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REPORT NO. DOT-TSC-OST-79-1, III

FREIGHT TRANSPORTATION ENERGY USE

Volume III

Freight Network & Operations Database

CACI, Inc.-Federal
1815 North Fort Myer Drive
Arlington, Virginia 22209

October 1978
FINAL REPORT

Prepared for:
U.S. Department of Transportation
Transportation Systems Center
Cambridge, Massachusetts 02142

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16. Abstract

The data sources, procedures, and assumptions used to generate the TSC national freight network and operations database are documented. National rail, highway, waterway, and pipeline networks are presented, and estimates of facility capacity, travel speed, fuel consumption, and average cost are made. Commodity characteristics and interregional flows are also presented. Other volumes of the report are:

Vol. I - Summary and Baseline Results
Vol. II - Methodology and Program Documentation
Vol. IV - Analysis of Selected Energy Conservation Options

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PREFACE

This study is one part of a larger Department of Transportation effort to examine transportation energy efficiency. The study was performed by CACI, Inc. - Federal for the DOT Transportation Systems Center. The TSC technical monitors were Dr. David Anderson and Dr. Russell Cherry. Their support, encouragement, and technical aid are gratefully acknowledged. Valuable guidance and assistance were also received from Paul Hoxie, Domenic Maio, and John Murphy of TSC. CACI participants in the study were Michael Bronzini, Roger Miller, John Sabo, Catherine Schourek, Conrad Strack, and Kenneth Wright. Both TSC and CACI also wish to acknowledge the cooperation of the Army Corps of Engineers, who made available for the study the multimodal network model and data developed under their inland navigation systems analysis program.

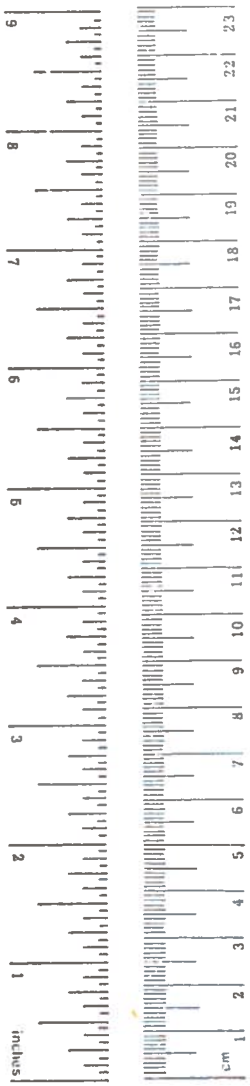
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

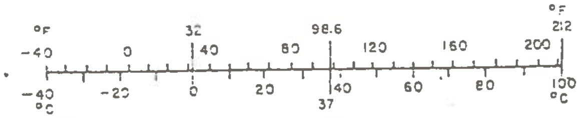
---

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

Operation of the TSC Freight Energy Model requires assembly of a rather large database. Elements of this database include national networks, facility capacity, travel speed, fuel consumption, transportation cost, and so forth. Basic modal data available in public files and published documents must be augmented by a considerable amount of analysis. Factors such as topography, route geometry, modal equipment operating capabilities, vehicle load factors, commodity characteristics, and the interrelationships between speed, fuel use, and cost must all be accounted for in developing modal operations data. Finally, care must be taken throughout the lengthy database gestation period to maintain comparability across all modes, in order to avoid imposing unintended biases upon the model's operation.

The data sources, procedures, and assumptions used to generate the TSC national freight network and operations database are documented in this volume. The remainder of this chapter describes the transportation network. Succeeding chapters take up rail, highway, waterway, and pipeline data. Commodity characteristics and interregional flows are presented in the final chapter.

Transportation Network

Figure 1-1 is a computer plot of the national multimodal intercity freight network included in the TSC database. This network is a condensed or aggregated and combined version of several individual modal networks obtained from various sources. As can be observed in the figure, the essential linehaul configuration and spatial organization of the more detailed modal networks survived the aggregation process rather well.

- Rail

The railroad network is an aggregated version of a large and detailed national network developed by the Federal Railroad Administration (FRA) (1,2). The original network contained 16,341 nodes and 19,476 links. In contrast, the TSC version contains 895 nodes and 1,754 links. The procedures used to eliminate the network detail not needed for national level analysis are described in a separate report (3). Basic rail network data include link length, number of tracks, type of signal system, and owning railroad.

- Highway

The highway network is based on a national network developed by the Federal Highway Administration (FHWA). The original FHWA network, which contained 3,041 nodes and 4,528 links, was aggregated to 582 nodes and 1,292 links following procedures described in a separate report (4). Highway link data include length, physical highway type, terrain, and identification of toll roads.

- Waterway

The inland waterway network is that developed by the Corps of Engineers for their Inland Navigation Systems Analysis (INSA) program (5). This network covers the Mississippi River-Gulf Coast and tributaries inland waterway system, and originally contained 397 nodes and 400 links. The TSC version of this network excludes some ports and channels of a local or intraregional nature, and contains 252 nodes and 255 links. Atlantic Coast, Pacific Coast, and New York-New England waterways, the Great Lakes, and all coastwise shipping lanes are presently excluded. * Detailed lock and channel data are available for the inland waterway network.

- Pipeline

The pipeline network was extracted from an aggregated representation of petroleum and natural gas pipelines in the United States and Canada developed for TSC by J.G. Debanne (6). Natural gas pipelines, Canadian pipelines, and offshore oil tanker routes in the Debanne network were deleted. The remaining petroleum pipeline network contains 60 nodes and 96 links, representing both crude and products pipelines. Key data elements for pipeline segments include length and flow capacity.

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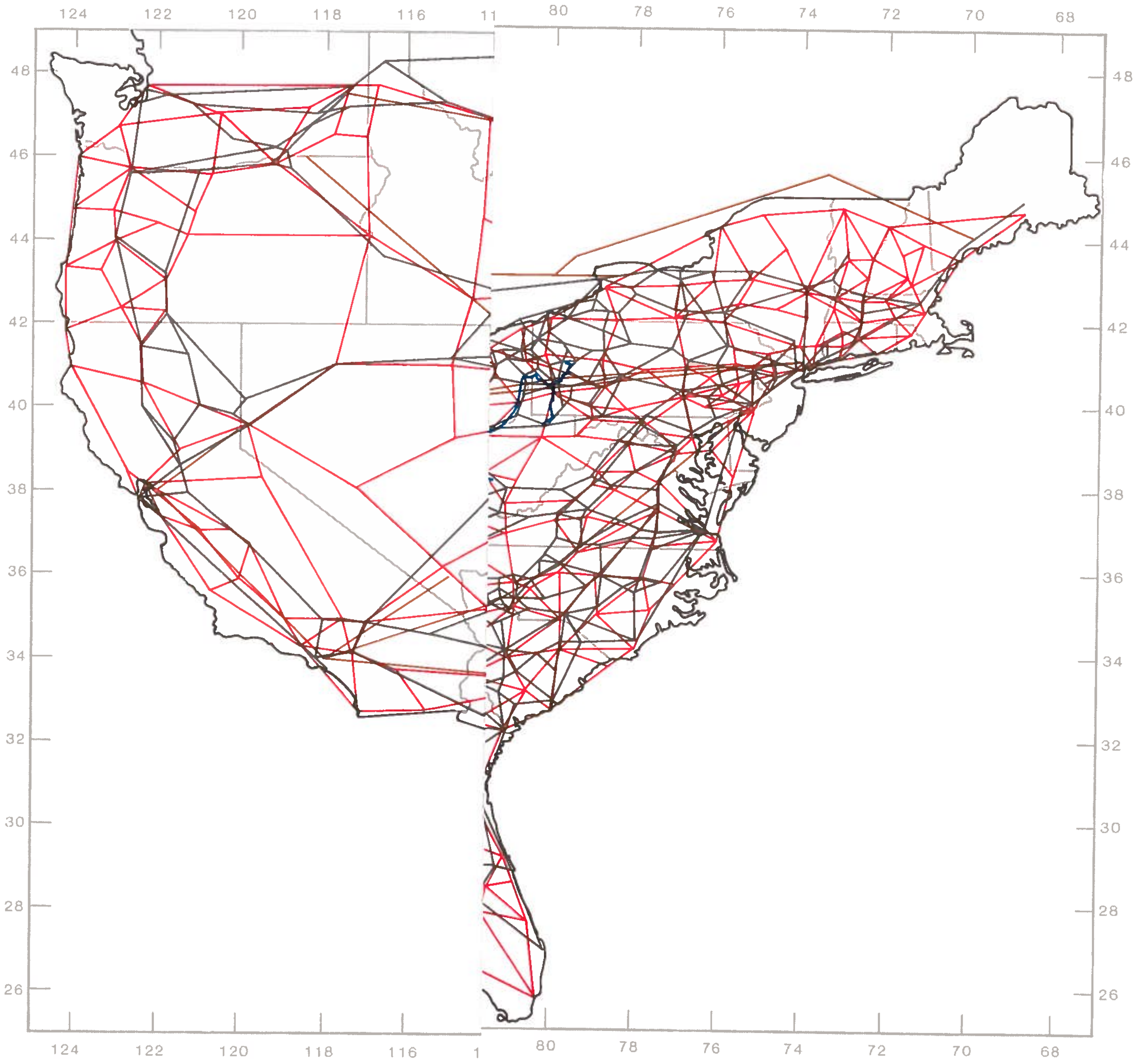
* Preliminary network data for these waterways has recently been compiled by the Corps of Engineers.

Figure 1-1



This computer plot is based on network data develo
Larger working versions of the plot usually display ir
access to the national network, and network place r
cost, capacity, and energy usage functions for each
3.7° of latitude or longitude (1 cm = approximately 1

- Highway
- Pipeline
- Rail
- Waterway

U.S. Department of Transportation
Transportation Systems Center
Cambridge, Massachusetts 02142

September 1977

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Regions

The origins and destinations of the commodity traffic which is moved through the transportation network are identified according to the functional economic areas defined by the Bureau of Economic Analysis (BEA) of the Department of Commerce, commonly referred to as "BEA regions" (BEAR's). There are 171 BEAR's in the contiguous U.S. mainland. These are shown in Figure 1-2 and further identified in Table 1-1.

- Access Links

Connections between the regions and the network are provided by a set of access links, which represent pick-up and delivery and local (intraregional) goods movement. All access links were defined by CACI using network plots showing the approximate regional center of economic activity and giving due consideration to network density, regional development density, and commodity flow patterns. The number of access links for each mode is shown in Table 1-2.

