \frac{CWCA}{CPY}

COPY = COPT \times CPY

Annual road costs (Section 6.4, 6.5)

CRY = (CTRM + CTR) \times CPY

Annual reserved truck costs (Section 6.3.9)

CTTY = CTT \times CPY
Total cost per ton

\[ CT = CUP1 + (CTR + CTRM) \times PC \]

Total cost per ton per mile

\[ CTM = \frac{CT}{\text{MT}} \]

Annual total cost per year

\[ CTY = CT \times CPY \]

Note that PC equals the percentage of road cost which is included in total cost. This percentage will vary with the relative use of the road by coal trucks compared with all other traffic. If no user cost is desired, it can be set equal to zero. Alternatively, a road use study can be made for the specific routes in question.
FIGURE 6.10: Total Cost Flow

Capital Cost → Road Cost → Data Adjustment → Annual Ownership Cost for Road

Number of Trucks → Reserved Truck Cost → Annual Ownership ($/ton) → Total Cost per ton
Operating Cost → Data Adjustment → Annual Operating Cost → Total Cost per ton/mile
This computer truck cost model was formulated for general use. Costs as well as other parameters are included in the attached table. The reader can substitute his own values by changing the values in the data file. If any item is not to be included a zero can be inserted to eliminate it. For example, if road cost and maintenance are to be omitted, a zero must be put in the data file. In addition, this model can be easily adjusted to represent any particular year by changing the inflation factor. The particular case presented here was run with data obtained from a private truck company.

The most common type of rear dump over the road truck used for coal hauling was a five axle, diesel engine type. It cost about $50,000, and had an average life of eight years. Its loaded capacity was 23 tons with an unloaded weight of 12 tons.

In the mine area, loading time was estimated at 0.015 hours. The unloading time was 0.01 hours. The waiting time for loading and the waiting time for unloading were about the same; 0.05 hours. Normal road speed was estimated to be 45 miles per hour. A ten percent bottle-neck condition was assumed with the bottle-neck speed assumed to be 10 miles per hour. Other values are estimated in the model. The specific parameters are as follows.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>3 axles</th>
<th>5 axles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck Price ($)</td>
<td>25,000-30,000</td>
<td>50,000-55,000</td>
</tr>
<tr>
<td>Life (yrs)</td>
<td>6-8</td>
<td>8-10</td>
</tr>
<tr>
<td>Rear Dump</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Engine</td>
<td>gas or diesel</td>
<td>diesel</td>
</tr>
<tr>
<td>Transmission</td>
<td>manual</td>
<td>manual</td>
</tr>
<tr>
<td>Tire (type)</td>
<td>10-120</td>
<td>10-120</td>
</tr>
<tr>
<td>Capacity</td>
<td>12 ton (24 Kips)</td>
<td>23 ton (46 Kips)</td>
</tr>
<tr>
<td>Loading time (hrs)</td>
<td>0.009-0.017</td>
<td>0.009-0.017</td>
</tr>
<tr>
<td>Unloading time (hrs)</td>
<td>0.009-0.017</td>
<td></td>
</tr>
<tr>
<td>Waiting Time load (hrs)</td>
<td>0.03-0.05</td>
<td>0.03-0.05</td>
</tr>
<tr>
<td>Waiting time unload (hrs)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Private Company
Input data file - FORTRAN IV

*The Number of Trucks Required

Input Data for Cycle Time

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT</td>
<td>Mileage between mine and plant</td>
<td>mile</td>
</tr>
<tr>
<td>PL</td>
<td>% of total mileage on level</td>
<td>*</td>
</tr>
<tr>
<td>VL</td>
<td>Level speed (regular speed)</td>
<td>mile/hr</td>
</tr>
<tr>
<td>PU</td>
<td>% of total mileage on up-grades</td>
<td>*</td>
</tr>
<tr>
<td>VU</td>
<td>Up-grade speed</td>
<td>mile/hr</td>
</tr>
<tr>
<td>PD</td>
<td>% of total mileage on down-grade</td>
<td>*</td>
</tr>
<tr>
<td>VD</td>
<td>Down-grade speed</td>
<td>mile/hr</td>
</tr>
<tr>
<td>PB</td>
<td>% of total mileage at bottle-neck</td>
<td>*</td>
</tr>
<tr>
<td>VB</td>
<td>Bottle-neck speed</td>
<td>mile/hr</td>
</tr>
<tr>
<td>TWL</td>
<td>Waiting time (loading)</td>
<td>hr</td>
</tr>
<tr>
<td>TWD</td>
<td>Waiting time (dumping)</td>
<td>hr</td>
</tr>
<tr>
<td>TL</td>
<td>Loading time</td>
<td>hr</td>
</tr>
<tr>
<td>TD</td>
<td>Dumping time</td>
<td>hr</td>
</tr>
</tbody>
</table>

Input Data for Operating Capacity

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPY</td>
<td>Demand capacity per year</td>
<td>tons/year</td>
</tr>
<tr>
<td>CPT</td>
<td>Truck capacity</td>
<td>tons/truck</td>
</tr>
<tr>
<td>OH</td>
<td>Operating time per day</td>
<td>hrs/day</td>
</tr>
<tr>
<td>OD</td>
<td>Operating days per year</td>
<td>days/year</td>
</tr>
<tr>
<td>PY</td>
<td>Probability of hauling exactly n units</td>
<td>*</td>
</tr>
</tbody>
</table>
**Input Data for Capital Cost**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1</td>
<td>Road construction cost for interstate rural highway</td>
<td>$/Mile</td>
</tr>
<tr>
<td>CR2</td>
<td>Road construction cost for interstate urban highway</td>
<td>$/Mile</td>
</tr>
<tr>
<td>CR3</td>
<td>Road construction cost for primary rural highway</td>
<td>$/Mile</td>
</tr>
<tr>
<td>CR4</td>
<td>Road construction cost for primary urban highway</td>
<td>$/Mile</td>
</tr>
<tr>
<td>CR5</td>
<td>Road construction cost for secondary rural highway</td>
<td>$/Mile</td>
</tr>
<tr>
<td>CR6</td>
<td>Road construction cost for secondary urban highway</td>
<td>$/Mile</td>
</tr>
<tr>
<td>MR1</td>
<td>Mileage of interstate rural highway</td>
<td>Mile</td>
</tr>
<tr>
<td>MR2</td>
<td>Mileage of interstate urban highway</td>
<td>Mile</td>
</tr>
<tr>
<td>MR3</td>
<td>Mileage of primary rural highway</td>
<td>Mile</td>
</tr>
<tr>
<td>MR4</td>
<td>Mileage of primary urban highway</td>
<td>Mile</td>
</tr>
<tr>
<td>MR5</td>
<td>Mileage of secondary rural highway</td>
<td>Mile</td>
</tr>
<tr>
<td>MR6</td>
<td>Mileage of secondary urban highway</td>
<td>Mile</td>
</tr>
<tr>
<td>DV</td>
<td>Current dollar value compared with base value (1967)</td>
<td>x</td>
</tr>
<tr>
<td>INT</td>
<td>Interest</td>
<td>x</td>
</tr>
<tr>
<td>LOR</td>
<td>Road life</td>
<td>Year</td>
</tr>
<tr>
<td>CM1</td>
<td>Maintenance cost of interstate rural highway per mile</td>
<td>$/Mile</td>
</tr>
<tr>
<td>CM2</td>
<td>Maintenance cost of interstate urban highway per mile</td>
<td>$/Mile</td>
</tr>
</tbody>
</table>

6-38
CM3  Maintenance cost of primary  
      rural highway per mile  
      $/Mile  F

CM4  Maintenance cost of primary  
      urban highway per mile  
      $/Mile  F

CM5  Maintenance cost of secondary  
      rural highway per mile  
      $/Mile  F

CM6  Maintenance cost of secondary  
      urban highway per mile  
      $/Mile  F

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>XA</td>
<td>KP</td>
<td>F</td>
</tr>
<tr>
<td>XB</td>
<td>KP</td>
<td>F</td>
</tr>
<tr>
<td>FR1</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FR11</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FR2</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FR3</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FR4</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FR5</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>PT</td>
<td>$/each</td>
<td>F</td>
</tr>
<tr>
<td>LOT</td>
<td>year</td>
<td>F</td>
</tr>
<tr>
<td>FV</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FB</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FU</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>FD</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>PC</td>
<td>*</td>
<td>F</td>
</tr>
<tr>
<td>OY</td>
<td>*</td>
<td>F</td>
</tr>
</tbody>
</table>
REFERENCES


***CPU***

**NO. OF TRUCK REQUIRED**

**CALCULATE CYCLE TIME OF TRUCK**

**IH** : TIME FOR Hauling
**IT** : TIME FOR RETURN
**TL** : PERCENTAGE OF TOTAL MILEAGE AT LEVEL
**PU** : PERCENTAGE OF TOTAL MILEAGE AT HUNGRY HOGS
**PD** : PERCENTAGE OF TOTAL MILEAGE AT ROLLING
**VL** : LEVEL SPEED (REGULAR SPEED)
**VU** : RISE SPEED
**VB** : ROLLING SPEED
**ML** : MILEAGE BETWEEN HIRE & PLANT
**TB** : TIME DURING BOTTLE-NECK
**PB** : PERCENTAGE OF TOTAL MILEAGE AT BOTTLE-NECK
**VB** : BOTTLE-NECK SPEED
**CT** : TOTAL CYCLE TIME
**TL** : TIME OF WAITING TO LOAD
**TD** : TIME OF WAITING TO DUMPING
**TU** : TIME FOR LOADING

**REAL AT/RT/NOTE/INT/LOC/LOF**

**REAL WASTE/VASA/KASHI/RAM/ORDR/ARM/DER/PAD/HAB/AD**

**COMPUTER USAGE FOR MILIL TRUCK ACCESS/CAST**

**COMPUTER 6/DEVICE TDC, T/ICE TOUT/DATE/ACCESS/SECURITY**

**INPUT DATA**

**REAL (G8,1) ML, VL, FU, VU, PB, VD, PB, VD**

**WRITE (G8,1) ML, VL, FU, VU, PB, VD, PB, VD**

**FORMAT (G8,1)**

**TH** — ML, VL, FU, VU, PB, VD, PB, VD

**TB** — ML, VU, PB

**TR** — TH
**0500**  Dimensions and Unit Initials

**0510**  READ (0703) CRY, CPT, GD, JD, FY

**0520**  WRITE (0703) CRY, CPT, GD, JD, FY

**0530**  33  FORMATTED I/O

**0540**  NOTE - (CRY, GD, FD) / (CRY, FY)

**0700**  REAL TRUCK NUMBER

**0900**  REAL TRUCK NUMBER

**0130**  REAL TRUCK NUMBER

**0240**  REAL TRUCK NUMBER

**0350**  NOT - SIZE OF CRY

**0460**  NOT - (FY)  Probability of Hauling Exactly N Units Available

**0570**  NOT - NOT/FY
**************  CRITICAL COST**

************** CONSTRUCTION COST OF ROAD**

************** TOTAL CONSTRUCTION COST**

************** CCR : TOTAL CONSTRUCTION COST OF ROAD**

<table>
<thead>
<tr>
<th>CR : COST OF CERTAIN TYPE ROAD PER MILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1 : MILEAGE OF EACH TYPE ROAD</td>
</tr>
<tr>
<td>XX1 : INTERSTATE RURAL HIGHWAY</td>
</tr>
<tr>
<td>XX2 : INTERSTATE URBAN HIGHWAY</td>
</tr>
<tr>
<td>XX3 : PRIMARY RURAL HIGHWAY</td>
</tr>
<tr>
<td>XX4 : PRIMARY URBAN HIGHWAY</td>
</tr>
<tr>
<td>XX5 : SECONDARY RURAL HIGHWAY</td>
</tr>
<tr>
<td>XX6 : SECONDARY URBAN HIGHWAY</td>
</tr>
</tbody>
</table>

************** INPUT DATA FOR DIFFERENT ROAD COST**

12700 READ(5,53) CR1,CR2,CR3,CR4,CR5,CR6
12800 WRITE(6,53) CR1,CR2,CR3,CR4,CR5,CR6
12900 56 FORMAT(6X,3F)

************** INPUT DATA FOR DIFFERENT ROAD MILEAGE BUILT**

13700 READ(5,57) MR1,MR2,MR3,MR4,MR5,MR6
13800 WRITE(6,57) MR1,MR2,MR3,MR4,MR5,MR6
13900 57 FORMAT(6X,3F)

************** INPUT DATA FOR DEPRECIATION & INTEREST**

14700 READ(5,63) DV,INTER,LOR
14800 WRITE(6,63) DV,INTER,LOR
14900 58 FORMAT(6X,3F)


************** DATA ADJUSTMENT FACTOR**

15400 **FR : ADJUSTMENT FACTOR**

15500 * DV : CURRENT DOLLAR VALUE COMPARING WITH BASE VALUE

15600 FR = 1/DV
**DEFRECIATION & INTERESTMENT OF ROAD CONSTRUCTION PER YEAR**

**CMAC : TOTAL CONSTRUCTION COST PER YEAR**

**INT : INTEREST**

**LOR : LIFE OF ROAD**

CMAC = (CMAC/INT) + INT*(LOR+1)*CMAC/INT/(LOR+2)

**UNIT COST (6, 10, 14)**

**CTR : COST OF ROAD CONSTRUCTION PER TON**

**CTRM : COST OF ROAD MAINTENANCE PER TON PER MILE**

CTR = CMAC/CMY

CTRM = CTR/MT

**MAINTENANCE COST OF ROAD**

**TOTAL MAINTENANCE COST**

**LOR : TOTAL MAINTENANCE COST OF ROAD**

**CMY : COST OF CONSTRUCTION OF ROAD PER MILE**

**MT : MILEAGE OF EACH TYPE ROAD**

**INPUT DATA FOR DIFFERENT ROAD MAINTENANCE COST**

READ(0,5Y) CM1,CM2,CM3,CM4,CM5,CM6

WRITE(0,5Y) CH1,CH2,CH3,CH4,CH5,CH6

FORMAT(5,5F)

CCN = CH1+CH1+CM2+CM2+CM3+CM3+CM4+CM4+CM5+CM5+CM6+CM6

**UNIT COST**

**CTR : COST OF ROAD MAINTENANCE PER TON**

**CTRM : COST OF ROAD MAINTENANCE PER TON PER MILE**

**MT : MILEAGE BETWEEN PLANT & MINE**

CTRM = CCN/CMY

CTRM = CTR/MT
**CALCULATE OPERATING COST OF TRUCK**

1. \( X_a \) : GROSS WEIGHT OF LOADED TRUCK
2. \( X_l \) : GROSS WEIGHT OF UNLOADED TRUCK
3. \( F_t \) : TON TRUCK (TON)
4. \( Y_1 \) : MAINTENANCE COST FOR LOADED TRUCK (FTN)
5. \( Y_2 \) : MAINTENANCE COST FOR UNLOADED TRUCK (FTN)
6. \( Y_3 \) : ADJUSTED MAINTENANCE COST OF TRUCK FOR LOADED TRUCK
7. \( Y_2 \) : UNLOADED TRUCK
8. \( Y_4 \) : ADJUSTMENT FACTOR FOR MECHANIC
9. \( Y_5 \) : ADJUSTMENT FACTOR FOR REPAIR PARTS
10. \( Y_6 \) : TIME COST OF TRUCK FOR LOADED TRUCK
11. \( Y_7 \) : TIME COST OF TRUCK FOR UNLOADED TRUCK
12. \( Y_8 \) : ADJUSTED Y2
13. \( Y_9 \) : ADJUSTED Y3
14. \( Y_{10} \) : ADJUSTMENT FACTOR FOR FUEL CONSUMPTION
15. \( Y_{11} \) : COST OF DEPRECIATION AND INTEREST OF LOADED TRUCK (FTN)
16. \( Y_{12} \) : UNLOADED
17. \( Y_{13} \) : ADJUSTED Y4
18. \( Y_{14} \) : ADJUSTED Y4
19. \( Y_{15} \) : ADJUSTMENT FACTOR FOR DEPRECIATION & INTEREST
20. \( Y_{16} \) : COST OF DRIVER'S WAGES OF LOADED TRUCK (FTN)
21. \( Y_{17} \) : UNLOADED
22. \( Y_{18} \) : ADJUSTED Y5
23. \( Y_{19} \) : ADJUSTED Y5
24. \( Y_{20} \) : ADJUSTMENT FACTOR FOR DRIVER'S WAGE
25. \( Y_{21} \) : PARTIAL SUM OF OPERATING COST FOR LOADED TRUCK
26. \( Y_{22} \) : UNLOADED
27. \( Y_{23} \) : ADJUSTED INDIRECT & OVERHEAD COST FOR LOADED TRUCK
28. \( Y_{24} \) : UNLOADED

**MAINTENANCE COST**

1. \( \text{READ(5,61)} X_a, X_l, F_t, Y_1, Y_2, Y_3, Y_4, Y_5, Y_6, Y_7, Y_8, Y_9, Y_{10}, Y_{11}, Y_{12}, Y_{13}, Y_{14}, Y_{15}, Y_{16}, Y_{17}, Y_{18}, Y_{19}, Y_{20}, Y_{21}, Y_{22}, Y_{23}, Y_{24} \)

**TIRES AND TUBES COST**

1. \( Y_2 = 1.74 - 0.01 * X_a + 0.00044 * Y_2 \)
2. \( Y_{22} = 1.74 - 0.01 * X_a + 0.00044 * X_l + Y_2 \)
3. \( Y_{22} = F_{R2} + Y_2 \)
4. \( Y_{22} = F_{R2} + Y_{22} \)
*********** COST OF FUEL

Y3 = 2.77*0.0014*100
Y3 = 2.77*0.004*100
Y3M = FR3*Y3
Y3A = FR3*Y3

*********** DEPRECIATION & INTEREST

Y4 = 0.06*0.1+0.005*Y4
Y4M = FR4*Y4
Y4A = FR4*Y4

*********** DRIVER'S WAGES & SUBSTANCE

Y5 = 14.1+0.02*Y4
Y5M = FR5*Y5
Y5A = FR5*Y5

*********** COST OF INDIRECT & OVERHEAD

Y10h = Y10h+13h+Y4+Y5h
Y10h = Y10h+13h+Y4+Y5h
Y10h = Y10h+(0.40-0.0912*Y4)
Y11h = Y11h+(0.45-0.0912*Y4)

*********** COST OF RESERVED TRUCK

*********** CTTK : TOTAL RESERVED TRUCK COST PER YEAR

CTTK = TOTAL RESERVED TRUCK COST PER YEAR
CTT = FUEL OR TRUCK
LUI = SERVICE LIFE OF TRUCK
CTT = COST OF RESERVED TRUCK PER TON
CTTM = COST OF RESERVED TRUCK PER TON PER MILE

*********** DEFRECIATION & INTEREST

*********** Input Data

*********** UNIT COST ($/T0N)

UNIT COST ($/T0N)

CII = CTTM / CII
CTTM = CII / CII
**OPERATING COST ADJUSTED BY RUNNING SPEED & GRADES**

**YMC : TOTAL UPDATE OPERATING COST PER VEHICLE-MILE FOR LOAD**

**YMC0 : TOTAL OPERATING COST PER VEHICLE-MILE FOR UNLOADED TRUCK**

**COPL : OPERATING COST AT LEVEL**

**COBP : OPERATING COST AT BOTTLE-NECK CONDITION**

**COBD : OPERATING COST AT UP-GRADE**

**COBD : OPERATING COST AT DOWN-GRADE**

**FY : SPEED ADJUSTMENT FACTOR**

**FD : SPEED ADJUSTMENT FACTOR FOR BOTTLE NECK (FD-FY)**

**FC : COST ADJUSTMENT FACTOR FOR CRANE**

**FD : COST ADJUSTMENT FACTOR FOR UNLOADING**

**COTN : OPERATING COST PER TON PER MILE**

**COT : OPERATING COST PER TON**

---

**INPUT DATA**

READ(5,63) FY,FBD,FU,FD
WRITE(5,63) FY,FBD,FU,FD
FORMAT(5,63)

**YMC = YMC0*(1+FY) + YMC0*(1+FBD)*(1+FD)**

**YMC0 = YMC0*(1+FY) + YMC0*(1+FBD)**

**FOR 1/2 A LIGHT TRUCK = 1/2**

**COPL = FBD*FU**

**COBF = FBD*FU**

**COBP = FBD*FU**

**COTN = (COPL+COBP+FBD+FUCFDF)/CH**

---

**TOTAL COST**

**COTN : TOTAL COST PER TON**

**COTN : TOTAL COST PER TON PER MILE**

**COPY : ANNUAL COST FOR OPERATING**

**CNY : ANNUAL COST FOR ROAD**

**CITY : ANNUAL COST FOR RESERVED TRUCK**

**CTY : ANNUAL TOTAL COST PER YEAR**

**FC : THE PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST**

**CFC : ANNUAL DEPRECIATION & INTEREST**

**GTOY : ANNUAL OPERATING TON ESTIMATE**

**CUCR : ANNUAL RUNNING CAPITAL COST**

**CFC : ANNUAL DEPRECIATION & INTEREST**

---

**40290**
INPUT DATA FOR THE PERCENTAGE OF ROAD COST

CUB: 1.57
CUB = CTU14 +.1 INT (CY1.)/OY2.
CUB = CUB
CUB = CUB FOR HEAVY TRUCK
CT = CUB FOR HEAVY TRUCK
CTH = CT/15
COT = COUT
COTY = COTY
CY = CY

WRITE (6171) CT1, CT12, COTY, CY, CUB, COT, CT, CUB1, CUB2
INTERIO CT1, CT12, COTY, CY, CUB, COT, CT, CUB1, CUB2
FORMAT(20X) THE TOTAL COST PER TON TRUCKED
20 INT (30X) THE TOTAL COST FOR TON TRUCKED
20 TOTAL MILEAGE COST FOR TOTAL OPERATING COST \$1.1
20 TOTAL MILEAGE COST FOR HEAVY \$1.1
20 TOTAL MILEAGE COST \$1.1
20 TOTAL TRUCK COST \$10.1
20 TOTAL NUMBER OF TRUCKS 10.1
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SPECIFICATION FOR TRUCK TRANSPORTATION

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COST ANALYSIS FOR TRUCK TRANSPORTATION

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SPECIFICATION FOR TRUCK TRANSPORTATION

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<tr>
<td>Truck Capacity</td>
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<tr>
<td>Percentage of Road Cost Included in Total Cost</td>
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COST ANALYSIS FOR TRUCK TRANSPORTATION

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<thead>
<tr>
<th>Cost Description</th>
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<tbody>
<tr>
<td>The Total Cost Per Ton</td>
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SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1,711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 855,252.4
ANNUAL COST FOR ROAD = 245,595.5
ANNUAL RESERVED TRUCK COST = 384,982.2
TOTAL ANNUAL COST = 855,252.4
TOTAL CAPITAL INVESTMENT COST = 354,069,0.9
TOTAL NUMBER OF TRUCK = 28.6

SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 750,000
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1,711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 1,282,878.5
ANNUAL COST FOR ROAD = 0.0
ANNUAL RESERVED TRUCK COST = 457,473.3
TOTAL ANNUAL COST = 1,282,878.5
TOTAL CAPITAL INVESTMENT COST = 531,1036.4
TOTAL NUMBER OF TRUCK = 42.9
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 10000000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSTS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1.711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 1710504.7
ANNUAL COST FOR ROAD = 0.0
ANNUAL RESERVED TRUCK COST = 609964.4
TOTAL ANNUAL COST = 1710504.7
TOTAL CAPITAL INVESTMENT COST = 7081381.8

TOTAL NUMBER OF TRUCK = 57.2
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLENECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 1.711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 855252.4
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVED TRUCK COST = 30498.2
TOTAL ANNUAL COST = 555954.0
TOTAL CAPITAL INVESTMENT COST = 3540690.9
TOTAL NUMBER OF TRUCK = 28.6

SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
MILEAGE BETWEEN MINE AND PLANT = 25.0
REGULAR SPEED = 45.0
BOTTLENECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 0.857
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 428295.2
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVED TRUCK COST = 16859.1
TOTAL ANNUAL COST = 428295.2
TOTAL CAPITAL INVESTMENT COST = 1786071.1
TOTAL NUMBER OF TRUCK = 14.9
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
DISTANCE BETWEEN MINE AND PLANT = 10.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 5.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 0.344
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 172121.0
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVED TRUCK COST = 7275.6
TOTAL ANNUAL COST = 172121.0
TOTAL CAPITAL INVESTMENT COST = 733299.2
TOTAL DURER OF TRUCK = 6.6
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 50,000,000
MILEAGE BETWEEN MINE AND PLANT = 50,0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.1

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 2.227
TOTAL COST PER TON PER MILE = 0.045
ANNUAL COST FOR TOTAL OPERATING COST = 867,881.6
ANNUAL COST FOR ROAD = 245,951.5
ANNUAL RESERVE TRUCK COST = 30,498.2
TOTAL ANNUAL COST = 1,113,476.7
TOTAL CAPITAL INVESTMENT COST = 690,1690.9
TOTAL NUMBER OF TRUCK = 28.6
SPECIFICATION FOR TRUCK TRANSPORTATION

DETAILED CAPACITY PER YEAR = 500,000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
TOLL TRUCK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.2

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 2,743
TOTAL COST PER TON PER MILE = 0.055
ANNUAL COST FOR TOTAL OPERATING COST = 86,951.0
ANNUAL COST FOR ROAD = 24,559.1
ANNUAL RESERVABLE TRUCK COST = 34,498.2
TOTAL ANNUAL COST = 137,117.6
TOTAL CAPITAL INVESTMENT COST = 102,626.9
TOTAL NUMBER OF TRUCK = 28.6
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.1

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 2,370
TOTAL COST PER TON PER MILE = 0.047
ANNUAL COST FOR TOTAL OPERATING COST = 871624.1
ANNUAL COST FOR ROAD = 3132024.3
ANNUAL RESERVED TRUCK COST = 38498.2
TOTAL ANNUAL COST = 1184826.5
TOTAL CAPITAL INVESTMENT COST = 7897690.9
TOTAL NUMBER OF TRUCK = 28,690
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
DISTANCE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.2

LOST ANALYSTS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 3,029
TOTAL COST PER TON PER MILE = 0.061
ANNUAL COST FOR TOTAL OPERATING COST = 887995.9
ANNUAL COST FOR ROAD = 3132024.3
ANNUAL RESERVED TRUCK COST = 30498.2
TOTAL ANNUAL COST = 1514400.7
TOTAL CAPITAL INVESTMENT COST = 12254690.9
TOTAL NUMBER OF TRUCK = 28.6
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 1.711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 855252.4
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVED TRUCK COST = 36498.2
TOTAL ANNUAL COST = 855252.4
TOTAL CAPITAL INVESTMENT COST = 3543690.9
TOTAL NUMBER OF TRUCKS = 28.6

SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 1.718
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 859145.0
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVED TRUCK COST = 34647.1
TOTAL ANNUAL COST = 859145.0
TOTAL CAPITAL INVESTMENT COST = 3632185.5
TOTAL NUMBER OF TRUCKS = 31.9
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 6.0

COST ANALYSIS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 1.737
TOTAL COST PER TON PER MILE = 0.035
ANNUAL COST FOR TOTAL OPERATING COST = 868633.5
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVE TRUCK COST = 42697.5
TOTAL ANNUAL COST = 868633.5
TOTAL CAPITAL INVESTMENT COST = 3855203.8
TOTAL NUMBER OF TRUCK = 40.0
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 4.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1,737
TOTAL COST PER TON PER MILE = 0.035
ANNUAL COST FOR TOTAL OPERATING COST = 868,633.5
ANNUAL COST FOR ROAD = 245,595.1
ANNUAL RESERVOIR TRUCK COST = 42,697.5
TOTAL ANNUAL COST = 868,633.5
TOTAL CAPITAL INVESTMENT COST = 3,855,203.8
TOTAL NUMBER OF TRUCK = 40.0
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1,673
TOTAL COST PER TON PER MILE = 0.033
ANNUAL COST FOR TOTAL OPERATING COST = 836,512.9
ANNUAL COST FOR ROAD = 245,595.1
ANNUAL RESERVED TRUCK COST = 22,907.6
TOTAL ANNUAL COST = 836,512.9
TOTAL CAPITAL INVESTMENT COST = 3,344,994.0
TOTAL NUMBER OF TRUCKS = 21.5

SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1,711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 855,252.4
ANNUAL COST FOR ROAD = 245,595.1
ANNUAL RESERVED TRUCK COST = 30,498.2
TOTAL ANNUAL COST = 855,252.4
TOTAL CAPITAL INVESTMENT COST = 3,540,690.9
TOTAL NUMBER OF TRUCKS = 28.6
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500,000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTION

THE TOTAL COST PER TON = 1.748
TOTAL COST PER TON PER MILE = 0.035
ANNUAL COST FOR TOTAL OPERATING COST = 873,991.8
ANNUAL COST FOR ROAD = 245,591.5
ANNUAL RESERVED TRUCK COST = 380,881.9
TOTAL ANNUAL COST = 875,991.8
TOTAL CAPITAL INVESTMENT COST = 373,638.7
TOTAL NUMBER OF TRUCKS = 35.7
SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 23.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 1.711
TOTAL COST PER TON PER MILE = 0.034
ANNUAL COST FOR TOTAL OPERATING COST = 855252.4
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVE TRUCK COST = 300498.2
TOTAL ANNUAL COST = 855252.4
TOTAL CAPITAL INVESTMENT COST = 3549690.9
TOTAL NUMBER OF TRUCK = 28.6

SPECIFICATION FOR TRUCK TRANSPORTATION

DEMAND CAPACITY PER YEAR = 500000.0
MILEAGE BETWEEN MINE AND PLANT = 50.0
REGULAR SPEED = 45.0
BOTTLE-NECK SPEED = 10.0
TRUCK CAPACITY = 12.0
PERCENTAGE OF ROAD COST INCLUDED IN TOTAL COST = 0.0

COST ANALYSIS FOR TRUCK TRANSPORTATION

THE TOTAL COST PER TON = 2.927
TOTAL COST PER TON PER MILE = 0.359
ANNUAL COST FOR TOTAL OPERATING COST = 1463297.9
ANNUAL COST FOR ROAD = 2455951.5
ANNUAL RESERVE TRUCK COST = 35073.0
TOTAL ANNUAL COST = 1463297.9
TOTAL CAPITAL INVESTMENT COST = 4713125.8
TOTAL NUMBER OF TRUCK = 54.8
CAC Document No. 223

COMPARATIVE COAL TRANSPORTATION COSTS: AN ECONOMIC AND ENGINEERING ANALYSIS

PNEUMATIC TRANSPORT
Volume 7

by

Michael Rieber and Shao Lee Soo

Center for Advanced Computation
University of Illinois

August 1977
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The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the subject of this report.
Abstract

Based on past and current studies, a theoretical analysis of a coal carrying pneumatic pipeline is presented including: friction factors, minimum transport velocity and pipeline telescoping. A 3.5 mile, 200TPH, pilot facility is designed. Cost analyses are presented. These and the design are extrapolated to a 100 mile line, smaller coal sizes and greater throughput.
This report was prepared by the Center for Advanced Computation of the University of Illinois at Urbana-Champaign under USLM Contract No. J0166163. The contract was initiated under the Office of University Relations. It was administered under the technical direction of the Division of Interindustry Analysis with Mr. Ronald Balazik acting as the Technical Project Officer. Mr. Robert Carpenter was the contract specialist for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period May 1976 to August 1977. This report was submitted by the authors on August 1977.