Network Summary

The TSC national freight network is an aggregated represenation of the U.S. freight transportation infrastructure, and was built from more detailed networks developed by FRA, FHWA, the Corps of Engineers, and TSC. A summary of the overall size of this network is given in Table 1-2.

There are presently no intermodal transfer links in the network data, although the TSC Freight Energy Model provides for such linkages. The primary reason for this is that there is no existing national network data on transfer facilities, and there are no available modal simulators which can be used to develop intermodal transfer capacity, cost, and energy-use estimates comparable to and consistent with the linehaul and access data presented in succeeding chapters. Also, as explained in chapter six, the commodity flow data available for this effort preclude meaningful consideration of intermodal transfer operations.

Table 1-1. BEA Regions

1	BANGOR, ME
2	PORTLAND-SOUTH PORTLAND, ME
3	BURLINGTON, VT
4	BOSTON, MA
5	HARTFORD, CT
6	ALBANY-SCHENECTADY-TROY, NY
7	SYRACUSE, NY
8	ROCHESTER, NY
9	BUFFALO, NY
10	ERIE, PA
11	WILLIAMSPORT, PA
12	BINGHAMTON, NY-PA
13	WILKES-BARRE-HAZLETON, PA
14	NEW YORK, NY
15	PHILADELPHIA, PA-NJ
16	HARRISBURG, PA
17	BALTIMORE, MD
18	WASHINGTON, DC-MD-VA
19	STAUNTON, VA
20	ROANOKE, VA
21	RICHMOND, VA
22	NORFOLK-PORTSMOUTH, VA
23	RALEIGH, NC
24	WILMINGTON, NC
25	GREENSBORO, NC
26	CHARLOTTE, NC
27	ASHEVILLE, NC
28	GREENVILLE, NC
29	COLUMBIA, SC
30	FLORENCE, SC
31	CHARLESTON, SC
32	AUGUSTA, GA
33	SAVANNAH, GA
34	JACKSONVILLE, FL
35	ORLANDO, FL
36	MIAMI, FL
37	TAMPA-ST. PETERSBURG, FL
38	TALLAHASSEE, FL
39	PENSACOLA, FL
40	MONTGOMERY, AL
41	ALBANY, GA
42	MACON, GA
43	COLUMBUS, GA-AL
44	ATLANTA, GA
45	BIRMINGHAM, AL
46	MEMPHIS, TN-AR
47	HUNTSVILLE, AL
48	CHATTANOOGA, TN-GA
49	NASHVILLE, TN
50	KNOXVILLE, TN
51	BRISTOL, VA-TN
52	HUNTINGTON-ASHLAND, WV-KY-OH
53	LEXINGTON, KY
54	LOUISVILLE, KY-IN
55	EVANSVILLE, IN-KY
56	TERRE HAUTE, IN
57	SPRINGFIELD, IL
58	CHAMPAIGN-URBANA, IL
59	LAFAYETTE-W. LAFAYETTE, IN
60	INDIANAPOLIS, IN
61	ANDERSON, IN
62	CINCINNATI, OH-KY-IN
63	DAYTON, OH
64	COLUMBUS, OH
65	CLARKSBURG, WV
66	PITTSBURGH, PA
67	YOUNGSTOWN-WARREN, OH
68	CLEVELAND, OH
69	LIMA, OH
70	TOLEDO, OH
71	DETROIT, MI
72	SAGINAW, MI
73	GRAND RAPIDS, MI
74	LANSING, MI
75	FORT WAYNE, IN
76	SOUTH BEND, IN
77	CHICAGO, IL
78	PEORIA, IL
79	DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
80	CEDAR RAPIDS, IA
81	DUBUQUE, IA
82	ROCKFORD, IL
83	MADISON, WI
84	MILWAUKEE, WI
85	APPLETON-OSHKOSH, WI
86	WAUSAU, WI
87	DULUTH-SUPERIOR, MN-WI
88	EAU CLAIRE, WI
89	LA CROSSE, WI
90	ROCHESTER, MN
91	MINNEAPOLIS-ST. PAUL, MN
92	GRAND FORKS, ND
93	MINOT, ND
94	GREAT FALLS, MT
95	BILLINGS, MT
96	BISMARK, ND
97	FARGO-MOOREHEAD, ND-MN
98	ABERDEEN, SD
99	SIOUX FALLS, SD
100	RAPID CITY, SD
101	SCOTTSBLUFF, NE
102	GRAND ISLAND, NE
103	SIOUX CITY, IA-NE
104	FORT DODGE, IA
105	WATERLOO, IA
106	DES MOINES, IA
107	OMAHA, NE-IA
108	LINCOLN, NE
109	SALINA, KS
110	WICHITA, KS
111	KANSAS CITY, MO-IL
112	COLUMBIA, MO
113	QUINCY, IL
114	ST. LOUIS, MO-IL
115	PADUCAH, KY
116	SPRINGFIELD, MO
117	LITTLE ROCK-NORTH LITTLE ROCK, AR
118	FORT SMITH, AR-OK
119	TULSA, OK
120	OKLAHOMA CITY, OK
121	WICHITA FALLS, TX
122	AMARILLO, TX
123	LUBBOCK, TX
124	ODESSA, TX
125	ABILENE, TX
126	SAN ANGELO, TX
127	DALLAS, TX
128	KILLEEN-TEMPLE, TX
129	AUSTIN, TX
130	TYLER, TX
131	TEXARKANA, TX-AR
132	SHREVEPORT, LA
133	MONROE, LA
134	GREENVILLE, MS
135	JACKSON, MS
136	MERIDIAN, MS
137	MOBILE, AL
138	NEW ORLEANS, LA
139	LAKE CHARLES, LA
140	BEAUMONT-PORT ARTHUR-ORANGE, TX
141	HOUSTON, TX
142	SAN ANTONIO, TX
143	CORPUS CHRISTI, TX
144	MCALLEN-PHARR-EDINBURG, TX
145	EL PASO, TX
146	ALBUQUERQUE, NM
147	COLORADO SPRINGS, CO
148	DENVER, CO
149	GRAND JUNCTION, CO
150	CHEYENNE, WY
151	SALT LAKE CITY, UT
152	IDAHO FALLS, ID
153	BUTTE, MT
154	SPOKANE, WA
155	SEATTLE-EVERETT, WA
156	YAKIMA, WA
157	PORTLAND, OR-WA
158	EUGENE, OR
159	BOISE CITY, ID
160	RENO, NV
161	LAS VEGAS, NV
162	PHOENIX, AZ
163	TUCSON, AZ
164	SAN DIEGO, CA
165	LOS ANGELES-LONG BEACH, CA
166	FRESNO, CA
167	STOCKTON, CA
168	SACRAMENTO, CA
169	REDDING, CA
170	EUREKA, CA
171	SAN FRANCISCO-OAKLAND, CA

Figure 1-2

DEPARTMENT OF COMMERCE

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Table 1-2. Size of the TSC National Freight Network

Transport Mode	Number of Network Elements			
	Nodes	Linehaul Links		Access
		Number	Miles	
Rail	895	1,754	102,709	175
Highway	582	1,292	103,578	194
Waterway	252	255	6,810	129
Pipeline	60	96	25,983	144
Total	1,789	3,397	239,080	642

II. RAIL FREIGHT OPERATIONS DATA

Introduction

A rail trip can be viewed as a combination of three elements: access links, nodes, and linehaul links. If the travel time, cost, and energy consumption characteristics of these elements are known, they can be summed to estimate rail trip time, cost, and energy consumption. With detailed knowledge about each link and node it might be possible to make very fine estimates of trip cost, time, and energy consumption. However, it would be very expensive to generate this information and, since the rail network is an abstraction from the actual rail system, detailed information about individual links and nodes is not available. So, the approach taken in this study is to group links with similar time, cost, and energy characteristics together and assign a single cost, time, and energy function to each group. This chapter describes the groupings (classes) and data used in defining rail time, cost, and energy functions.

Before proceeding with the function definitions and data, a more detailed description of what part of a rail trip is included in an access link, a linehaul link, and a node is in order. Figure 2-1 presents a schematic diagram of this trip breakdown. An access link occurs at each end of the rail trip. It includes the pick-up or delivery and the time spent in the rail terminal where the linehaul portion of the trip begins or ends.

A linehaul link includes that portion of the rail trip between the origin and destination terminals where the shipment or car is moving or is delayed on a siding.

Finally, nodes include activities which occur in intermediate yards or at interchange points.

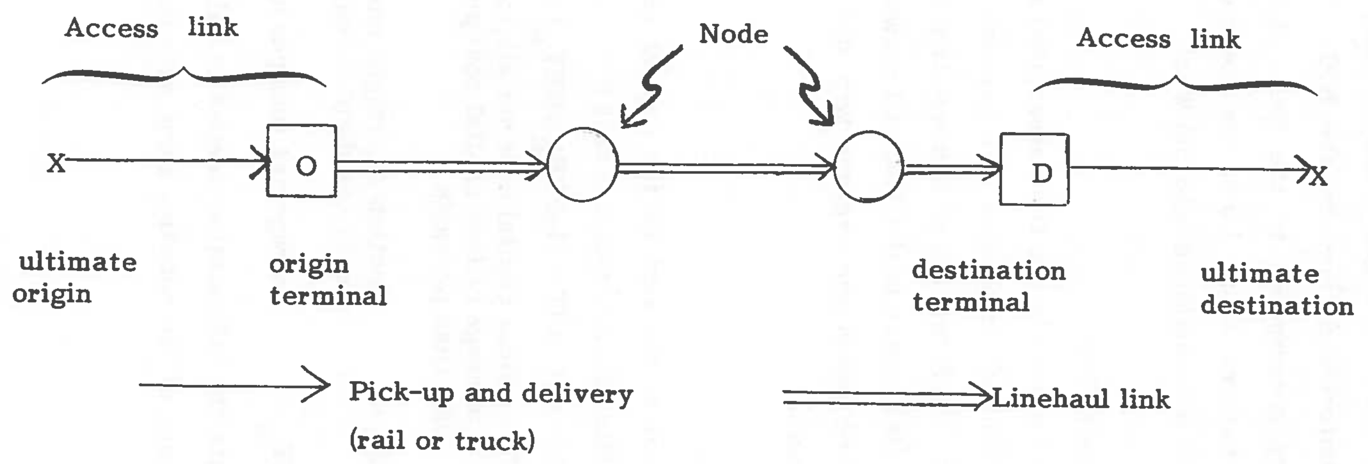

Figure 2-1. Rail Trip Components

Nodes

- Node Classes

Node classes are based on region: East, South, or West. Figure 2-2 shows the railroad territories defined by the ICC. In node classification, the Official territory corresponds to the East, the Southern territory to the South, and the Western Trunk Line, the Southwestern, and the Mountain-Pacific territories are combined into the West.