This volume is a part of the eight volume report completed for this contract. The draft final report was submitted in May 1977.

The principal authors, Michael Rieber and Shao Lee Soo, are, respectively, Research Professor, Center for Advanced Computation, the Graduate College; and Professor of Mechanical Engineering, College of Engineering; both at the University of Illinois at Urbana-Champaign.
Subject Inventions

This is to certify that, to the best of my knowledge and belief, there were no Subject Inventions made or have resulted from the performance of this contract.

August 1977

Michael Rieber
Principal Investigator
COMPARATIVE COAL TRANSPORTATION COSTS: AN ECONOMIC AND ENGINEERING ANALYSIS OF TRUCK, BELT, RAIL, BARGE AND COAL SLURRY AND PNEUMATIC PIPELINES

VOLUME 7

PNEUMATIC TRANSPORT

by

Michael Fieber and Shao Lee Soo
with
P. King, Y. T. King, T. Leung, H. Wu and J. Wu

prepared for

Bureau of Mines, Department of the Interior
and the
Federal Energy Administration
Contract No. J0166163

Center for Advanced Computation
University of Illinois
at Urbana-Champaign
Project 46-26-17-372

August 1977
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7. PNEUMATIC TRANSPORT

7.1 INTRODUCTION

A new mode of coal transportation based on the principles of pneumatic conveying has been recently proposed by Soo, et al. [5]. Pneumatic transport is not a novel concept and commercial experience with pneumatic pipelines for short haul distances is plentiful. The list of applications is long and includes transporting ores, chemicals and pharmaceutical products, agricultural products, and domestic and industrial wastes. The study by Soo, et al. [5] updated an earlier one [10] and presented the most recent economic evaluation of pneumatic transportation of coal. Their preliminary study concluded that there are immediate advantages for short-distance transport (less than 100 miles) and that it is both technologically and economically feasible. That study also concludes that pneumatic transport has a higher potential and more promising profitability in long-distance applications than rail if new track and roadbed must be built. Some of the advantages of long and short distance pneumatic pipeline transport of coal compared to rail and slurry transport are:

1) Replacement of diesel fuel consumed by unit trains, as the pipeline can be powered by coal-generated electricity;

2) Reduction of the skilled-labor costs required for upgrading and maintaining railroads;

3) Elimination of signaling, rerouting and overpass costs due to increased rail traffic on mainline trackage;

4) Elimination of wind loss of coal fines which occur with some coals during rail shipping, and its environmental and safety impacts;

5) Elimination of major loading and unloading facilities from mine mouth to plant delivery;

6) Reduction of storage space and facilities needed for continuous supply;

7) Elimination of the high cost of preparation and separation of coal slurry [13];

8) No water requirement and therefore none of the associated handling and environmental problem with which slurry pipelines must be concerned;
9) Power failures, pumping outages and their handling are not a problem when compared to slurry pipelines;

10) Suitability for the complete automation of the entire system by means of programmed remote control; and

11) Provision for flexibility of route design, for example:

a) shorter and more direct transportation routes,

b) improved profitability of railroads by serving as feeders from new mines and distributors to new consumers,

c) distribution from a large production coal mine to several small consumers, or feeding from multi-mine mouths to a large coal consuming gasification or liquefaction facilities can be served by simply branching the conduits using switching locks or rotary distributors,

d) gathering from mines to a rail head [15].

It appears that the most immediate application of a pneumatic pipeline is that of a conveyor system for coal transport in conjunction with the use of the right of way of a railroad system. Substitution of short distance coal haulage or transfer by pneumatic pipeline would eliminate loading and unloading features which involve both tight scheduling and significant costs. Pipeline augmentation of railroads as feeders and distributors, replacement of abandoned railroads, and short distance haulage all should be more cost competitive than capital and labor intensive railroads.

The U.S. Bureau of Mines has made two feasibility studies (1962, [10] 1967 [16]) of the pneumatic transport of coal. Based on the technical uncertainty of the compression of the coal-gas mixture, the confused state of pressure drop correlations and the unacceptable energy requirements of the system, both studies ruled out the technical as well as the economic feasibility of such application for large tonnages and long distance transport. However, the hypothetical model on which those conclusions were based was less than realistic. Operating an unsteady flow of pulverized coal and compressing the coal-gas
mixture to a pressure of 100 atmospheres undoubtedly lead to questions of operability and technical feasibility. High energy requirements resulted from the misused high loading ratio and the extrapolation of the friction factor from small scale laboratory work.

In this study, a conceptual design as well as an economic evaluation of pneumatic pipeline transport is developed and extended to a possible 3.5 mile pilot system. An economic analysis of the coal transport costs of a feeder (1000 ft) and an intermediate distance (100 miles) pneumatic pipeline is included for comparison.

A list of symbols used in this study is presented here for convenience.

**NOMENCLATURE**

<table>
<thead>
<tr>
<th>Letter</th>
<th>Symbols</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>Pipe cross-sectional area</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>Particle diameter</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Pipe diameter</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Gravitational constant</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Mass flow (M/A)</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Pipe roughness</td>
<td></td>
</tr>
<tr>
<td>k</td>
<td>Suspension parameter as defined in (7.3.7a)</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Pipe length</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>Mass flow rate</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Static pressure</td>
<td></td>
</tr>
<tr>
<td>δp</td>
<td>Pressure drop</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>Volumetric flow rate</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Gas constant</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Vs</td>
<td>Saltation velocity for single particle</td>
<td></td>
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</table>
Nominal velocity ($V/\rho A$)

Settling velocity of solids in an infinite fluid, as defined in [45]

Elevation

**Dimensionless Group**

<table>
<thead>
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<th>Description</th>
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<tbody>
<tr>
<td>$A$</td>
<td>Correlation constant as defined in (7.4.8)</td>
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<tr>
<td>$C_l$</td>
<td>Constant as defined in (7.3.4)</td>
</tr>
<tr>
<td>$C_D$</td>
<td>Drag coefficient, $4\pi d (\rho_p - \rho_f)/3\rho_f V^2$</td>
</tr>
<tr>
<td>$f$</td>
<td>Friction coefficient</td>
</tr>
<tr>
<td>$Fr$</td>
<td>Froude number ($V^2/d$)</td>
</tr>
<tr>
<td>$\dot{\bar{M}}$</td>
<td>Mass flow ratio ($\dot{m}_s/\dot{m}_f$)</td>
</tr>
<tr>
<td>$Re$</td>
<td>Pipe Reynolds' number ($VE/V$)</td>
</tr>
<tr>
<td>$S$</td>
<td>Exponential correlation constant as defined in (7.3.4)</td>
</tr>
<tr>
<td>$\rho^*$</td>
<td>Density ratio ($\rho_s/\rho_f$)</td>
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</tbody>
</table>

**Greek Symbols**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$\alpha$</td>
<td>Parameter as defined in (7.3.4)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>$d/6 = C_D Re_p^{2/3}$ Parameter defines the spread of the sizes of particles</td>
</tr>
<tr>
<td>$\delta$</td>
<td>$3V^2/4d (\rho^*-1)^{1/3}$, feet</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>Shape factor</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Pipe inclination</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Dynamic viscosity</td>
</tr>
<tr>
<td>$\omega$</td>
<td>$\frac{4}{3} a \sqrt{(p^* - 1)}^{1/3}$ ft/sec.</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Kinematic viscosity</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Density</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Correlation constant as defined in (7.4.10)</td>
</tr>
</tbody>
</table>

**Subscripts**

- **a**: Air
- **C**: Minimum transport condition
- **f**: Fluid
- **m**: Mixture
- **p**: Particle
- **s**: Solid
- **l**: Inlet
- **2**: Outlet
"Design of today's pneumatic conveying systems still hinges around the empirical approach, with particular emphasis on so called 'seat of the pants' engineering. Judgment and experience play a large part in specification and selection. Most know-how is closely held by the relatively few engineers who specialize in the pneumatic field."

This statement appeared in John Fischer's article, "Practical Pneumatic Conveyor Design" "Math Doesn't Tell Whole Story" [18,1958]. It illustrates the state of the art of pneumatic transport systems. The reason why pneumatic conveying has not yet come into general use seems to be traceable to the absence of a well-founded, precise, scientific theory which embraces all problems of detail and has undergone verification in practice. The variety of the physical properties of the materials being conveyed and the multiplicity of design possibilities hamper calculation by specific formulae and make research extremely expensive. The first installations were built mainly on an empirical basis adopting the results of research made by the industry, [19] or by extending and scaling up from current practice.

The details of such empirical methods are presented by Fischer [18] EEUU [19], Hudson [20,21,22], DallaValle [23], Bannister [24], and Gluck [25]. These authors present approximate methods and formulae for calculating the overall pressure drop in the gas-solid system, starting from a recommended superficial air (carrier gas) velocity based on the type of material conveyed. Typical of such tabulated data is that given in reference [19] page 61. Such data are, in fact, the air rate at which blockage occurs plus a margin established by practice and experience for the particular material listed. They can serve only as a rough guide for new situations and are useful only where subsequent adjustments can be readily made in operation and where efficiency is not of prime importance.
Pneumatic conveying is not a new field of development; experimental investigations on grains and other particulate material were first reported by Gasterstadt [26] as well as Cramp and Priestley [27] in 1924. Further investigations of the fundamental phenomena and design were motivated by the application of transporting coal and grains in pipelines. The bibliographical review compiled by Wendy A. Thornton [28] contains the most comprehensive literature survey of the fundamental research, application, and other related studies of pneumatic transport of solids in pipes. It should also be noted that Dukler, et al. [29] reported that by 1964, over 20,000 experimental data from various sources had been employed for obtaining correlations and generalizations of pressure drop, hold-up and friction factors. However, different approaches have been undertaken by theoretical investigators for their correlations and analyses of results. A representative, rather than an accumulative listing, includes:

1) Empirical correlations are the most commonly employed techniques.

2) Dimensional analysis has been used by Boothroyd [30], Jones and Hitchcock [31], Chowdhury [32], and Rose and Duckworth [33]. The work by Rose and Duckworth provides the most detailed and convincing solution for this type of approach.

3) An approach through the solution of equations of motion was presented in references [34,35].

4) Summation models which make a linear summation of the momentum of the two phases were considered by Soo [36], Peskin [37] and Trezck [38,39].

5) Continuum mechanics has been utilized by McCarthy and Olson [40].

6) A first trial of similarity analysis was claimed by Dukler, et al. [29] and

7) Statistical analyses have recently been employed [41,42].
Much arduous research has been reported, but the published results seem more useful to theoretical investigators whose interest lie in advancing the understanding of suspension flow, than to industrial designers and users whose primary concern is a workable application. Furthermore, the phenomena which occur in pneumatic conveying are too varied and too complex to be expressed in an equation of general form. For example, the solid friction factor, as presented in Rose and Duckworth's analysis, could be a function of thirteen variables or ten non-dimensional groups.

Symbolically:

\[
\begin{align*}
\left( f_s \right) &= F \left[ \rho_f', v, D, \mu, g, M_s, \rho_s, \epsilon, \alpha, k, z, \\
& \quad \beta, \Theta \right] \\
&= F \left[ \left( \frac{\rho_s V D}{\mu} \right), \left( \frac{V^2}{g D} \right), \left( \frac{M_s}{M_f} \right), \left( \frac{\rho_s}{\rho_f} \right), \\
& \quad \left( \epsilon \right), \left( \frac{d}{D} \right), \left( \frac{k}{D} \right), \left( z \right), \left( \beta \right), \left( \Theta \right) \right]
\end{align*}
\]

(Notations are explained in NOMENCLATURE)

Attempts made to generalize the empirical work have not been successful.

A comment of an earlier reviewer [43,1959] illustrates the problem:

"A good many of the experimental investigations reported had been aware of only a few of the many possible system variables, so that they dealt with a comparatively narrow range of conditions. As a result, most of the published data on gas-solid systems were restricted in scope and frequently conflicting. Also, scarcity of the fundamental information and the lack of uniformity of presentation made a comparative study of the experimental evidence extremely arduous."

7-8
In spite of considerable technical effort, the design of systems for the pneumatic transport of solids has not become an exact science. Nevertheless, a theoretical analysis and correlation of friction factor data for dilute gas-solid suspensions has been reviewed by Pfeffer, et al. [44]. While there is no reliable generalized design equation for pneumatic transport, Duckworth [45] has tabulated pressure gradients, and velocity correlations of dilute phase gas-solid flows, and discussed their pertinence to the application of design.

7.2.3 Minimum Transport Velocity

Of all the determinations to be made in designing a dilute gas-solid suspension system, the most fundamental one must be the establishment of the minimum permissible gas flow rate for a given system. This minimum must be high enough to prevent settling of solids, especially in a horizontal transport system, thus maintaining a steady flow condition. If the air flow rate is reduced below this value, it leads to unstable operation and the possibility of solid flow stoppage. On the other hand, operation of a system at a velocity which is too high leads to unnecessarily high power requirements. In either of these two extreme cases, the system operates uneconomically due to the frequent shutdown of the system in the former case, and to excessive power consumption in the latter.

The importance of establishing the minimum air flow as a fundamental design parameter is emphasized by the following:

1) Power requirements for gas-solid transport systems might be higher than those of more conventional conveyors;

2) Blower power requirements increase approximately as the cube of the gas velocity;

3) Pipe erosion increases significantly as gas velocity increases;

4) Particle size attrition.

7-9
Successful design depends, therefore, upon first establishing the minimum carrier gas velocity at which the material may be steadily conveyed. The successful prediction of the minimum gas velocity for any given system with a reasonable degree of certainty is a pre-requisite to an economical design.

Although most of the basic studies of the lift force on a particle in a gas-solid suspension treated cases of particle size smaller than the thickness of the laminar sublayer in the turbulent flow [46,47], these do not apply to the case of transport of large particles above millimeter size [5]. Using particles of size greater than the laminar sublayer thickness, Thomas [48] claims that his equation applies to all suspensions of particles which conform to the size criterion. However, the great complexity of his equation, coupled with the fact that it was developed from data obtained in rather small scale model tests, discourages the use of this correlation for design purposes. It is also interesting to note that there is a considerable overlap in the variables used in the correlations developed by Doig and Roper [49] (Equation 7.3.1), Duckworth [45] (Equation 7.3.2) and Matsumoto [50] (Equation 7.3.3) that the minimum transport velocity, \( V_c \), is related to the mass flow ratio, \( \alpha \), and the settling velocity of solids in an infinite fluid, \( V_s \).

\[
\frac{V_c}{\sqrt{(gD)}} = Fr_c = \left[ \log_e \left( \frac{V_c^{2/3}}{28} \right) \right] \times 0.25 \quad (7.3.1)
\]

\[
V_c = \left[ \frac{4gd(\rho_s - \rho)}{3c_D} \right]^{1/2} \quad 10 < V_c < 40 \text{ (ft/s)} \quad (7.3.1a)
\]

\[
Fr_c = \text{Constant} \times \alpha^{0.2} \times \left( \frac{D}{d} \right)^{0.6} \left[ \frac{V_c}{\sqrt{(gD)}} \right]^{0.5}
\]

\[
(7.3.2)
\]
\[ \text{Fr}_c = 10 \left( \frac{1}{11.1} \right)^{0.333} \cdot \left( \frac{10 \alpha}{1} \right)^{0.767} \cdot \rho^* \cdot \rho_{\text{m}}^{0.1833} \]

\[ \text{Fr} = 10 \left( \frac{1}{11.1} \right)^{0.333} \cdot \left( \frac{10 \alpha}{1} \right)^{0.767} \cdot \rho^* \cdot \rho_{\text{m}}^{0.1833} \]

\[ \left( \frac{V \alpha}{10 (gD)} \right)^{0.5} \]

(7.3.3)

where \( \rho^* \) is the material density ratio \( \frac{\rho_p}{\rho_g} \) of particle to gas, \( d \) is the particle diameter, \( D \) is the pipe diameter, \( g \) is the gravitational constant, and \( C_L \) is the drag coefficient of the particle.

Matsumoto, et al., claims that their equation also covers Barth's correlations which are extensively used for designing pneumatic wheat conveyors. However, they do not provide enough information for the formulation of our large scale system.

Zenzen [51] who claims his correlation is applicable to large scale coal conveying installations of 8 inch and 12 inch pipe diameters and coal sizes ranging from 200 mesh to less than \( \frac{3}{4} \) inch, is extended as follows for \( \rho > 10 \):

\[ \alpha = C_1 \rho^s \]

(7.3.4)

where \( C_1 = 0.90 \) for spherical particles and \( 0.5 \) for angular particles; \( s = 0.45 \), and

\[ \rho = \frac{d}{\delta} = \left[ C_D \text{Re}_p \right]^{1/3} \]

(7.3.5)

where

\[ \delta = \left[ \frac{3V^2}{4g} / (\rho^* - 1) \right]^{1/3} \text{ (ft.)} \]

and

\[ \alpha = V_s / u \text{D}_{\text{in}}^{0.5} \]

(7.3.6)

where

\[ u = \left[ \frac{4gV}{3} (\rho^* - 1) \right]^{1/3} \text{ (ft/s)} \]

(7.3.6a)
\( D_{\text{in}} \) is pipe diameter in inches; other groups are dimensionless. Here \( \rho^*_s \) is the material density ratio of solid gas; \( \nu \), kinematic viscosity of the gas; \( g \), gravitational constant; and \( V_s \), minimum suspension velocity of a single particle. For the mass flow ratio of particle \( \rho_D U_D \), and for minimum transport velocity, \( V_c \) in fps, Zenz suggested an approximate relation:

\[
\frac{M_p}{\left(\frac{\pi}{4}\right) D^2 \rho_D} = 0.7 S^{1.5} \left[ \frac{V_c}{V_s} - 1 \right]
\]

(7.3.7)

Soo went still further to include a suspension parameter \( k \), in his formulation [5], so that

\[
\frac{M_p}{\left(\frac{\pi}{4}\right) D^2 \rho_D} = 0.7k S^{1.5} \left[ \frac{V_c}{V_s} - 1 \right] = \frac{\dot{m}^* V_c}{\bar{\rho}}
\]

(7.3.7a)

Correlation of the Konchesky data obtained from a large scale experimental model, with the above relations on suspension velocity shows that the distribution in particle size of coal in his tests is represented by \( d = \frac{1}{16} \) inch (1.6mm) with flow velocity \( V \) above the value of \( V_c \) obtained from Equation (7.3.7a). In that equation, the suspension parameter ranges from 1 to 10, and is consistent with the largest capacity data of Konchesky [54]. The calculated values of the parameters in his case are:

\[
\dot{M}_p = 55 \text{ tons/hr}
\]

\[
\dot{m}^* = 7.32
\]

\[
f_a = 0.0031824
\]

\[
f_m = 0.009385
\]

\[ k \geq 0.81 \text{ for } 1/16'' \text{ coal} \]

\[ k \geq 7.084 \text{ for } 1-1/2'' \text{ coal} \]
Based on the data of the Radmark Pneumatic Conveying System [55] which represents a current and workable system, further correlation results also fall into this range of suspension parameter values. The calculated values of the parameters in this case are:

\[ Q_a = 2000 - 12000 \text{ cfm at 15 psi} \]
\[ f^* = 6.0 - 6.61 \]
\[ f_m = 0.004 - 0.009181 \]
\[ k > 2.733 - 5.551 \text{ for 3" particle} \]

7.2.4 Friction Factor

Duckworth [45] recently identified some of the representative correlations on pressure gradients and also discussed their practicality for design purposes. Pfeffer, et al. [44], have done an extensive systematic study on pressure drop correlations with suspension in pipe flow. In both studies, due to the different independent variables correlated and the wide range of scattered data involved, no general correlation was deduced, but some trends were noted.

For our study, with reference to a previous investigation [5], some basic design limits on the friction factor, which will be extended to recent results and practice, is presented in the following: For isothermal pipe flow of a gaseous suspension in the system with pipe diameter \( D \), length \( L \), elevation \( z \) at one end, and the total flow of solids and air, \( \dot{m}_D \) and \( \dot{m}_A \) respectively, the pressure drop \( dP \) over a length \( dx \) is given by:

\[ dP = -4 f_m \frac{(d^2)}{D} \left[ \rho \cdot \frac{(v^2/2)}{2} \right] - \left[ d (\rho_m v^2) \right] - \rho_m \cdot g \cdot dz \]

(7.4.1)

where \( f_m \) is the friction factor of the mixture of solid and gas; \( v \), gas velocity; \( \rho_m \), density of
mixture; \( \rho_m = \rho + \rho_p \); \( g \), gravitational constant for \( \rho g \) in \( \text{lbm/ft}^3 \) (\( \rho \) in \( \text{kg/m}^3 \)); and \( dz \), the rise in elevation of \( dx \). In Equation (7.4.1), the first term on the right-hand side is the pressure drop due to friction; the second term, acceleration; and the third term, the gravity effect due to elevation. Note that mass flow \( G \) is given by

\[
\rho_1 V_1 = P_2 V_2 = V = \frac{M_a}{(\pi/4)D^2} = G
\]

(7.4.2)

Subscript 1 denotes inlet and 2, outlet.

The friction factor of turbulent pipe flow of a simple fluid, e.g., air, in a smooth pipe is given by

\[
f_a = 0.046/Re^{0.2}
\]

(7.4.3)

where the Reynolds number \( Re \) is given by

\[
Re = \frac{DpV}{\mu} = \frac{DG}{\mu}
\]

(7.4.4)

where \( \mu \) is the viscosity of the gas.

For small changes in pressure or density of the gas phase, Equation (7.4.1) is integrated as an incompressible fluid:

\[
P_1 - P_2 = 4f_m L \frac{G^2}{2p} + 1+M^* \rho (V_2^2 - V_1^2) + \\
(1+M^*) \rho g z
\]

(7.4.5)

for small \( \phi \), \( P = P \) of the gas.

\[
1 - \left(\frac{P_2}{P_1}\right)^2 = 4f_m \left(\frac{L}{D}\right) \left(\rho_1^2 V_1^2 \frac{RT}{P_1^2}\right) \\
+ (1+M^*) (2G^2 \frac{RT}{P_1}) \ln(P_1/P_2) \\
+ (1+M^*) (2 P^2 g z/RTP_1^2)
\]

(7.4.6)

for inlet pressure \( P_1 \) and velocity \( V_1 \); \( P = (P_1 + P_2)/2 \).
Soo used Equation (7.4.5) to evaluate the data of Konchesky [52] obtained from the vacuum transport of crushed coal. Data for \( \frac{f_m}{f_a} \) versus Re are shown in Figure 7.1 with ranges of \( M^* \) and pipe size as indicated. Experiments by Sproson, et al. [53], show ranges similar to Konchesky's. Shown in Figure 7.2 are the evaluated data of the straight run of pipes based on Konchesky's study of pressure transport of crushed coal [54]. Also included is the evaluated practical range of the gas-solid mixture friction factor based on the data from the Radmark Pneumatic Conveying System [55]. In this plot, it should be noted that the drag reduction characteristic of the gas-solid flow is a phenomena which still needs investigation. The order of magnitude of the value of the friction factor shows reasonably good agreement with the value of the specific pressure drop defined by J.D. Constance [58] for industrial application.

Equation (7.4.7) shows that when the operating pressure of a pneumatic pipeline is high, the pressure drop due to acceleration and elevation (in hundreds of feet) for a pipeline of many miles in length become minors and the main pressure drop is that of friction:

\[
1-\left(\frac{p_2}{p_1}\right)^2 = 4 f_m \left(\frac{L}{D}\right) \left(\frac{V_1^2}{RT_1}\right) \tag{7.4.7}
\]

for an isothermal flow with velocity \( V_1 \) and temperature \( T_1 \) at the inlet. The gas temperature \( T \) tends to be a constant value for a long distance pipeline because of heat exchange with the surroundings over a large surface area.

Konchesky's results appear to be adequately correlated by the relation proposed by Dogin and Lebedev [56] according to

\[
f_m = f_a + A (\frac{d}{D})^{0.1} \Re^{0.4} \Fr^{-0.5} \rho^* \frac{M^*}{M} \tag{7.4.8}
\]

where \( \Fr \) is the Froude number

\[
\Fr = \frac{V^2}{gD} \tag{7.4.9}
\]

which accounts for the gravity effect in horizontal pipe flow. \( A \) is a parameter depending on the roughness of the pipe. For the Konchesky data, \( A \) appears to be \( 2 \times 10^{-7} \) in both pressure and vacuum.
transport [52,54], instead of \(10^{-6} < A < 2 \times 10^{-6}\) proposed by Dogin, et al.

Rose and Barnacle [57] proposed the following correlation:

\[
f_m = f_a \left( \frac{\rho}{\bar{g}} \right)^{0.5} \rho^{0.5} \chi \quad (7.4.10)
\]

\(\chi\) was given as a function of Re having a value below \(10^{-5}\) for \(Re > 35,000\). However, calculations from Konchesky's data given \(\chi = 0.8 \times 10^4 = 1 \times 10^{-4}\). Coding various sources of data and disregarding other factors, Pfeffer, et al. [44] proposed a simple correlation recommended for predicting pressure drops associated with a fully developed turbulent flow of gas-solid suspensions in smooth tubes.

\[
f_m = f_a \left( 1 + \frac{\rho}{\bar{g}} \right)^{0.3} \quad (7.4.11)
\]

This correlation tends to give an optimistic estimate of pressure drop, and shall be treated as lower bound of \(f_m\) as suggested by Soo [5].

7.2.5 Design Approach to a Pneumatic Coal Transport Pipeline

Given the technical experience of the 1962 and 1967 Bureau of Mines' studies on pneumatic transport of coal, our design is based on current technology and information. Emphasis has been placed on:

1) clarification of the gas-solid mixture friction factor,

2) reduction of energy requirements, and

3) the possibility of an intermediate distance pipeline (about 100 miles) without pumping stations, thus eliminating the recompression process for the coal-gas mixture.

A recent finding [5] has indicated that the pipe flow friction factors on which the 1962 study was based were 10 to 50 times higher than those determined from recent experimental data at the
Bureau of Mines [52] and experiments in England [53], as shown in Figure 7.1. This is also supported by our present evaluation of data from reference [54] and additional information from current practice [55].

Equation (7.4.7) shows that as long as a uniform pipe diameter $D$ is used, large differences in pressure $P_1$ and $P_2$ at the inlet and outlet will not necessarily increase the pipe length $L$ because of the large pressure drop caused by increased flow velocity at low air density as the pressure is lowered, thus causing greatly increased friction loss. This suggests telescoping the pipe diameters as the pressure is lowered. In this way, the flow velocity is kept just high enough for the suspension but minimizes friction loss. Therefore, an optimum selection of various lengths of standard pipe of various diameters must be made consistent with the constraints of optimum pressure drop and suspension velocity. Based on the analysis presented in Section 7.2.3, a computer program for the design of a telescoping pneumatic coal transport system is formulated. Figure 7.3 illustrates the simplified logic employed.
Friction Factor ($f_m$) of Vacuum Transport of Crushed Coal Suspension at Various Flow Reynolds Numbers (52).
Friction Factor ($f_m$) of Pressure Transport of Crushed Coal Suspension at Various Flow Reynolds Numbers (54). ($M^* = \text{lb coal/lb air}, D = \text{pipe diameter, inches}$)
FIGURE 7.3:

Input:
- Particle Diameter
- Capacity
- Leading Ratio
- Suspension Parameter

Initial Guess
- Inlet pressure
- Temperature
- No. of iterations

I = 1

Compute:
- $\Delta$, $\beta$, $\alpha$, $\omega$, $A$, $\gamma x$

I = I + 1

Compute:
- $D$, $US$, $V1$

Print:
- $P1$, $\Delta$, $\beta$, $\alpha$, $\omega$, $A$, $\rho^*$, $\gamma$, $V1$, $D$

 Iterate:
- YES

READJUST:
- Inlet pressure
- Temperature
- No. of iterations

SORTING:
- Use Standard Pipe Dia.
- $D1$, $D2$
- $\Delta1$, $\Delta2$

INTRAPOLATE
- $A$

Compute:
- $\gamma$, $\omega$, $\rho$, $P1$, $V1$
- $Re$, $fa$, $fm$

$fm = A\ln(F1, F2, F3)$

Have all parameters for standard pipes been obtained?
- NO
- YES

Compute:
- Pipe section lengths $L$, basing on minimum transport velocity

Compute:
- Pipeline length

Stop

SIMPLIFIED LOGIC DIAGRAM FOR TELESCOPING PNEUMATIC COAL TRANSPORT SYSTEM PARAMETERS CALCULATIONS.
7.3 PILOT FACILITY

A model for this study has been developed with the cooperation of the Peabody Coal Company and the Illinois Power Company. This pneumatic pipeline model is 3.5 miles long and has a transport capacity of 200 tons per hour or 1.584 million tons of coal per year based on operations of 24 hours per day and 330 days per year. The current rail system has a total coal capacity of 18,000 tons per day or 5 million tons per year.

A right-of-way of 50 feet for the pipeline is assumed to be along-side the present rail system (Figure 7.4). Additional land is needed at the mine and an area of 30' x 100' for the receiving facility for unloading (Figures 7.5 and 7.6) is needed at the receiving end. Figure 7.7 shows a layout of the pipeline route.