- Node Transit Time

The time spent at a node is the time associated with intermediate yards and interchanges. Reebie (7) estimates 3.92 days are spent in these activities on the average trip. AAR reports an average trip length of 511 miles in 1972. The average rail link length in the TSC rail network is 59 miles, so there are (511/59 - 1) = 7.66 nodes per average trip and the average node causes a delay of 12.28 hours.

- Node Cost

Node cost is equal to the sum of the capital cost of idle railcars plus the switching cost. Idle railcar capital cost is :

$$RCC = (CC \times IT \times (1+FEB_R)/NET_R) \times 1000$$

where
RCC= railcar capital cost per kiloton
CC = average railcar capital cost per hour
IT = idle time per node

FEB_R = fraction of freight movements which result in an empty backhaul in region R

NET_R = average net tons per loaded car in Region R

Table 2-1 presents the information needed to calculate idle railcar cost per node for each region of the country, along with the calculated cost.

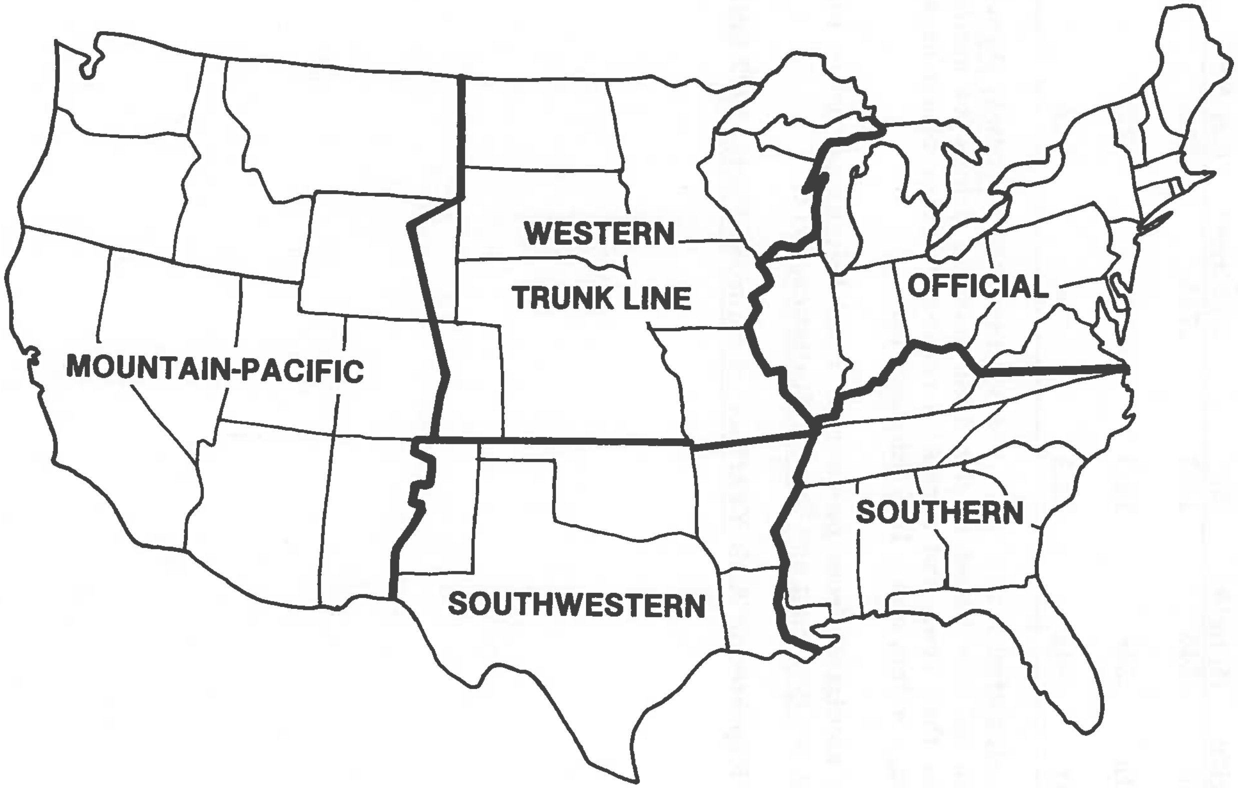

Figure 2-2. ICC Railroad Territories

Table 2-1. Regional Railroad Operating Parameters (1972)

Region	Railcar Capital Cost ($/Hr) *	Idle Time Per Node (hr)	Fraction Empty Return**	Net Tons Per Loaded Car ***	Railcar Capital Cost Per Kiloton Per Node
East	.246	12.3	.768	54.6	$97.98
South	.246	12.3	.832	59.3	$93.48
West	.246	12.3	.748	56.0	$94.45

* Calculated from: 1970 costs presented in Railway Age, Nov. 29, 1976, p. 3; an inflator based on the AAR index of prices for materials and supplies other than fuel; and a capital recovery factor based on a 20 yr. life, 10% salvage value, and a 10% interest rate.

** Calculated from percent of total freight car miles loaded reported by AAR in Operating and Traffic Statistics, 1972.

*** Reported in AAR Yearbook of Railroad Facts, 1977 Edition, p. 40.

The switching cost is associated with the interchange switch and the intertrain and intratrain switch. The times for these activities are shown in Table 2-2. Deboer (8) reports the average distance between yards as 200 miles. This fact, the average trip length, and number of nodes per trip along with the assumption that two interchange switches occur for every intertrain or intratrain switch yields the regional switch minutes per car per node shown in Table 2-2. Switch cost is:

$$SC = (SM_R \times CPSM \times (1 + FEB_R)/NET_R) \times 1000$$

where SC = Switching cost per kiloton per node

SM_R = Switch minutes per car per node in region R

$CPSM$ = Cost per switch minute

and FEB_R and NET_R are previously defined and reported.

The results of this calculation are presented in Table 2-2 along with the data used in the calculation.

- Node Energy Use

Node energy consumption is simply the switch energy.

Switch energy is:

$$SE_R = (GPM \times SM_R\ (1 + FEB_R)/NET_R) \times 1000$$

where SE_R = switch energy (gallons/kiloton) per node in region R

GPM = switch engine fuel consumption (gallons per switch minute)

and SM_R, FEB_R and NET_R are previously defined.

Murphy (9) reports that switch engine fuel consumption is 10 gallons per hour. Fuel consumption per node is presented in Table 2-3 along with the final node time and cost estimates.

Table 2-2. Switch Costs per Node by Region

Region	Interchange Switch Time Per Car (Min.)	Intertrain and Intratrain Switch Time Per Car (Min.) *	Ave Switch Time Per Node Per Car (Min.)	Cost Per Switch Min ($) **	Switch Cost Per Kiloton Per node
East	13.9	4.0	3.5	.98	$112.05
South	12.6	2.9	3.2	.98	$ 95.45
West	14.1	3.2	3.7	.98	$111.87

* Rail Carload Cost Scales 1973, ICC, pp. 138, 140.

** Ref. (9), p. 76.

Table 2-3. Rail Node Time, Cost, and Energy

Region	Time (Hrs)	Cost ($/Kton)	Energy (Gal/Kton)	Energy (BTU/Ton) *
East	12.3	210.03	18.89	2620
South	12.3	188.93	16.48	2285
West	12.3	206.32	19.25	2670

* 1 gal.=138,690 BTU

- Rail Node Commodity Factors

The average net tons per loaded car, the ratio of empty to loaded car miles, and the average railcar cost vary depending on the commodity shipped. Since these parameters affect node cost and energy consumption, commodity specific time, cost and energy adjustment factors are developed which, when multiplied by the standard time, cost and energy estimates in Table 2-3, yield estimates which are appropriate for the commodity in question. Table 2-4 presents the commodity specific parameters along with the resultant adjustment factors.

Table 2-4. Commodity Adjustment Factors for Rail Nodes

Commodity	STCC	Net tons Per Loaded Car (1)	Fraction Empty Return (2)	Average Railcar Capital Cost/hr. (3)	Adjustment Factor Time	Adjustment Factor Cost	Adjustment Factor Energy
Field Crops	01	70.6	.90	.217	1.0	.85	.85
Forestry & Fishery Products	08,09	--	--	--	--	--	--
Metallic ores	10	80.7	.95	.208	1.0	.77	.77
Coal *	11	77.3	.91	.185	.5	.53	.53
Crude Petroleum	13	55.1	1.07	.293	1.0	1.19	1.19
Nonmetallic Minerals	14	75.2	.93	.203	1.0	.81	.81
Food & Kindred Products	20	46.2	.88	.230	1.0	1.29	1.29
Textiles & Apparel	22,23	19.7	.69	.199	1.0	2.72	2.72
Lumber & Furniture	24,25	49.0	.86	.216	1.0	1.21	1.21
Pulp, Paper & Allied Products	26	37.8	.71	.195	1.0	1.44	1.44
Chemicals	28	65.2	.99	.254	1.0	.97	.97
Petroleum & Coal Products	29	70.0	1.00	.211	1.0	.91	.91
Primary Metal Products	33	63.6	.82	.206	1.0	.91	.91
Fabricated Metal Products	34	34.4	.81	.205	1.0	1.67	1.67
Nonelectrical Machinery	35	23.5	.69	.213	1.0	2.28	2.28
Electrical Machinery	36	16.1	.70	.201	1.0	3.35	3.35
Transport Equipment	37	23.2	.70	.206	1.0	2.33	2.33
Misc. Manufactured		64.9	.91	.212	1.0	.93	.93
TOFC **		30.6	.45	.310	1.0	1.30	1.46

* One-third of the coal volume is assumed to be shipped in unit trains which do not experience node interchange or intratrain switching, or intermediate yard delay.

** Data on TOFC is taken from Reebie (7), p 70.

Sources

(1) Calculated from average tons per car by railroad car type and commodity, 1972, Table B-2, and percent of tons moving on each railroad car type by commodity, 1972, Table B-5, in Ref. (10).

(2) Calculated from the ratio of empty to loaded freight car miles by railcar type in Table B-6 and the percent of tons moving on each railroad car type by commodity, 1972, Table B-5, in Ref. (10).

(3) Calculated from: the percent of tons moving on each railroad car type by commodity, 1972, Table B-5, Ref. (10); 1970 railroad car costs reported in Railway Age, Nov. 29, 1976, p. 3: an inflator based on the AAR index of prices for material and supplies other than fuel, and a capital recovery factor based on a 20 yr. life, 10% salvage value and a 10% interest rate.

Linehaul Links

- Rail Link Classes

Rail linehaul link classes are identified in Table 2-5. Horsepower per trailing ton is a characteristic of the operating policy of the railroad which owns the link. Terrain and region in combination give a general indication of track layout and operating restrictions. The exact influences of terrain and region are not known, but they include grade, curvature and speed limits. These influences are captured by using TSC's train performance calculator (TPC) over an actual route in the region-terrain class. The resulting free-speed (Table 2-6) and uncongested fuel consumption (Table 2-7) are used to estimate the time, cost and energy functions for linehaul links.

- Link Transit Time

The free speed calculated by the TPC (see Table 2-6) is used in a train delay model* to produce estimates of delay due to congestion as a function of the number of trains on the link. Figure 2-3 presents delay functions for a single track facility. The number of trains on a link per day can be converted to net kilotons per year with a constant which reflects the average net tons per train. Delay and free speed can be combined to produce an estimate of effective speed over the link. Effective speed as a function of net annual tons shipped on the link is the relationship used in the transportation network model and in the rail link cost model which will be referred to below. Figure 2-4, 2-5, and 2-6 present the set of single-track speed functions developed for each of the three regions.

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* See Volume 2 of this report.

Table 2-5. Rail Linehaul Link Classes

Terrain Type ** / Average Horsepower per gross trailing ton ***	Region *					
	East		South		West	
	Hilly	Flat or Rolling	Hilly	Flat or Rolling	Hilly	Flat or Rolling
3.0		EF130			WH130 WH230	WF130
2.5	EH125	EF125 EF225	SH125 SH225	SF125		WF125 WF225
2.0	EH120 EH220 EH320	EF120 EF220 EF320	SH120 SH220	SF120 SF220 SF320		WF120 WF220 WF320
1.7	EH117 EH217	EF117 EF217 EF317	SH117	SF117 SF217		WF117 WF217

* Based on ICC regions East = Official, South = Southern,
West = Western Trunk, Southwestern, and
Mountain Pacific.

** Based on the terrain classification in Ref. (11).

*** Calculated from data reported in AAR Statistical Summary 57, "Statistics of the Railroads of Class I", Nov., 1973, assuming the average freight locomotive has a horsepower of 2500 hp.

\# 5-digit class names shown in table are constructed as follows:

Digits	Symbol (Meaning)
1	E (East), S(South), W(West)
2	F (Flat), H (Hilly)
3	1 (single track), 2 (double track), 3 (3 or more tracks)
4,5	(HP per gross trailing ton) x 10

Table 2-6. Rail Link Free Speed Travel Rates

(HR/MILE) / Speed Grouping

Region	East		South *		West	
Terrain / Horsepower Per Trailing Ton (HP/TT)	Hilly	Flat	Hilly	Flat	Hilly	Flat
3.0	.024 / C	.023 / B	.029 / D	.025 / C	.022 / B	.019 / A
2.5	.025/ C	.023/ B	.029/ D	.026 / C	STALLED	.019 / A
2.0	.027/ C	.023/ B	.031/ D	.026 / C	STALLED	.020 / A
1.7	.029/ D	.024/ C	.033 / D	.027 / C	STALLED	.020/ A
Representative Route (Round Trip)	Allentown to Buffalo	Weehauken to Buffalo via Selkirk	see note	see note	Los Angeles to N. Platte via Salt Lake City	Topeka to Tucumcari

* Since no track charts were accessible, free speed in the south was calculated from those of the East and West using the formula

$$S_s = \frac{1}{2}\left(\frac{S_E A_S}{A_E} + \frac{S_W A_S}{A_W}\right)$$

where

S_i= Speed by region (S = South, E =East, W = West)

A_i=AAR reported average Speed by region

A_E=17.4 MPH or .057 HR/mi

A_S=16.5 MPH or .061 HR/mi

A_W=23.5 MPH or .043 HR/mi

Table 2-7. Rail Link Free Speed Fuel Consumption

Horsepower per Trailing Ton (HP/TT)	Trailing Ton-Miles/Gallon		
	Hilly		Flat or Rolling
3.0	423		548
2.5	483	South and East	567
2.0	520	South and East	596
1.7	552	South and East	625