7.3.1 Conceptual Design of the Pneumatic Coal Transport Pipeline

Table 7.1 provides an outline of the initial design parameters of the pneumatic coal transport system. The initial design configurations of the system are shown on Figures 7.8 and 7.9. Figure 7.8 illustrates the high pressure blow tank system. Its major facilities include coal feeding, air compression, transport pipeline, and separation and receiving facilities. Coal is transferred from the 50 ft. diameter by 200 ft. height storage silo by a 150 ft. by 24 in. belt conveyor which is built across an auxiliary rail track, to a steel superstructure. This steel superstructure houses the feeding facilities which includes a 20 ft. by 14 in. diameter screw feeder and two 500 cu. ft. blow tanks with wye fitting and a motor driven rotary feeder. The tanks are connected so that while one is discharging the other is being filled, so that continuous feeding is possible. The operating cycle time is programmed and automatically controlled. The air source is supplied by a compressor package (motor driven) which also includes an intake filter and silencer.

Ground elevations at the mine and the power plant are 465 ft. and 435 ft. respectively. As the terrain is flat, the pipeline is basically horizontal. The pipeline is laid along the left side of the rail track from the mine to the power plant.
The intersection with a country road which will require an overhead crossing should not cause any difficulty for the layout. The coal-air mixture is separated by using two cyclone separators in series to ensure high recapture efficiency, and the coal-dust laden air is de-dusted by a dust filter before venting into the atmosphere.

Figure 7.9 illustrates the positive-negative (or push-pull) system. This system employs air flows created by the application of both pressure and vacuum principles. This flow operation is similar to that of the blow tanks system except that it has gravity feeding. Based on current technology, this system is limited to 20 psig on the pressure side using a rotary feeder valve, and 10 psig on the vacuum side with a suction blower. Selection of the type of pneumatic system is determined by the allowable solid size, energy requirement and economic feasibility.

7.3.2 Design Calculations

In our design, set here for a 2 x 0" size coal, preliminary analysis suggests a preference for using the blow tank system instead of the push-pull system which is more suitable to 1/4 x 0" coal. Given the design capacity input, the basic parameters required to design telescoping pipelines are determined from the computer program. Figure 7.3 shows the simplified logic for calculating telescoping pneumatic transport system parameters. A self explanatory flowchart of the computer program (Appendix IV) is shown in Figure 7.10. Based on given particle size, transport tonnage rate and distance, loading ratio, and correlated suspension parameter, the computer program determines the air properties along the flow, telescoping diameter, minimum suspension velocity, correlated friction factors, optimum pressure drop and telescoping length. With these, the air and power requirements are then calculated.
For 2 x 0" size coal, based on a capacity of 200 tons per hour and a distance of 3.5 miles, telescoped pipeline configuration and parameters are shown on Figure 7.11. A theoretical power requirement of 1750 hp., for a pressure drop of 122 psig, is indicated. The blower capacity is nearly 8800 scfm. From the air and power requirement results, a detailed major equipment list is tabulated in Table 7.2.

7.3.3 Alternative Design for 1/4 x 0

Based on a pneumatic coal transport system of 3.5 miles and a capacity of 200 tons of 1/4 x 0" size coal per hour, using the loading ratio of 10 and suspension parameter (k) of 10, a significant reduction of power requirement is readily seen by comparing Figure 7.11 with Figures 7.12 and 7.13. With the configuration of Figure 7.13, a power reduction as much as 76 percent is possible. Figures 7.12 and 7.13 also signify the effect of telescoping pipeline on the power requirements. From our analysis, it is shown that the loading ratio must be properly selected for an optimal system, as small loading ratios lead to higher power requirements and bigger pipes which in turn lead to higher costs. It is also concluded that there is a significant cost reduction by transporting small size coal. One possible mode of operation is via a storage and primary crushing facility at the delivery end and discharge directly into coal bunkers at the receiving end.
TABLE 7.1: Outline of Initial Design Study

I. PROCESS

A. Pneumatic
   1. Selection of Types of Pneumatic System
   2. Selection of Optimum or Allowable Solid Size and Concentration
   3. Determination of Minimum Operating Flow Velocity

E. Structural
   1. Determination of Pipeline Diameter
   2. Telescoping of the Pipeline
   3. Terrain Consideration Including Layout
   4. Establishment of Design Pipeline Life.

C. Operability - Stability
   1. Selection of Mode of Operation and Emergency Procedures
   2. Establishment of Shutdown and Start-up Technique
   3. Consideration of Hold-up.

II. MECHANICAL

A. Number and Location of Pump Station
B. Sizing of Equipment and System Design
C. System Automation and Control.

III. ECONOMIC EVALUATION

A. Capital Investment
B. Operational Cost
<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>SIZES</th>
<th>REMARKS</th>
<th>AVAILABLE SUPPLIERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belt conveyor</td>
<td>150 ft. of 24&quot; belt</td>
<td>300 fpm</td>
<td>Bulk material handling group of Willis and Paul, Inc.</td>
</tr>
<tr>
<td>Screw feeder</td>
<td>20 ft. of 14&quot; diameter</td>
<td>with motor and drive</td>
<td>Aerodyne Machinery Div., General Resource Corp.</td>
</tr>
<tr>
<td>Rotary feeders</td>
<td>two 10&quot; size</td>
<td></td>
<td>Ingersoll-Rand Co.</td>
</tr>
<tr>
<td>Compressor package</td>
<td>1920 hp. 8740 SCFM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline</td>
<td>3.5 miles</td>
<td>1.3773 mi. of 8&quot; dia.</td>
<td>U.S. Steel Corp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.1747 mi. of 10&quot; dia.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.47 mi. of 12&quot; dia.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.478 mi. of 14&quot; dia.</td>
<td></td>
</tr>
<tr>
<td>Cyclone separators</td>
<td>two-8740 SCFM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duct collector</td>
<td>8740 SCFM</td>
<td>Cloth bags with electric motor shaker</td>
<td>western Precipitation Div., Joy Manufacturing Co.</td>
</tr>
</tbody>
</table>
FIGURE 7.4:

Proposed Pneumatic Coal Pipeline Route at Receiving End
FIGURE 7.5:

PIVLINE ALONG RIGHT OF WAY GRANTED BY PEABODY COAL CO. & IFC.
RECEIVING FACILITY (100430) BY IFC.

Aerial View of Space and Right-of-Way Along Current Railroad and Pipeline Installation Plan at Receiving End in Relation to Current Coal Handling Facilities.
FIGURE 7.6: LOCATION OF RECEIVING END FACILITY

SAMPLE HOUSE
(SEE DWG. H-18)

TUNNEL ENTRANCE ENCLOSURE

GO-TRACK HOPPER CONVEYOR
3000 TPH @ 650 FPM

LOCKER ROOM

SECTION "3-3"
SCALE 1/4" = 1'-0"

2'-6" WIDE WALKWAY

1'-0" GROUT

3'-0"

6'-0"

0'-0"

11'-2"

61'-6"

Side View of Space for Receiving End Facility Showing Integration into Existing Facilities.
FIGURE 7.7:
Proposed Route of 3.5-mile Pilot Plant of Pneumatic Coal Transport Pipeline.
Schematic Diagram Showing Pressure (Blow Tank) Pneumatic Transport of Coal.
Schematic Diagram Showing Pressure-Vacuum (Push-Pull) Transport of Coal.
Flow Chart of Computer Programs for Calculating of Telescoping Pneumatic Coal Transport System Parameters.
**2 x 0" SIZE COAL**

- **CAPACITY:** 200 TPH
- **AIR FLOW:** 8738 SCFM
- **PRESSURE DROP:**
- **THEORETICAL HP:** 1751 hp

---

### Schematic Diagram of the 3.5-miles Telescoping Pneumatic Coal Transport Pipeline and Flow Parameters for Peabody-Baldwin Pilot Plant of 200 Tons of 2 x 0" Coal Per Hour (k=20).
FIGURE 7.12:

Schematic Diagram of a 3.5-miles Pneumatic Coal Transport Pipeline (Constant Diameter) and Flow Parameters for Transport Capacity of 200 Tons of 3/8 x 0" Coal Per Hour (k=10).

\[ \dot{M}^* = 10 \]
\[ K = 10 \]
Nominal diameter = 16 in.
Inlet pressure = 15.376 psia
Outlet pressure = 14.7 psia
Minimum transport velocity = 48.6 ft/s
Pressure drop = 8738 SCPM
Air flow = 8738 SCFM
Theoretical Horsepower = 522 hp.
FIGURE 7.13:

Schematic Diagram of a 3.5-miles Telescoping Pneumatic Coal Transport Pipeline and Flow Parameters for Transport Capacity of 200 Tons of \( \frac{1}{4} \times 0.0\)" Coal Per Hour (k=10).

<table>
<thead>
<tr>
<th>Section</th>
<th>Standard Pipe #20 Nominal Diameter (in.)</th>
<th>Inside Diameter (in.)</th>
<th>Section Length (mile)</th>
<th>Inlet Pressure (psia)</th>
<th>Minimum Transport Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>15.376</td>
<td>0.161</td>
<td>29.98</td>
<td>52</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>17.376</td>
<td>2.293</td>
<td>28.34</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>19.25</td>
<td>1.036</td>
<td>18.53</td>
<td>66</td>
</tr>
</tbody>
</table>

1/4 x 0" SIZE COAL

CAPACITY = 200 tph
AIR FLOW = 8738 scfm
PRESSURE DROP = 14.28 psig
THEORETICAL HP = 420.7 hp

K = 10
\( \frac{x}{x} \)
M = 10
7.4 Cost Evaluation of Pilot Plant

7.4.1 Capital Cost Estimation

In the previous section, material and energy requirements and balance calculations were made for the conceptual design of a 3.5-mile pneumatic coal transport system for 200 tons of 2 x 0" size coal per hour. The resulting information was utilized in sizing and specifying the major items of equipment. Capital investment was estimated by the method described by Guthrie [59], and Peters and Timmerhaus [60]. The purchased or installed equipment costs were estimated with the aid of cost data for similar items of equipment, cost indices and available cost-capacity factors. Fixed capital investment was then calculated with the aid of the purchased cost and Lange factors [60] for the item. The capital investment figures presented here do not include the costs for standby equipment and spares. However, allowances have been made on estimating contingency costs.

Owing to the similar nature of natural gas pipelines and pneumatic coal pipelines, it is reasonable to make the assumption that the cost for installing a pneumatic coal pipeline should not be very different from that of a natural gas pipeline with the same dimensions. Based on this argument, this assumption should also be applicable to the cost of similar compressor facilities with the same power capacity. Figure 7.14 shows the cost correlation of natural gas pipelines, based on the construction cost which includes material, labor, right-of-way, interest, surveys, engineering, inspection, legal fees, and contingencies as released by the Federal Power Commission in 1974 [61]. Also, the average cost per installed horsepower for compressor facilities was $302 as reported by the FPC [61]. These costs were escalated to 1976 values at the rate of 7 percent per annum.

The bare module cost for the major equipment shown in Table 7.2 is given in Table 7.3. The bare module cost for buildings includes a house for control and administration, one steel superstructure (15' x 30' x 30') for blow tanks at the sending point, and one steel superstructure (20' x 60' x 40') for the separation facilities at the receiving point.
For all building costs, the medium categories [59] were used.

The costs for site development and offsite facilities were estimated at 5 percent and 8 percent, respectively, of the bare module costs of major equipment. Offsite facilities include water, instrument, air, oil, fire protection equipment, power distribution and yard lighting. The charges for engineering and contractors were included and were calculated at 7 percent and 5 percent of the total module cost, respectively.

All bare module costs were based on 1968 data, escalated to mid-1973 by a factor of 1.26 (344.1/273.1) as estimated from the Marshall and Stevens Index, and to 1976 dollars using an assumed annual escalation rate of 7 percent.

A summary of the capital investment estimation for the conceptual design of the pneumatic coal transport system is given in Table 7.4. The fixed capital investment was estimated to be $1,463,700 (1976 $). Working capital was calculated at 10 percent of fixed capital investment. The total capital investment amounted to $1,610,100.

7.4.2 Annual Operating Cost

The total annual cost of the conceptual design of the pneumatic coal transport system was estimated to be $745,600. A summary of these costs is presented in Table 7.5. The pertinent assumptions and bases for these estimates are as follows:

1) 100 percent capacity.
2) 330-day annual operation.
3) Horsepower required for other equipment is considered insignificant compared to that for gas compression. The cost of fuel was estimated on the equivalence of coal required. The assumptions of an average of 10,500 BTU per lb. coal; 10,800 BTU per kw-hour; and up to $15 per ton coal FOB at the mine were also applied (93¢/MMBtu of heat).
4) Operating labor costs were calculated assuming 2 men per shift at an annual wage of up to $20,000 per man or $150,000 total. Supervisory manpower was taken as 20 percent of the operating labor.

5) Maintenance and repairs were calculated at 6 percent of the fixed capital investment to include both material and labor. Operating supplies were assumed to be 15 percent of maintenance and repair.

6) Administrative costs were taken as 40 percent of operating labor; and plant overhead at 50 percent of the sum of operating labor plus supervisory labor plus maintenance and repairs.

7) Fixed charges were assumed to be 50 percent of the total fixed capital investment on a debt to equity ratio of 55 percent to 45 percent. The interest rate on debt and equity were 9 percent and 15 percent respectively.

8) A 25-year plant life with no salvage value for the equipment was assumed for depreciation calculations using the straight line method.

9) Taxes and insurance were each estimated at 1 percent of fixed capital investment.

7.4.3 Cost Analysis

The capital investment estimates are based on a new facilities situation in conjunction with the use of the right-of-way of a railroad system. The output of the cost evaluation of our conceptual design of a 3.5 mile telescoping pneumatic coal transport system of 200 tons of 2 x 0" size coal per hour indicates an investment requirement of $1,610,100 or a $95.84 investment per ton-mile capacity; and a coal transport cost of 13.45¢ per ton-mile.

The coal transport cost for this system is found to be considerably higher than the 1.14¢ per ton-mile transport cost projected by Soo in reference [5] for the same transport distance, but quadruple our design haulage capacity. The differences are due to
additional equipment and installation factors considered, a different design basis and a different accounts procedure employed. A cost projection of the pneumatic pipeline versus a belt conveyor (3.5 mile, 18,000 tons per day) as estimated by Soo [5] is included in Table 7.6 for comparison. At 18,000 tons of coal per day, the conveyor belt would ship coal at 3.83¢/ton-mile. Actual operations at 10-12¢/ton-mile have been experienced on a belt conveyor 5 to 6 miles in length [67].

7.4.4 Cost Comparison to Belt Conveyor

A belt conveyor was considered as an alternative to the current unit train. Based on the same design assumptions and accounting procedures used in the conceptual design of a 3.5 mile pneumatic pipeline system, a cost analysis of a 24" conveyor belt system was made. This estimate is independent of the more general one made in Volume 5. The results of the estimated economic analysis are shown in Table 7.7 using the following assumptions:

1) The estimation of conveyor equipment costs and fixed capital costs were based on the cost estimation for a 30" belt reported by the U.S. Department of Interior [10]. Average conveyor equipment and capital costs for the 24" belt were estimated to be $978,700 per mile and $1,397,700 per mile, respectively. These costs were escalated from 1962 to mid-1973 by a factor of 1.443 (344.1/238.5) as estimated from the Marshall and Stevens Index and to 1976 dollars using an assumed annual escalation rate of 7 percent. The conveyor equipment cost included structural work, fire protection and water supply, dust control, mechanical equipment, belting, electrical work, covering and terminal. Capital cost included conveyor equipment cost, construction overhead, contingency, right-of-way, escalation and interest during construction.