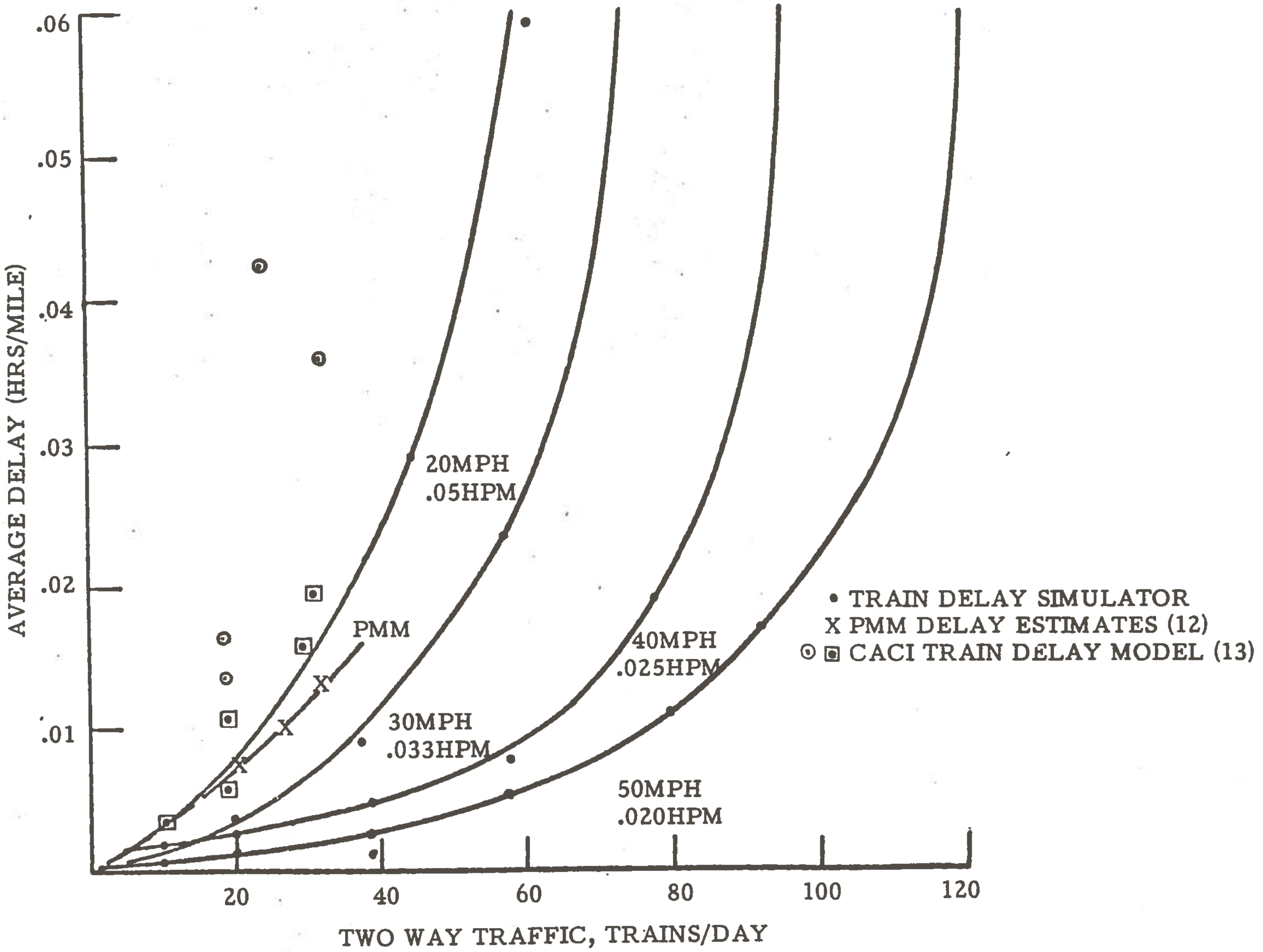


Figure 2-3. Single Track Train Delay Functions

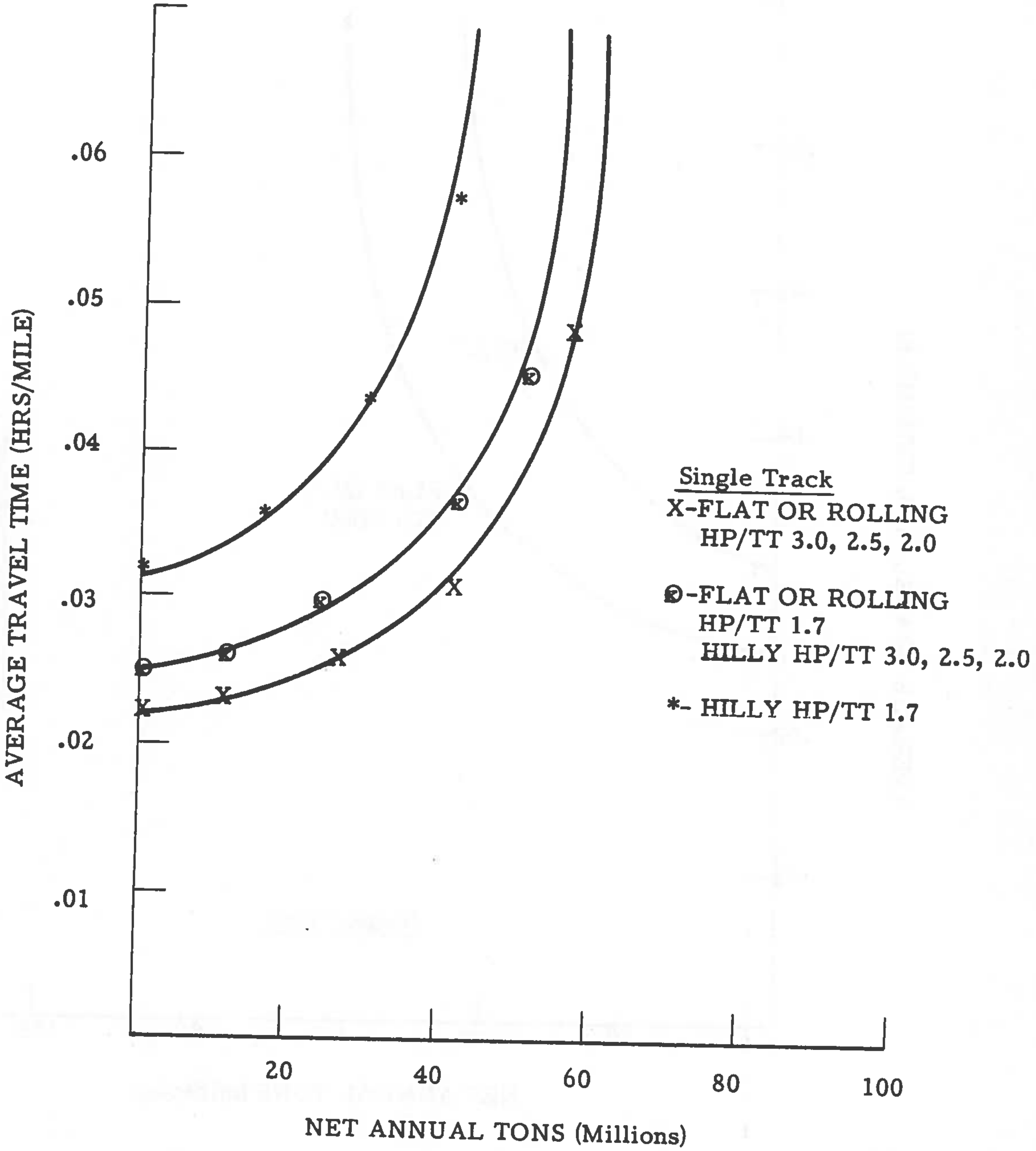


Figure 2-4. Eastern Region Rail Time Functions

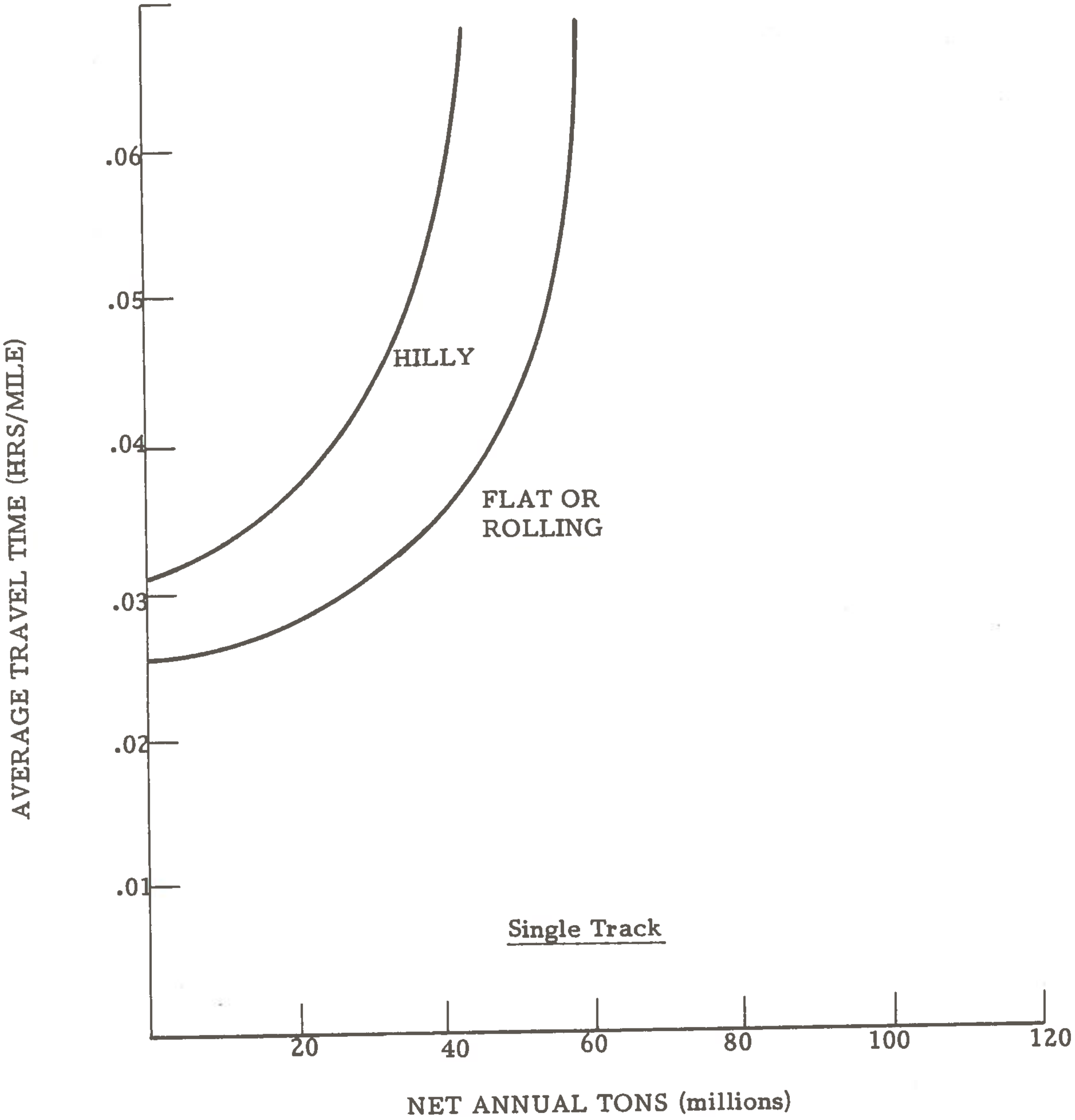


Figure 2-5. Southern Region Rail Time Functions

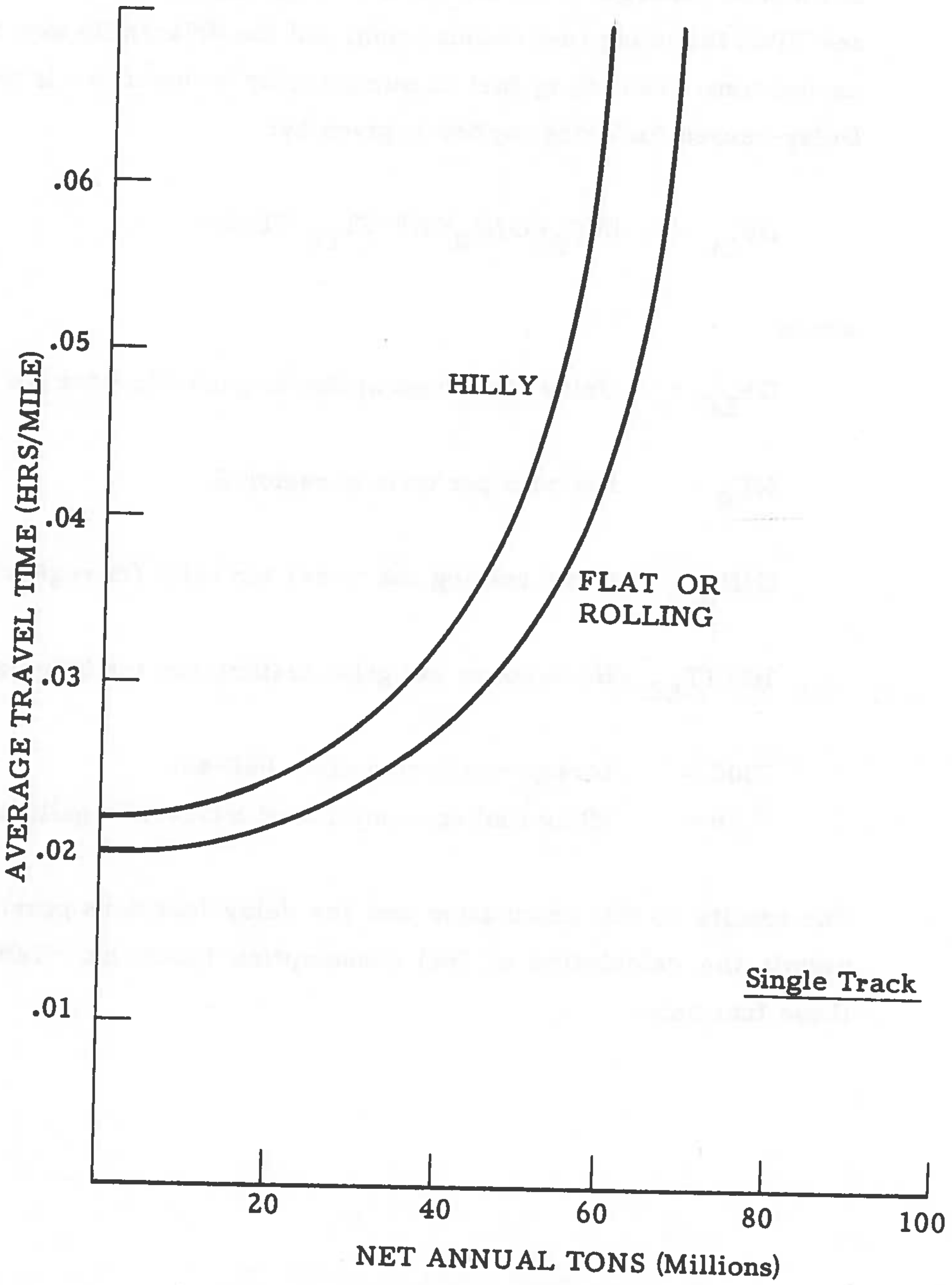


Figure 2-6. Western Region Rail Time Functions

- Link Energy Consumption

Three variables permit the calculation of fuel consumption as a function of net annual tonnage. They are the fuel consumption on the route produced by the TPC; the idling fuel consumption; and the delay/mile as a function of net annual tons. The idling fuel consumption by locomotives is presented in (9). Delay-caused fuel consumption is given by:

$$DF_{LC} = (NT_R \cdot G/N_R \cdot HP/TT_{LC}/3000)6$$

where

DF_{LC} = Delay fuel consumption in gal/train-hour for link class LC

NT_R = Net tons per train in region R

G/N_R = Gross trailing ton to net ton ratio for region R

HP/TT_{LC} = Horsepower per gross trailing ton for link class LC

3000 = horsepower/locomotive (GP-40)
6 = Idling fuel consumption of a GP-40 in gallons/hour

The results of this calculation and the delay functions previously presented permit the calculation of fuel consumption functions. Table 2-8 presents these functions.