2) Working capital was estimated at 10 percent of fixed capital cost.

3) Except for fuel, annual operating costs used the same assumptions as those used in
the estimation of pneumatic coal transport costs.

4) Fuel costs were estimated on 240 hp. motor fuel cost = ($0.01/Kw-hr) x 240 hp. x 7920 hr. x 0.746 kw/ph.

It was found that the installation of a belt conveyor system is very capital intensive ($2,050,700 per mile, 1976 $) and is comparable to the capital cost of constructing a double track railroad ($1.584x10^6 per mi., 1975 $) [63]. It requires 5 times the investment of an equivalent pneumatic pipeline system. Analysis of unit transport costs shows that the pipeline has a cost advantage ($/ton mile) of as much as 3.6 times. Our findings confirm those made in the earlier study [5] (see Table 7.6) that there is a definite cost advantage to the use of a pneumatic pipeline rather than the belt conveyor for this case of coal transportation.

7.4.5 Cost Comparison to Railroad

The receiving facility has a coal transport system consisting of a 3.5-mile roadbed and trackage costing $400,000 to $500,000 per mile, 25 100-ton cars valued at $25,000 to $30,000 each and two locomotives valued at $300,000 to $400,000 each. The total investment was $3.5 million with a fixed charge of 20 percent. This railroad is run by a 7-man crew costing $140,000 per year; and includes a fuel cost of $80,000 per year; maintenance of $40,000 for cars and locomotives and $75,000 per year for the tracks. The total annual cost was estimated to be $1.1 million for a shipment of 4-5 million tons per year. These estimates suggest a charge of 24¢/ton although the cost may be as high as 50¢/ton because of the waste incurred by idle hours, waiting labor, and repairs on the locomotives [66,67].
<table>
<thead>
<tr>
<th>ITEMS</th>
<th>ESTIMATION</th>
<th>1968 COST</th>
<th>1976 COST</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belt conveyors</td>
<td>$540(150)^0.652.18</td>
<td>$32,900</td>
<td>$50,800</td>
<td>(59)</td>
</tr>
<tr>
<td>Screw feeder</td>
<td>$290(20)^0.752.05</td>
<td>5,600</td>
<td>8,700</td>
<td>(59)</td>
</tr>
<tr>
<td>Blow tanks</td>
<td>$16.1(3740)^0.652.2</td>
<td>14,800</td>
<td>23,000</td>
<td>(59)</td>
</tr>
<tr>
<td>rotary feeder</td>
<td>$6000+$1000(motor)</td>
<td>14,000</td>
<td>21,600</td>
<td>(62)</td>
</tr>
<tr>
<td>Compressor package</td>
<td>$346(1751/90%)</td>
<td></td>
<td>673,200</td>
<td>(61)</td>
</tr>
<tr>
<td>Pipeline</td>
<td></td>
<td></td>
<td>141,500</td>
<td>(61)</td>
</tr>
<tr>
<td>Cyclone separators</td>
<td>$3(8740)^0.82.18</td>
<td>18,600</td>
<td>28,700</td>
<td>(59)</td>
</tr>
<tr>
<td>Duct collector</td>
<td>$25(8740)^0.682.18</td>
<td>26,100</td>
<td>40,300</td>
<td>(59)</td>
</tr>
<tr>
<td>Discharge hoppers</td>
<td></td>
<td></td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total major equipment costs</strong></td>
<td></td>
<td></td>
<td><strong>$997,800</strong></td>
<td></td>
</tr>
<tr>
<td>Control House</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel structure:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sending end</td>
<td>$0.51x15'x30'x30'</td>
<td>6,890</td>
<td>10,600</td>
<td>(59)</td>
</tr>
<tr>
<td>Receiving end</td>
<td>$0.51x20'x60'x40'</td>
<td>24,400</td>
<td>37,800</td>
<td>(59)</td>
</tr>
<tr>
<td><strong>Total building costs</strong></td>
<td></td>
<td></td>
<td>60,400</td>
<td></td>
</tr>
</tbody>
</table>

* (0.325 x 1.3773 + 0.45 x 1.1747 + 0.59 x 0.4705 + 0.74 x 0.4775) x 10^5 - 3.5(5500)

+ Average U.S. right-of-ways cost/mile (61)
TABLE 7.4: Capital Investment Estimation
Pilot Plant (1976$)

<table>
<thead>
<tr>
<th>BARE MODULE COSTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1a, Major equipments</td>
<td>$997,800</td>
</tr>
<tr>
<td>1b, Buildings</td>
<td>60,400</td>
</tr>
<tr>
<td>1c, Site development (5% of la)</td>
<td>49,900</td>
</tr>
<tr>
<td>1d, Offsite facilities (8% of la)</td>
<td>79,900</td>
</tr>
<tr>
<td>1. Total Bare Module Cost</td>
<td>$1,188,000</td>
</tr>
<tr>
<td>2a, Contractor Fee (5% of 1)</td>
<td>59,400</td>
</tr>
<tr>
<td>2b, Engineering and Supervision (7% of 1)</td>
<td>83,200</td>
</tr>
<tr>
<td>2. Total Module Cost</td>
<td>$1,330,600</td>
</tr>
<tr>
<td>3a, Contingencies (10% of 2)</td>
<td>133,100</td>
</tr>
<tr>
<td>3. Fixed Capital Investments</td>
<td>$1,463,700</td>
</tr>
<tr>
<td>4. Working Capital (10% of 3)</td>
<td>146,400</td>
</tr>
<tr>
<td>5. Total Capital Investments</td>
<td>$1,610,100</td>
</tr>
</tbody>
</table>
TABLE 7.5: Total Annual Cost Estimation of Pilot Plant (1976$)

I. **ANNUAL FIXED CHARGES**

A. Fixed Charge (11.7% x 0.5 x 5*) $ 94,200
B. Depreciation (3% x 25) 58,500
C. Taxes (1% of 3*) 14,600
D. Insurance (1% of 3*) 14,600

$ 181,900

II. **ANNUAL OPERATION COSTS**

A. Fuel $ 93,000
B. Labor 150,000
C. Supervision (20% of IIB) 30,000
D. Maintenance and Supplies (6% of 3*) 87,600
E. Operation Supplies (15% of IIB) 11,200
F. Administrative Costs (40% of IIB) 60,000
G. Plant Overhead (50% of IIB,C,D) 134,000

$ 567,900

III. **TOTAL ANNUAL COSTS**

$ 749,800

IV. **UNIT COST**

A. Cost/Ton 47.34$
B. Cost/Ton-Mile 13.53$
C. Investment Cost/Ton per Day-Mile $ 95.84

* Cost figure in Table 7.4

Note: For fuel capacity load at 18,000 tons/day

\[
\frac{18,000 \text{ tons}}{200 \times 24} = 2.21
\]

Therefore unit costs are 21.3$/ton and 6.09$/ton-mile
TABLE 7.6. Cost Projection of Pneumatic Pipeline Versus Belt Conveyor (3.5 miles, 18,000 tons of 1/4 x 0" coal per day) coal per day)

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Pipeline</th>
<th>Belt Conveyor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land and Improvements</td>
<td>$32,500</td>
<td>$32,500</td>
</tr>
<tr>
<td>Structures and Buildings</td>
<td>35,000</td>
<td>35,000</td>
</tr>
<tr>
<td>2500-hp. Motor Compressor</td>
<td>325,000</td>
<td></td>
</tr>
<tr>
<td>Piping</td>
<td>25,000</td>
<td></td>
</tr>
<tr>
<td>Fans and Venturi</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td>Engineering and Contingencies</td>
<td>60,720</td>
<td>100,000</td>
</tr>
<tr>
<td>Pipeline 16&quot; dia. @ $92072/mile</td>
<td>322,300</td>
<td>26,800</td>
</tr>
<tr>
<td>Conveyor Belt @ $1.71 x 10^6/mile</td>
<td>6,000,000</td>
<td></td>
</tr>
<tr>
<td>Electrical Transmission @ $0.24/ft.</td>
<td>4,400</td>
<td>4,400</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td><strong>$824,900</strong></td>
<td><strong>$6,198,700</strong></td>
</tr>
</tbody>
</table>

II. **ANNUAL FIXED COSTS**

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Pipeline</th>
<th>Belt Conveyor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Charges</td>
<td>48,300</td>
<td>362,700</td>
</tr>
<tr>
<td>Taxes</td>
<td>13,500</td>
<td>101,600</td>
</tr>
<tr>
<td>Depreciation</td>
<td>33,000</td>
<td>268,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>94,800</strong></td>
<td><strong>712,300</strong></td>
</tr>
</tbody>
</table>

III. **ANNUAL OPERATING COSTS**

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Pipeline</th>
<th>Belt Conveyor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manpower</td>
<td>75,000</td>
<td>75,000</td>
</tr>
<tr>
<td>Material and Maintenance</td>
<td>9,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Administration and Engineering</td>
<td>44,500</td>
<td>44,500</td>
</tr>
<tr>
<td>Fuel</td>
<td>35,000</td>
<td>35,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>168,500</strong></td>
<td><strong>168,500</strong></td>
</tr>
</tbody>
</table>
**TABLE 7.6: Cost Projection of Pneumatic Pipeline Versus Belt Conveyor**
(3.5 miles, 18,000 tons of 1/4 x 0" coal per day)
(Continued)

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Pipeline</th>
<th>Belt Conveyor</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV. TOTAL ANNUAL COST</td>
<td>263,300</td>
<td>880,800</td>
</tr>
<tr>
<td>V. UNIT COSTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Cost/ton</td>
<td>4¢</td>
<td>13.4¢</td>
</tr>
<tr>
<td>B. Cost/ton-mile</td>
<td>1.14¢</td>
<td>3.83¢</td>
</tr>
<tr>
<td>C. Investment Cost/ton per day-mile</td>
<td>$13.1</td>
<td>$ 98.4</td>
</tr>
</tbody>
</table>

*Based on reference (5)*
TABLE 7.7: Cost Estimation of 24" Belt Conveyor System of 3.5 Miles for 200 Tons of 2x0" Coal Per Hour

I. CAPITAL INVESTMENTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conveyor Equipment Costs,</td>
<td>$ 5,237,100</td>
</tr>
<tr>
<td>e $1,496,306/mile 1)</td>
<td></td>
</tr>
<tr>
<td>Fixed Capital Cost,</td>
<td>$ 7,177,500</td>
</tr>
<tr>
<td>e $2,050,700/mile 1)</td>
<td></td>
</tr>
<tr>
<td>Working Capital</td>
<td>717,800</td>
</tr>
<tr>
<td>Total Fixed Capital Investment</td>
<td>$ 7,895,300</td>
</tr>
</tbody>
</table>

II. ANNUAL FIXED COSTS 3)

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Fixed Charges</td>
<td>$ 461,900</td>
</tr>
<tr>
<td>B. Depreciation</td>
<td>287,100</td>
</tr>
<tr>
<td>C. Taxes</td>
<td>71,800</td>
</tr>
<tr>
<td>D. Insurance</td>
<td>71,800</td>
</tr>
<tr>
<td></td>
<td>$ 891,600</td>
</tr>
</tbody>
</table>

III. ANNUAL OPERATION COSTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Fuel 4)</td>
<td>$ 14,200</td>
</tr>
<tr>
<td>B. Labor and Supervision 3)</td>
<td>72,000</td>
</tr>
<tr>
<td>C. Maintenance and Repairs 3)</td>
<td>430,700</td>
</tr>
<tr>
<td>D. Operating Supplies 3)</td>
<td>64,600</td>
</tr>
<tr>
<td>E. Administrative Costs 3)</td>
<td>24,000</td>
</tr>
<tr>
<td>F. Plant Overhead 3)</td>
<td>251,300</td>
</tr>
<tr>
<td></td>
<td>$ 856,800</td>
</tr>
</tbody>
</table>

IV. TOTAL ANNUAL COST

                                           | $ 1,748,400 |

V. UNIT COSTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Cost/Ton</td>
<td>$ 1.104</td>
</tr>
<tr>
<td>B. Cost/Ton-Mile</td>
<td>31.532</td>
</tr>
<tr>
<td>C. Investment Cost/Ton per Day-Mile</td>
<td>470.0</td>
</tr>
</tbody>
</table>

+ 1976 $  
* ) Assumption Number
FIGURE 7.14

Transmission Pipeline Construction Costs by Diameter (61).

* Includes right-of-way costs, U.S. average R.O.W. cost $5500/mile
7.5 OTHER CASES OF APPLICATION

7.5.1 Hypothetical Cases of Application

It was stated earlier in this study that the pneumatic coal pipeline system would be an effective and promising means to supplement future coal transportation by utilizing it as a small-capacity, short-distance coal feeder or distributor to a rail head for small scale applications, and as a large-capacity, intermediate-distance (about 100 miles) coal delivery system if railroad is non-existent. Thus, two hypothetical pneumatic coal transport systems are developed to evaluate the economics of these applications. Based on these evaluations, we try to formulate the general cost conditions of pneumatic coal transport systems for a range of capacities. The small scale hypothetical system is based on a design capacity of 200 tons of 2 x 0" size coal per hour (4800 tons per day) and a 1000' transport distance, while the large scale system assumes a capacity of 1000 tons of 1/4 x 0" size coal per hour (24,000 tons per day) and a transport distance of 100 miles. The former transport distance is realistic for a short haul loading and unloading system. The latter should be reasonable for a medium length gathering/distribution system. Based on the design procedure outlined in Section 7.3.1, the design parameters for each hypothetical system were generated from a computer program. Because of the short distance involved in the small scale system, telescoping of the pipeline might not be necessary even though it is feasible. The pneumatic system could be pressure, vacuum, or even a push-pull system. The final design should be determined on the basis of power requirements and cost effectiveness. The basic system design parameters for the small and large scale systems are shown in Table 7.8 and Figure 7.15, respectively. The vacuum system is selected for the economic evaluation as it requires a lower power requirement which leads to minimum cost.

7.5.2 Comparison of Costs

Included in the cost evaluation is the previously discussed system, but assuming that smaller sizes of coal (1/4 x 0") are being transported. It is anticipated that there should be
a cost advantage over the 2 x 0" size coal, as shipping small size coal requires less power. The system is shown in Figure 7.16 with the design parameters which are employed as the basis for the cost evaluation.

Estimates of the capital investment and annual operating costs required for the three hypothetical pneumatic coal transport systems are shown in Table 7.9. The findings of the conceptual design of a 3.5-mile system shown in Tables 7.3, 7.4 and 7.5, are also summarized in Table 7.9 for direct comparison. The assumptions for cost evaluation, discussed in previous sections (see Sections 7.4.1 and 7.4.2), are also employed in these cost evaluations.

7.5.3 Cost Advantages of Shipping 1/4 x 0

It can be seen in Table 7.9 that there is a significant cost advantage in shipping the smaller size coal. This is estimated as a 27 percent reduction in capital investment and a 22 percent reduction in unit transport cost. An even greater cost advantage may be anticipated. The size of coal being shipped is only a matter of the location of the coal preparation plant (either at the sending point, or the receiving point of the pipeline for mine to power plant operation). The unit coal transport cost should be invariant to the cost of pulverizing the coal as it must be accounted for either at the preparation plant or at the power plant. Power for crushing to 1/4 x 0" size only amounts to 10 to 12 kwh/ton. Shipping of smaller size coal (1/4 - 1") is also technically feasible as future mining and washing techniques require smaller size coal [52,64], while 1/4 x 0" size coal should not cause any problem in present coal burning technology, or such future coal utilization technology as gasification and liquefaction.

\[
C = 252380(ATM)^{-0.513142}
\]

for the 2 x 0" size coal short distance shipment (below 3.5 miles), and
\[ C = 31600(\text{ATM})^{-0.39578} \]

for the \(1/4 \times 0\)" size coal intermediate shipment (3.5 miles to about 100 miles).

where

\[ C = \text{unit coal transport rate in 1966 dollars (mills/ton-mile)} \]

\[ \text{ATM} = \text{annual ton-mile transported by the pneumatic coal transport pipeline}. \]
<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>Standard Pipe #20</th>
<th>Length</th>
<th>Inlet Pressure</th>
<th>Outlet Pressure</th>
<th>Minimum Transport Velocity</th>
<th>Pressure Drop</th>
<th>Theoretical Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nominal Diameter</td>
<td>Inside Diameter</td>
<td>in.</td>
<td>psia</td>
<td>psia</td>
<td>psig</td>
<td>hp.</td>
</tr>
<tr>
<td>Pressure</td>
<td>12</td>
<td>12.25</td>
<td>1000</td>
<td>23.23</td>
<td>14.7</td>
<td>116.9</td>
<td>8.53</td>
</tr>
<tr>
<td>Vacuum</td>
<td>14</td>
<td>13.376</td>
<td>1000</td>
<td>14.7</td>
<td>10.17</td>
<td>147.0</td>
<td>4.53</td>
</tr>
</tbody>
</table>

Air flow = 8738 scfm
K = 20
M* = 10
### TABLE 7.9 Summary of Cost Analysis of Pilot Plant and Other Hypothetical Case of Pneumatic Coal Transport (1976$)

<table>
<thead>
<tr>
<th>Cases</th>
<th>Pilot Plant</th>
<th>Pilot Plant Alternative</th>
<th>Short Distance</th>
<th>Intermediate Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSPORT MODE</td>
<td>Pressure (Fig. 11)</td>
<td>Pressure (Fig. 16)</td>
<td>Vacuum (Table 8)</td>
<td>Pressure (Fig. 15)</td>
</tr>
<tr>
<td>SIZE OF COAL</td>
<td>2 x 0&quot;</td>
<td>1/2 x 0&quot;</td>
<td>2 x 0&quot;</td>
<td>1/2 x 0&quot;</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>200 TPH</td>
<td>200 TPH</td>
<td>200 TPH</td>
<td>1000 TPH</td>
</tr>
<tr>
<td>TRANSPORT DISTANCE</td>
<td>3.5 Miles</td>
<td>3.5 Miles</td>
<td>1000 Feet</td>
<td>100 Miles</td>
</tr>
</tbody>
</table>

#### I. CAPITAL INVESTMENTS

A. Major Equipment
- Belt Conveyor: $50,800
- Screw Feeder: $8,700
- Blow Tanks: $23,000
- Rotary Feeders: $21,600
- Compressor Package: $673,000
- Pipeline: $141,500
- Cyclone Separators: $28,700
- Duct Collectors: $40,300
- Discharge Hoppers: $10,000

<table>
<thead>
<tr>
<th></th>
<th>Pilot Plant</th>
<th>Pilot Plant Alternative</th>
<th>Short Distance</th>
<th>Intermediate Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$997,800</td>
<td>$713,900</td>
<td>$162,900</td>
<td>$21,877,400</td>
</tr>
</tbody>
</table>

B. Buildings
- $60,400

C. Offsite Facilities (5% of IA)
- $49,900

D. Offsite Facilities (5% of IA)
- $79,900

<table>
<thead>
<tr>
<th></th>
<th>Pilot Plant</th>
<th>Pilot Plant Alternative</th>
<th>Short Distance</th>
<th>Intermediate Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Contractors' Fees</td>
<td>$1,188,000</td>
<td>$867,100</td>
<td>$214,000</td>
<td>$25,021,500</td>
</tr>
<tr>
<td>F. Engineering and Supervision</td>
<td>$1,330,600</td>
<td>$971,200</td>
<td>$239,700</td>
<td>$28,024,100</td>
</tr>
</tbody>
</table>

G. Contingencies
- $133,100

**I-1 FIXED CAPITAL INVESTMENT**
- $1,463,700

**I-2 TOTAL CAPITAL INVESTMENT**
- $1,610,100

H. Working Capital
- $146,400

**II. ANNUAL FIXED CHARGES**

A. Fixed Charges
- $94,200

B. Depreciation
- $58,500

C. Taxes and Insurance
- $25,200

<table>
<thead>
<tr>
<th></th>
<th>Pilot Plant</th>
<th>Pilot Plant Alternative</th>
<th>Short Distance</th>
<th>Intermediate Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$181,900</td>
<td>$132,800</td>
<td>$32,830</td>
<td>$3,833,400</td>
</tr>
</tbody>
</table>

**II. ANNUAL OPERATING COSTS**

A. Fuel
- $88,700

B. Labor and Supervision
- $180,000

C. Maintenance and Repairs
- $87,800

D. Operating Supplies
- $13,200

E. Administrative Costs
- $60,000

F. Plant Overhead
- $114,000

<table>
<thead>
<tr>
<th></th>
<th>Pilot Plant</th>
<th>Pilot Plant Alternative</th>
<th>Short Distance</th>
<th>Intermediate Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$563,700</td>
<td>$453,100</td>
<td>$175,100</td>
<td>$568,786</td>
</tr>
</tbody>
</table>

**IV. TOTAL ANNUAL COST**
- $745,600

**V. UNIT COSTS**

A. Cost/Ton
- $47.07c

B. Cost/Ton-Mile
- $11.54c

C. Investment Cost/ton-per-day-mile
- $95.84

$122 Blower hp

7-52
Schematic Diagram of the 100-miles Telescoping Pneumatic Coal Transport Pipeline and Flow Parameters for Transport Capacity of 200 Tons of \(\frac{3}{4}\) x 0' Coal per Hour (k=20).
FIGURE 7.16:

1/4 x 0" SIZE COAL

<table>
<thead>
<tr>
<th>Standard Pipe #20</th>
<th>Nominal Diameter Diameter</th>
<th>Inside Length</th>
<th>Minimum Transport Pressure</th>
<th>Transport Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>in.</td>
<td>mile</td>
<td>psia</td>
<td>ft./s</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>17.376</td>
<td>25.66</td>
<td>49.1</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>19.25</td>
<td>2.877</td>
<td>23.855</td>
</tr>
</tbody>
</table>

C/0 = 20
M = 10

THEORETICAL HP = 339.25 hp

Schematic Diagram of the 3.5-miles Telescoping Pneumatic Coal Transport Pipeline and Flow Parameters for Transport Capacity of 200 Tons of 0" x 0" Coal Per Hour (k=20).

7-54
7.6 GENERAL DISCUSSION

7.6.1 Short Distance Coal Transport

Installation and experience based on short distance coal movements is plentiful [55]. The results of the economic evaluation of the hypothetical system examined in this study indicates a considerably higher unit transport cost compared with those of larger capacity. Whether the short distance pneumatic coal delivery system can provide costs below those of conventional methods such as belt conveyors remains to be determined. However, from the economic evaluation of belt conveyors shown in Table 7.7, it can also be deduced that the belt conveyor system is more capital intensive ($470 investment/ton-mile to $319.1 of pipeline) and a potential economic advantage of short distance pneumatic pipelines over belt conveyor systems should not be ruled out. Moreover, a short distance pneumatic coal transport system may still be more favorable if a dollar credit can be assigned to eliminating the loading and unloading charges required for rail coal shipment.

7.6.2 A Hyperbolic Cost Model of a Hypothetical Pneumatic Coal Transport Pipeline

The total capital costs for a pneumatic coal transport pipeline based on the conceptual design discussed in detail, and the other three hypothetical pipeline cost estimations were plotted against the corresponding annual ton-mile transport. The graph is shown in Figure 7.17. The arrows indicate the scale to be read. The capital cost requirement for a pneumatic coal transport pipeline may be roughly estimated from Figure 7.17 by finding the capital cost that corresponds to the capacity in annual ton-miles for the pipeline design. Also included in Figure 7.17 is the relation of unit coal transport cost (c per ton-mile) to the annual ton-mile transport of the pipeline. Hyperbolic curves were fitted to the data in order to generalize these cost relationships. They resulted in the following equations:
7.6.3 Economic Evaluation of an Intermediate Distance Telescoping Pneumatic Coal Transport Pipeline

The cost evaluation of the hypothetical intermediate distance telescoping pneumatic coal transport pipeline of 100 miles and 1000 tons of 1/4 x 0" size coal per hour capacity yields a capital requirement of $33,909,200. The resulting unit transport cost is 1.1 cents per ton-mile. No direct cost comparison with other transport modes is made in this section. The results obtained from this hypothetical pipeline can serve as a guideline for the cost estimation of a pipeline of medium distance.

An intermediate distance system appears to be best suited as a complement or supplement to a rail system by 1) replacing an abandoned or unprofitable rail line for coal delivery, and 2) completing an existing rail coal shipment network where the cost of building a railroad appears prohibitive. In many cases it is either mandatory from a practical standpoint or just economic to combine unit trains with other modes of coal transportation to achieve a satisfactory mine-to-consumer route. At present, barge/rail shipments are probably the most common combination. Barges are limited by the availability of water routes, which also tend to be less direct. Yet, if lengthy waterways exist, large shipments are efficient. Table 7.10 shows the modal split and distribution cost estimation of rail unit train-barge combination system reported by the Bechtel Study [65] using U.S. Bureau of Mines data. It can be seen that on a tariff basis considerable savings are obtained from this practice. Barge-pneumatic pipelines and rail-pneumatic pipeline-barge or any combination of these three modes could be an innovative system for achieving lower coal transport costs.

As proposed by Soo [5], an intermediate pneumatic pipeline-rail combination seems a feasible alternative to the 273-mile, 5 x 10^6 tpy Black Mesa coal slurry line in Arizona. His proposed combination consists of a 120-mile pneumatic pipeline from Black Mesa to Winona, by unit train (covered) from Winona to Kingman (220 mile) via the Santa Fe Railroad, and from Kingman by a 30-mile pneumatic line to Mohave. Based on the data supplied by Bechtel [65], the existing slurry line required 1.7¢/ton-mile in 1974, or $5.02/ton and $5.314/ton in 1976 assuming Bechtel's annual escalation rates of 4
percent and 7 percent respectively. From Ballard's cost estimation [13, Table 7.5], the unit cost for Black Mesa ranges from 1.72 - 1.94¢/ton-mile depending on exclusion or inclusion of state tax, these cost figures in 1976 would be $4.883 - $5.508/ton and $5.024 - $5.667/ton at an annual escalation rate of 4 percent and 7 percent respectively.

According to our hyperbolic cost model for the intermediate distance telescoping pneumatic coal transport pipeline (Section 7.6.2), as the annual ton-mile capacities for both pneumatic pipeline sections are well within the range of the model, the 120-mile section of the proposed alternative would be $1.458 per ton while the 30-mile section would be $0.610/ton of coal moved. If the unit transport price of 220-mile unit train shipments were 0.504¢/ton-mile as estimated from reference [13, Table 7.4], the coal transport cost of using this alternative would be $3.255/ton of coal moved. Even if the unit train transport price were doubled, the overall cost of coal shipment would still be $4.423 per ton. Thus, it is anticipated that the proposed alternative application of the intermediate distance pneumatic coal transport pipeline to supplement the incomplete rail coal delivery network is feasible from the standpoint of cost. More important, the proposed alternative would be more significant if dollar credits were assigned to the benefits derived from the elimination of operational and environmental problems associated with the slurry pipeline [13,14].

7.6.4 Cost Evaluation of a Hypothetical Long-Distance, Large-Capacity, Telescoping, Pneumatic Coal Transport Pipeline

If the hyperbolic cost model of the intermediate distance pneumatic coal pipeline is reasonably correct, then its applicability to a long-distance large-capacity pipeline should yield a conservative cost estimate. Lower costs would be expected as annual ton-mile capacity increases. Based on the data provided in Ballard's cost evaluation of a slurry pipeline compared to rail [13, Table 7.5] his results are correlated in terms of annual ton-miles moved (Figure 7.18). The hyperbolic curve for an intermediate distance is plotted and extrapolated to long-distance large-tonnages (i.e., large value of annual ton-miles moved). It is interesting to note
that for long-distance large-capacity transport, where railbed is already available, the unit cost of pneumatic transport appears to be comparable with that of railroad with new rail and ties, and only rail with upgrading can provide costs under those indicated for pneumatic transport. However, if railroad is nonexistent, a long-distance telescoping pneumatic pipeline may have a cost advantage over the building of new railroads and slurry pipelines. Another case of the cost comparison based on the cost data from the Bechtel study [65] further confirms these findings and is shown in Figure 7.19. This result may provide a referent for long-term energy transportation planning and policy.
### TABLE 7.10: Coal Distribution Modal Split and Distribution Cost Estimate

**Modal Split (%)**

<table>
<thead>
<tr>
<th>Rail</th>
<th>Unit Train</th>
<th>Barge</th>
<th>Cost ($/Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>-</td>
<td>-</td>
<td>3.90</td>
</tr>
<tr>
<td>46</td>
<td>24</td>
<td>30</td>
<td>3.13</td>
</tr>
<tr>
<td>100</td>
<td>-</td>
<td>-</td>
<td>4.55</td>
</tr>
<tr>
<td>37</td>
<td>33</td>
<td>30</td>
<td>2.84</td>
</tr>
<tr>
<td>24</td>
<td>6</td>
<td>70</td>
<td>2.10</td>
</tr>
<tr>
<td>35</td>
<td>31</td>
<td>34</td>
<td>2.46</td>
</tr>
<tr>
<td>100</td>
<td>-</td>
<td>-</td>
<td>4.55</td>
</tr>
<tr>
<td>82</td>
<td>18</td>
<td>-</td>
<td>5.25</td>
</tr>
<tr>
<td>51</td>
<td>49</td>
<td>-</td>
<td>4.10</td>
</tr>
<tr>
<td>38</td>
<td>20</td>
<td>42</td>
<td>4.31</td>
</tr>
<tr>
<td>-</td>
<td>100</td>
<td>-</td>
<td>4.17</td>
</tr>
<tr>
<td>56</td>
<td>44</td>
<td>-</td>
<td>3.41</td>
</tr>
<tr>
<td>26</td>
<td>74</td>
<td>-</td>
<td>4.79</td>
</tr>
<tr>
<td>64</td>
<td>36</td>
<td>-</td>
<td>4.54</td>
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<tr>
<td>100</td>
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<td>-</td>
<td>4.51</td>
</tr>
<tr>
<td>-</td>
<td>100</td>
<td>-</td>
<td>4.25</td>
</tr>
</tbody>
</table>

**Notes:**
- Based on Reference [65]
- Source: BOM
- Costs are estimated in 1975 dollars
- Assumed all rail
- Assumed all unit train

7-59
FIGURE 7.17:

UNIT COAL TRANSPORT COST ($/ton-mi)

ANNUAL TON-MILE TRANSPORT

TOTAL CAPITAL COST (1976$)

TOTAL CAPITAL COST ($/ton-mi)

Total Capital Cost and Unit Transport Cost for Short and Intermediate Distance Coal Pipeline (1976).
FIGURE 7.18: Cost Comparison Showing Unit Transport Cost Extrapolated From Hyperbolic Cost Model (Eq. 7.2.1) For Long-Distance Large-Capacity Shipment as Compared to Cost Data of Rail and Slurry Pipeline From Reference (13).