Table 2-8. Fuel Consumption by Rail Link Class (Gal/net ton-mile)

Link Class	Vol.: Net Annual Tons (Millions)				Consumption at .07 hrs/mile	Vol.
	0	20	40	60		
EF130	.0040	.0040	.0041	.0044	.0046	62
EF125	.0038	.0038	.0039	.0041	.0043	62
EF120	.0036	.0036	.0037	.0039	.0040	62
EF117	.0035	.0035	.0036	-	.0038	57
EH130	.0051	.0051	.0052	-	.0057	57
EH125	.0045	.0045	.0046	-	.0050	57
EH120	.0042	.0042	.0043	-	.0046	57
EH117	.0039	.0039	.0041	-	.0042	45
SF130	.0039	.0039	.0040	-	.0047	59
SF125	.0038	.0038	.0039	-	.0043	59
SF120	.0036	.0036	.0037	-	.0040	59
SF117	.0034	.0034	.0035	-	.0037	59
SH130	.0051	.0052	.0054	-	.0056	45
SH125	.0045	.0046	.0048	-	.0049	45
SH120	.0041	.0042	.0043	-	.0044	45
SH117	.0039	.0039	.0041	-	.0042	45
WF130	.0042	.0042	.0043	.0045	.0049	70
WF125	.0040	.0040	.0041	.0043	.0046	70
WF120	.0038	.0038	.0039	.0040	.0043	70
WF117	.0037	.0037	.0038	.0039	.0041	70
WH130	.0054	.0054	.0056	.0060	.0061	61

- Rail Linehaul Costs

Rail linehaul link cost functions are based on the fuel consumption and effecive speed functions developed earlier and on train and operating characteristics. The model used to calculate the cost functions is described in Volume 2 of this report. Table 2-9 presents a list of the train and operating data used to generate costs. Figures 2-7 through 2-11 present the cost functions for the major linehaul link classes. High cost at low annual volume results from the fixed costs of maintaining the roadway. High costs at high annual volumes result from high locomotive and railcar capital cost caused by large congestion delays.

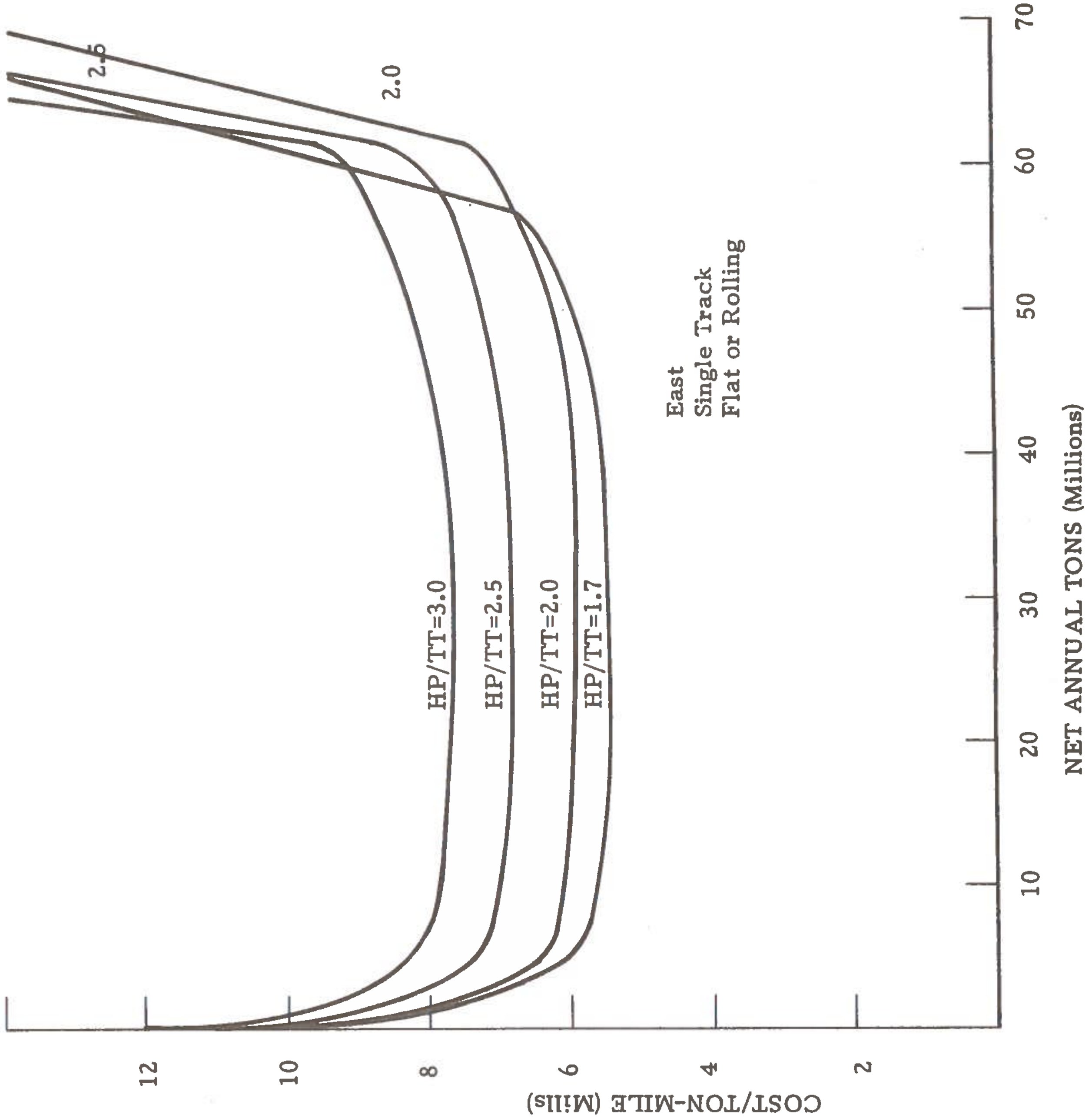
In general lower HP/TT classes have lower cost at any volume. This results from fewer locomotives per net-ton and less sensitivity to locomotive capital costs. A countering effect is that lower HP/TT results in slightly lower speed and more delay (see Figure 2-3). A comparison between the 1.7 HP/TT function and the other functions in the eastern region illustrates this effect. However, because only four discrete speed classes were used, this effect is only apparent in the east.

- Rail Link Commodity Factors

As with the node classes, commodities differ substantially with regard to the average attributes influencing cost. Average net tons per car, average car tare weight, car cost, and fraction empty backhaul combine to produce commodity-specific linehaul cost adjustment factors. Table 2-10 presents this information along with the linehaul link adjustment factors.

Table 2-9. Sample Rail Linehaul Cost Data

Train		
	Horsepower/Trailing Ton	3.0
	Number of Loaded Cars	35.30
	Number of Empty Cars	0.0
	Fraction of Empty Backhaul	.768
	Interest Rate	.100
Roadway	1 Track	
	Welded (1) or Jointed (2)	2.
	K1-Inspection	.830
	K2-Rails	.830
	K3-Ties	.830
	K4-Surfacing	.830
	Investment, ¢ per Gross Trailing Ton	.023
	Investment Life (years)	25
Locomotive		
	Maintenance/Mile ($)	.55
	Horsepower/Locomotive	3000
	Locomotive Weight (tons)	133
	Value/Locomotive ($)	360000
	Salvage (fraction)	.100
	Locomotive Life (years)	15
	Annual Hours Utilization	3482
Railcar		
	Tare Weight (tons)	30.2
	Maintenance/Mile ($)	.032
	Value/Car ($)	18661
	Salvage (fraction)	.100
	Railcar Life (years)	20
	Annual Hours Utilization	8760
	Net Tons/Loaded Car	54.6
Miscellaneous		
	Crew Cost/Mile ($)	2.72
	Fuel Cost/Gallon ($)	.12
	Helper Locomotive, Mills/Ton-Mile	0.0
	Inflator/Deflator from 1972	1.00
	Factor to convert to gallons	.460
	Misc.Costs ¢/Gross Trailing Ton-Mile	.0740



East
Single Track
Flat or Rolling
HP/TT=3.0
HP/TT=2.5
HP/TT=2.0
HP/TT=1.7
2.5
2.0
COST/TON-MILE (Mills)
2
4
6
8
10
12
NET ANNUAL TONS (Millions)
10
20
30
40
50
60
70