Cost Comparison Showing Unit Transport Cost Extrapolated from Hyperbolic Cost Model (Eq. 6.2.1) for Long-Distance Large-Capacity Shipment as Compared to Cost Data of Rail and Slurry Pipeline from Reference (13).
FIGURE 7.19: Unit Coal Transport Cost Extrapolated from Hyperbolic Cost Model (Eq. 7.2.1) for Long-Distance Large-Capacity Shipment and Cost Data of Other Modes of Coal Transportation As from Reference (65).
References


55. Radmark Engineering, Division of Radar Pneumatics Ltd., Data of The Radmark Pneumatic Conveying System.


63. Ferguson, J. A., "Unit Train Transportation of Coal," M.S. Thesis, Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, December 1974.


APPENDIX

COMPUTER PROGRAM FOR TELESCOPING PNEUMATIC COAL PIPELINE SYSTEM PARAMETERS CALCULATIONS
&JOB

REAL MS, MP, K, L, NU, K1, K2
READ, OPIN, K, MS, TON, T1

RHO=1.4*62.4
NU=1.018E-5*0.672
GF=53.35
GC=32.174
S=0.45
PI=3.14159
MP=TON/3600
DP=OPIN/12
K1=4*MP/(PI*RHO)
K2=0.7*K**1.5

DO 200 IIM1, 10
READ, A1, A2, O, D1, D2

A=A1+(A2-A1)*(O*D1)/(O2-D1)
GO=K1/O**2
G=(1+GO/K2)/(A*GO**0.25)
Q=GO/G

XA=0**3
XB=4*GC*NU/3
XC=NU*RHO
RHO=(-XR+(XR**2+4*XA*XC)**0.5)/(2*XA)
RHR=RHO/RHO
P=RHO*R/K2
P=K/P(14.7*144)
V1=GO*RHO/RHO/MS

RE=V1*RHO/NU
PA=0.944/RE**0.2
WRITE(6, 137) RE, PA

107 FORMAT((X, T6, ' RE=', T26, E15.3, //, T6, ' PA=', T26, F15.7, //)

P=V1+V/GO/O
A1=2.3*7
A2=1.0*4
PM1=A**1.4*(OP/D)**0.4*A*RE**3.4*FR*(0.5)*RHR*MS
FM1=A**3.14159/8.3*FR*MS*RHR*H.5*2
FM3=FAM*(1.0+MS)**0.3
PRINT, FM1, FM2, FM3

FM = AMIN1( FM1, FM2, FM3 )
GO TO 59

49 IF (FM=FM1) 11, 21, 11
11 IF (FM=FM2) 12, 22, 12
12 IF (FM=FM3) 13, 23, 13

13 PRINT, ' FM DO NOT MATCH ! '
21 PRINT, ' DOGIN FM = ', FM, FM1
GO TO 59

22 PRINT, ' ROSE FM = ', FM, FM2
GO TO 59
23 PRINT, ' PPEFFER FM = ', FM, FM3

50 WRITE(6, 51) D, A, G, O, PA, V1, FM
51 FORMAT((X, F10.6, GF10.6, F7.2, F10.6, ///))
200 CONTINUE
STOP
REAL MS, MP, K, L, NU, K1, K2
READ, OPIN, K, MS, TON, P1X, T1, XCR

RHOP=1.0*62.4
NU=1.918E+5*0.672
R=53.35
GC=32.174
C1=9.2
S=0.45
PIN=14159
G=10

MP=TON*2090/3600
DP=OPIN/12
K1=MP/(PIN*RHOP)
K2=0.7*K*S=1.5
PRINT K1, K2
NX=(P1X-1)/XCR + 2

DO 1000 I=1, NX
PA=P1X-XCR*(I-1)
P1=P1*(1./P1*T1)
VIS=NU/RH0
RHOR=RHOP/RHO
DELTAS=(0.75*NU**2/(GC*(RHOR=1.)*RHO**2))**0.333
BETAS=DP/DELTAS
ALPHA=C1*BETA**9
OMEGA=((1.3333*GC*VIS*(RHOR=1.))**BETA)**0.333
A=1./(MS**12**1.5*ALPHA*K1**0.25/RHOR)
ALLOW=1/30

200 GX=1/0/(A*(G*OMEGA)**0.25=OMEGA/K2)
DIFF=ABS(G-GX)
IF (DIFF.LE.ALLOW) GO TO 100
G=G
GO TO 200

100 D=(K1/(G*OMEGA))**0.5
DIN=12.*D

US=ALPHA*OMEGA*DIN**0.5
UPMIN=G*OMEGA*RHOR/MS
VMU=UPMIN

WRITE(6,300)PA,P1,DELTA,BETA,ALPHA,OMEGA, A, RHOR, G, V1, D
300 FORMAT(1X,2F10.2, E13.5, F 8.2, F 6.2, 2F10.6, F12.6, F10.6, F 7.2, C F10.6,//)

1000 CONTINUE
STOP
END
CAC Document No. 223
COMPARATIVE COAL TRANSPORTATION COSTS:
AN ECONOMIC AND ENGINEERING ANALYSIS
YELLOW BALL RAIL
Volume 8
by
Michael Rieber and Shao Lee Soo
Center for Advanced Computation
University of Illinois
August 1977
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The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the subject of this report."
Title and Subtitle: Comparative Coal Transportation Costs: An Economic and Engineering Analysis of Truck, Belt, Rail, Barge, and Coal Slurry and Pneumatic Pipelines, Volume 8 - Yellow Ball Rail

Abstract: Describes and costs the use of overage rail cars and locomotives as a gathering system for groups of small coal mines in the vicinity of existing lightly used or railbanked track. A transloader is used to establish unit train lots.

Key Words and Document Analysis:

Coal transportation
Yellow-ball rail cars
Transloading facility
Coal mines (small)
Railbank

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This report is a summary of the work recently completed as part of this contract during the period May 1976 to August 1977. This report was submitted by the authors on August 1977.

This volume is a part of the eight volume report completed for this contract. The draft final report was submitted in May 1977.

The principal authors, Michael Rieber and Shao Lee Soo, are, respectively, Research Professor, Center for Advanced Computation, the Graduate College; and Professor of Mechanical Engineering, College of Engineering; both at the University of Illinois at Urbana-Champaign.
Subject Inventions

This is to certify that, to the best of my knowledge and belief, there were no Subject Inventions made or have resulted from the performance of this contract.

August 1977

[Signature]
Michael Rieber
Principal Investigator
CAC Document No. 223

FINAL REPORT

COMPARATIVE COAL TRANSPORTATION COSTS: AN ECONOMIC AND ENGINEERING ANALYSIS OF TRUCK, BELT, RAIL, BARGE AND COAL SLURRY AND PNEUMATIC PIPELINES

VOLUME 8

YELLOW BALL RAIL

by

Michael Rieber and Shao Lee Soo
with
P. King, Y. T. King, T. Leung, H. Wu and J. Wu

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August 1977
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8. YELLOW-BALL RAIL

8.1 INTRODUCTION

Rail cars are referred to as "yellow-balled" when they are sufficiently old or damaged to preclude their efficient operation on long-haul or main line routes. For most coal carrying railroads, their alternative value is salvage. This, however, does not necessarily preclude their effective use, on a limited basis, by small mines located near existing trackage. Because of age, the sizes of these hopper and gondola cars are currently 50 and 70 tons rather than the 100 tons commonly built at the present time.

As a gathering system, yellow-ball rail could provide an alternative, particularly in Kentucky, western Pennsylvania and West Virginia, to coal trucks, conveyor belts and pneumatic pipelines [4,p.17]. belts and pneumatic pipelines. Rail service of this type provides a limited alternative to track abandonment, a possible financial return to a railbank [3], a direct contribution to service demand on main lines, and a means by which many small eastern coal mines could retain or regain competitive viability [4]. In terms of energy efficiency, compared to trucking coal, the total direct energy impact (fuel) of yellow-ball rail can be expected to range from 280-990 Btu/ton-mile while that for trucks ranges from 1850-3120 Btu/ton-mile [2].

It is primarily as a gathering, rather than a distribution system, that yellow-ball coal transport has an impact. In appearance and structural characteristics these cars are not suitable for use in populated areas. Furthermore, they are not suited for the large tonnage continuous use which would be required for coal fired utilities.

The application of yellow-ball coal cars to the viability of small coal mines, the preparation equipment required, and the integration of these mines has already been explored in a study prepared for FEA [4]. In that study it was estimated that: (1) if the track, ballast and subgrade were already in place; (2) if old rail were available for replacement as needed (115 to 119 pound rail are entirely adequate); and (3) if train speeds were held to 5-10 mph; then a twelve car train moved by a 400 hp switcher type engine could move from 400 T/D to 2000 T/D for a cost of about 2-2.5¢/T/mile. The smaller load implies a train every sixteen hours. The larger load suggests one train every three hours and is close to the maximum for a single line delivery at this scale [4,p.64].
8.2 FACILITY DESCRIPTION

8.2.1 Train Facility

We assume that track, ballast, and subgrade are already in place. If not, it is not worth considering building a rail system for small mines. The rail system can, however, include lightly used, railbanked, or "abandoned" track. The principal costs are those of upkeep of the existing subgrade, ballast and drainage. Even railbanked systems will deteriorate due to weathering. It is assumed that track replacement is based on the purchase of adequate mainline track which has been replaced because it is too light or otherwise inadequate for heavy duty service.

Depending on mine size, car loading is accomplished by silos, conveyors and/or front end loaders. Coal crushing, washing or other preparation facilities are optional. Small equipment exists [4, Section VI], but its location is more likely to be at the receiving, rather than the gathering, end for small mine operations.

Yellow-ball cars, both gondola and hopper, if not used in this service, have only salvage value. The railroads must pay for their cost of removal or the implied cost of their storage. Assuming a current cost of $25-$27,000 for 100 ton hopper cars, if the salvage value is 5 percent, car costs are $1,250-$1,350/car. To this should be added the cost of moving the car to the new owners. However, as the cars under consideration are only 50-70 tons, the reduction in car costs probably balances this.

For a single small mine, it would be inefficient to buy a locomotive. A more likely scenario would assume that the locomotive is leased, rented, or paid for by the trip for actual car pickup. Ownership would reside with a large mine in the system, with the transloading facility, or with a consortium of small mines operating the system. Switching locomotives have been valued at $430,000 or $53,800/year at eight year straight line depreciation [1,p.9]. Current large purchases of locomotives indicate a price of about $500,000 [5]. These are not small size switch engines. If used, smaller, engines are available, the $430,000 might be reduced by half or more.
It has been estimated [3] for Pennsylvania trackage, that for light density lines which already meet FRA Class I standards, total annual maintenance costs per mile are about $5,058 for traffic densities of less than 0.2 MMTY and $5,988 for densities between 0.2 MMTY and 5 MMTY [3,p.11]. Rehabilitation costs to reach Class I standards average $225/mile/year [3, p.6]. Track and hardware, on a salvage basis range from $273-$280/mile for 115 lbs - 119 lb track and $310-$312/mile for 132-136 lb track. Reusable good ties are valued at $4/tie [3,p.5]. Unless there is a major turnaround in current eastern railroad maintenance practice which produces a surplus of old material, these figures appear to be low. Even a doubling, however, would provide a low cost road sufficiently serviceable for yellow-ball coal service.

Alternative values proposed by the PRA have been cited in [3, p. A-2,3]. These include:

rail - $125/ton (178 tons per mile)

other track material - $125/ton
(61.3 tons per mile)

good ties - $5/tie (2816 ties/mile.
Required replacement depends on current conditions)

8.2.2 COAL PREPARATION AND LOADING FACILITIES

These have been discussed in [4, Section IV]. The costs vary widely depending on complexity, scope of services and throughput. Cost efficiency suggests that this function, except for loading, would be advantageously placed at the unit train loading facility or divided between that facility and the receiver.

8.2.3 Transloading Facilities

Descriptions of loading and other preparation facilities can be found in [1 and 4, p. 87-96]. The costing in [1] appears to be unusually reliable. For example, a transloader built in 1967, is in current operation [1,p.3]. The bottom line for a 4MMTY transloader is:
$7,402,000 - capital costs

$491,600 - annual depreciation

$799,500 - annual operating costs

$0.45-$0.50/ton - break-even rate depending on the cost of capital [1, p.1]

It appears that smaller sizes are available. These would be cheaper and more suitable to cooperative transport/preparation ventures among small mines. It should be noted that the estimates derived in [4] anticipate a 1-1.5 MMTY unit train facility.
8.3 RETURNS TO YELLOW-BALL SERVICE

Given the assumptions on cost and output in [3], a sample of nine Pennsylvania light density lines carrying between 75,000 and 250,000 tons of coal per year was investigated. It appeared that under the varying scenarios presented, one of the nine had a positive net cash flow within three years. The rest showed positive flows in 9-10 years [3, Table 4a]. If the higher costs of the PRA are used, the break-even point is pushed back 1-2 years for all lines.

The break-even analysis is not entirely relevant to yellow-ball coal service because it anticipates the increases in coal output and therefore traffic density related costs. It does indicate, within the bounds of the assumptions, that light density lines need not be entirely unprofitable. What is needed is a "bankruptcy" to reduce the burden of the past capital structure. Responsibility for maintenance and operations, with ownership, would go to the mining consortium, a railroad company or, less likely, the receiver.

The mine owners would possibly find that rail ownership was the price for keeping their mines open. In this case the operation would have to be shown to be cheaper than alternative transport modes. Other advantages are found in the ability to make longer term contracts (as a group) rather than rely on a brokered spot market. Both spot contracts and lower transport costs could lead to lower cost financing for a mining consortium[1,4].

To the railroads, ownership of both a transloading facility and the light density line, with the mines owning only the yellow-ball cars and, possibly, the locomotive(s), would have to be shown to be profitable in the context of additional freight. They would give up revenues associated with single car or multiple car shipments and replace them with the lower per ton rate for unit trains. However, without the unit train rate, the coal traffic from these mines would be largely lost to the railroads in any event.

If ICC regulations were changed, it is possible to conceive of an expanded descriptor of a unit train which would permit still more mines to be competitive. This could be patterned after the old form of passenger transport on some railroads along the eastern seaboard: loaded cars would be picked up in multiple groups (say 20) at each of five small transloading facilities and either all delivered to a single destination or redivided in contiguous sections among a few receivers. The service
would be dedicated. The return trip would merely pick up the empties and drop them off at their respective transloaders. To be effective, the loading and unloading would be along a single repetitive route. The result could be more traffic for the railroads, more mines that could be opened, and a greater viability of east coast or Appalachian coal.

Aside from any benefits to the mines or immediate advantages to the railroads, there are some national considerations. At a time when, because of fuel economics, Europeans are rapidly expanding their trackage and upgrading their systems for even greater loads and speeds, the U.S. is in the process of eliminating a significant proportion of its northeast and north central trackage. An EPRI study [6] has shown that there are a number of transport linkage problems in the east. Elimination of perhaps 6,000 miles of line in twelve states will exacerbate linkage problems in the future, particularly if coal output is expected to increase. Maintenance and use of light density lines, particularly in the coal areas, is one way of maintaining a viable coal option.