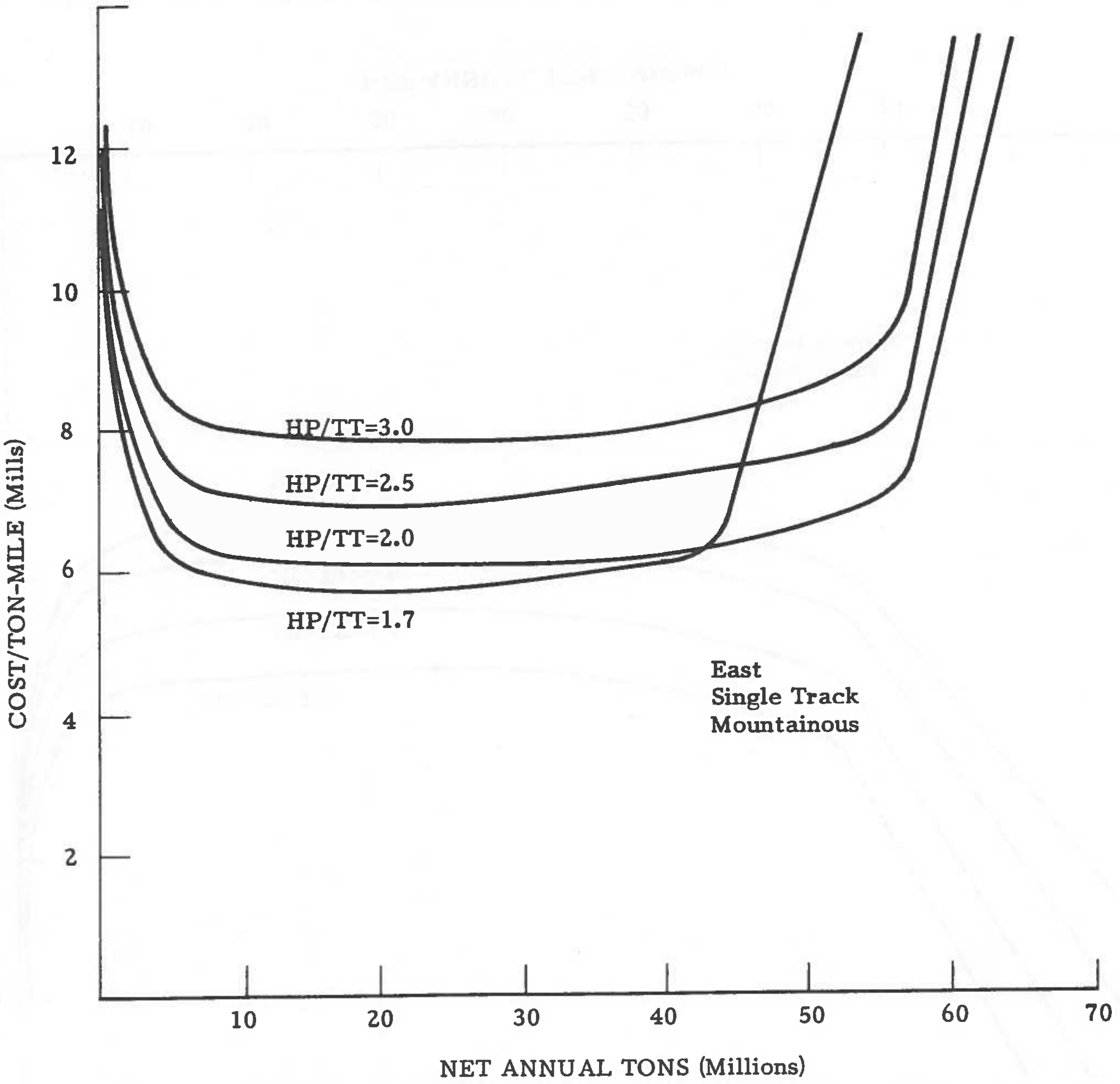


Figure 2-8. Rail Linehaul Link Cost Functions, East

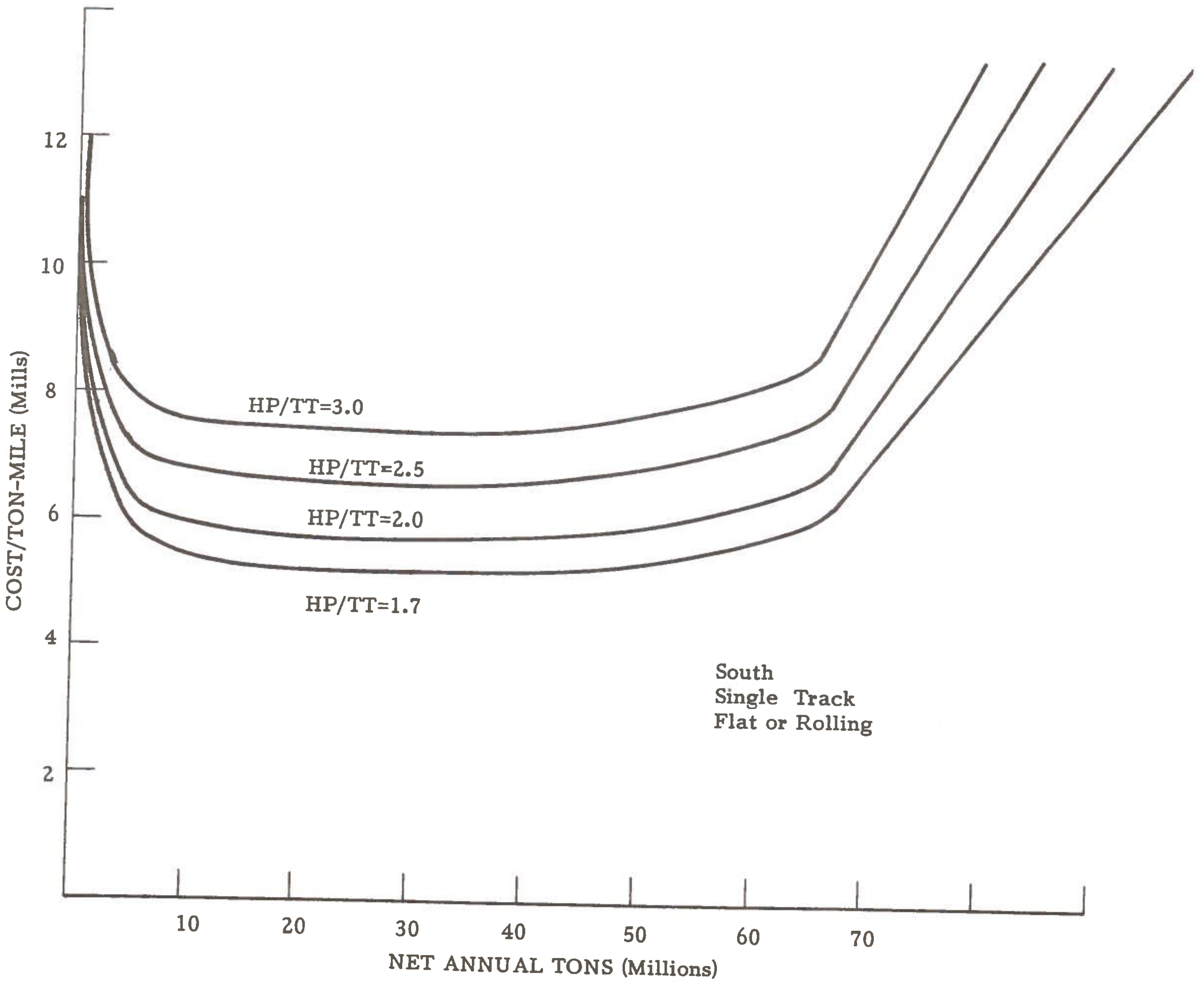


Figure 2-9. Rail Linehaul Cost Functions, South

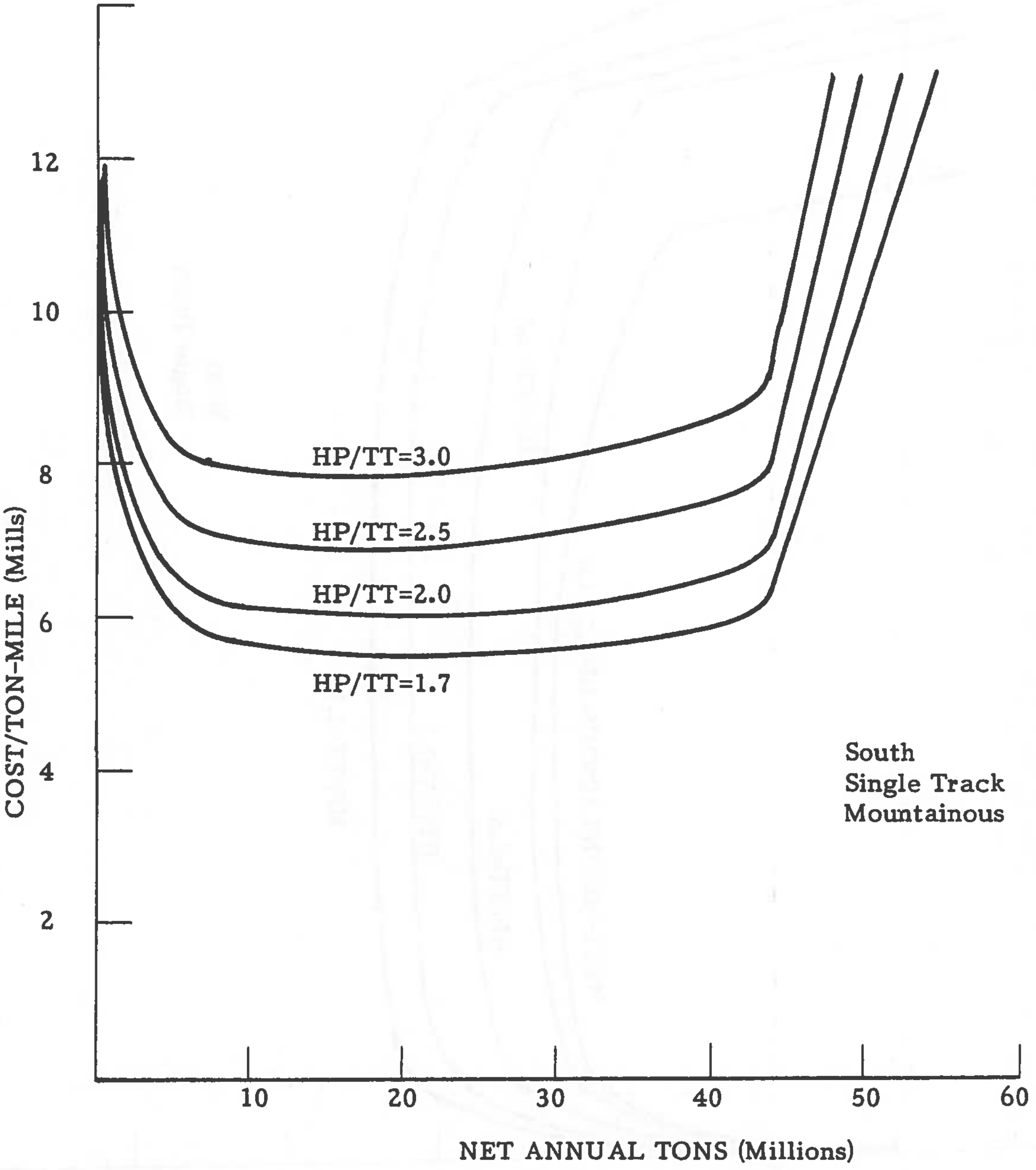


Figure 2-10. Rail Linehaul Cost Functions, South

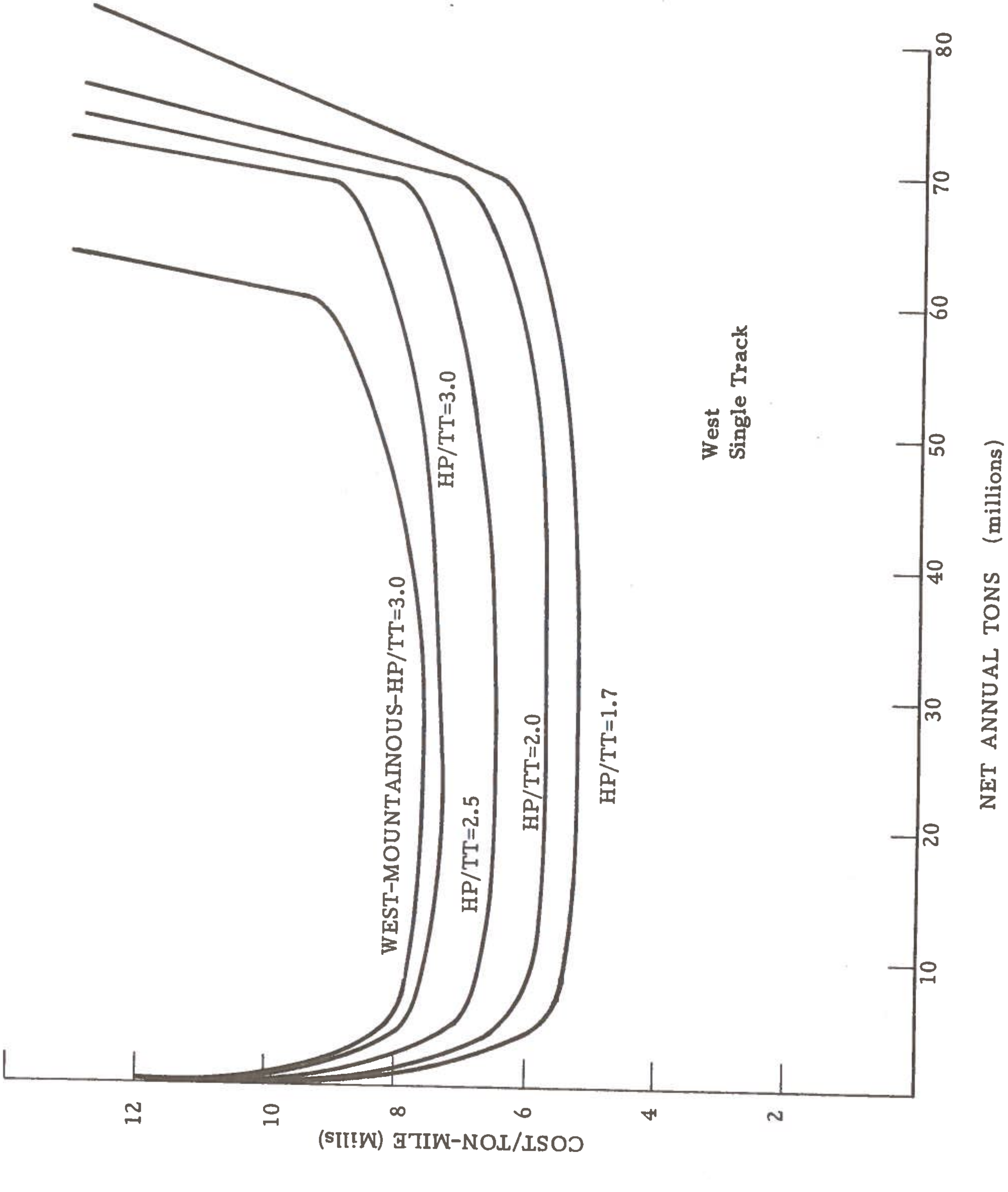

West
Single Track
WEST-MOUNTAINOUS-HP/TT=3.0
HP/TT=3.0
HP/TT=2.5
HP/TT=2.0
HP/TT=1.7
COST/TON-MILE (Mills)
12
10
8
6
4
2
NET ANNUAL TONS (millions)
10
20
30
40
50
60
70
80

Table 2-10. Commodity Adjustment Factors for Rail Linehaul Links

Commodity	STCC	Net Tons/Car [1]	Car Tare [2] Weight (tons)	Car Cost [1]	Fraction Empty [1] Backhaul	Commodity Adjustment Factors Time	Cost	Energy
Field Crops	01	70.6	30.4	$16,458	.90	1.0	.94	.92
Forestry & Fishery	08,09	---	---	---	---	1.0	1.0	1.0
Metallic Ores	10	80.7	28.8	$15,719	.95	1.0	.89	.86
Coal*	11	77.3	26.1	$13,981	.91	1.02	.75	.70
Crude Petroleum	13	55.1	31.1	$22,198	1.07	1.0	1.16	1.10
Non-Metallic Minerals	14	75.2	28.0	$15,358	.93	1.0	.91	.87
Food & Kindred	20	46.2	32.6	$17,418	.88	1.0	1.18	1.18
Textiles & Apparel	22,23	19.7	32.2	$15,036	.69	1.0	1.85	1.90
Lumber & Furn	24,25	49.0	31.3	$16,357	.86	1.0	1.11	1.11
Paper & Allied	26	37.8	30.7	$14,745	.71	1.0	1.19	1.21
Chemicals	28	65.2	31.2	$19,211	.99	1.0	1.03	.99
Petro & Coal Prod.	29	70.0	27.0	$16,000	1.00	1.0	.96	.90
Primary Metals Prod.	33	63.6	31.1	$15,558	.82	1.0	.95	.96
Fab, Metals	34	34.4	31.3	$15,532	.81	1.0	1.33	1.34
Non-Elect, Machinery	35	23.5	35.4	$16,128	.69	1.0	1.70	1.79
Elect Machinery	36	16.1	32.6	$15,228	.70	1.0	2.18	2.25
Transport Equipment	37	23.2	33.3	$15,618	.70	1.0	1.68	1.74
Misc. Manuf.**		64.9	30.2	$16,087	.91	1.0	.97	.95
TOFC***		30.6	46.1	$23,483	.45	1.0	2.03	1.93

* One-third of the coal volume is transported in unit trains which have 4 locomotives and 70% lower horsepower per trailing ton.

** Predominantly stone, glass and clay products.

*** TOFC is assumed to use 1/3 higher HP/TT.

SOURCES

1) See Table 2-4 for source.
2) Calculated from average tare weight by car type, Table B-6, and percent of tons moving on each railroad car type by commodity, 1972, Table B-5, Reference (10).

Access Links

- Access Link Classes

Access links are classified by the region of the country, and by the average length of the access link. Table 2-11 summarizes the classes. No distinction is made between access and egress.

- Access Time

Access time is the time it takes a rail shipment to travel from the plant to the origin of the linehaul rail trip plus the time the shipment spends at the origin rail terminal. The travel is calculated from the average access trip length and the regional average rail speed. The time at the origin is 34.4 hrs.*

- Access Cost

Access cost is the sum of the capital cost of idle railcars, the movement cost, the switching cost at the origin terminal, and a miscellaneous cost which covers rail expenses not included elsewhere. Access cost is computed as:

$$AC_c = CC_c + MC_c + SC_c + MISC$$

where

AC_c=Total access cost per kiloton for access class C

CC_c=Railcar capital cost per kiloton

MC_c=Movement cost per kiloton

SC_c=Switching cost per kiloton

$MISC$=Miscellaneous cost per kiloton

---

* This is one half of the loaded car time spent at the rail carrier terminal, reported by Reebie Associates (7).

Table 2-11. Access Link Classes

	Length	(miles)
Region	50	25
East	EAR50	EAR25
South	SOR50	EAR25
West	WSR50	WSR25

Table 2-12. Railcar Capital Cost for Access Links

Region	Capital Cost $/hr	Idle Time hrs.	Fraction Empty Return	Net Tons per car	Railcar Capital Cost per kiloton
East	.246	80	.768	54.6	$637.10
South	.246	80	.832	59.3	$607.84
West	.246	80	.748	56.0	$614.14

Railcar capital cost is:

$$CC = (RC \times IT\ (1 + FEB_R)/NET_R) \times 1000$$

where

RC = average capital cost per hour for the cars used in the access trip

IT = Idle time for the railcar associated with the access trip

FEB_R = Fraction of movements which result in an empty backhaul in region R

NET_R = Average net tons per loaded railcar in region R

Idle time is the sum of idle time at the consignee/consignor terminal plus the idle time at the origin or destination terminal. Idle time at the consignee/consignor is half of the time spent in the consignee and the consignor terminal (36.42 hrs.) because some of the time is spent at each terminal empty and some loaded or loading. The FEB_R parameter in the above equation captures the empty time. The idle time at the origin/destination is one quarter of the loaded plus empty car time (43.74 hrs*). Table 2-12 presents the railcar capital cost for idle time in the access portion of the trip along with the data used to derive it.

The movement cost is calculated using the rail cost model and the data presented in Table 2-13. Four horsepower per trailing ton, one locomotive, and half the standard crew were assumed as well. Table 2-13 also presents the cost per kiloton for a 25 and a 50 mile access trip.

---

* This is different from access time spent at the carrier terminal because the time a shipment spends in access was derived from the loaded time only.

Table 2-13. Rail Access Movement Cost

Region	Speed* (mph)	Fuel Consump.** (Ton-mi/gal.)	Ave. Railcar Tare Wt.* (tons)	Loco. Utilization (Hrs/yr.)	Cost $/Kton-mile	Cost/Kiloton 25mi	Cost/Kiloton 50mi
East	17.4	825	30.2	3482	12.69	$326.88	$653.77
South	16.5	837	29.4	4060	13.08	$317.14	$634.28
West	23.5	775	31.3	3636	12.06	$301.43	$602.85

* Average for each region in 1972 reported by AAR.
** Estimate based on a Train Performance Calculator run at 16.5 mph average speed and HP/TT ratio of 4.0.

Table 2-14. Rail Access Switch Cost

Region	Switch Minutes Per car**	Cost per Switch min.** ($)	Switch cost Per Kton
East	13.7	.98	$434.75
South	11.5	.98	$348.17
West	12.8	.98	$391.55

* From ICC Rail Carload Cost Scales 1973.
** From (9), p. 76.

The switch cost is:

$$SC = (SM_R \text{ x } CPSM\ (1 + FEB_R)/NET_R) \text{ x } 1000$$

where

SM_R=switch minutes per railcar in region R.

CPSM=cost per switch minute

and FEB_R and NET_R are defined above. Table 2-14 presents data on the switch minutes per car and the cost per switch minute along with the resultant switch cost by region.

The final access cost category, miscellaneous cost, covers those costs not accounted for elsewhere. Table 2-15 presents the ICC cost categories covered by this cost. Half the average cost per originating kiloton is assigned to access. It is $770 per kiloton.

Table 2-17 presents total access cost, time, and energy by access link class.

- Access Energy

Access energy is the sum of the movement energy calculated using the TPC and the switch energy. Switch energy is

$$SE_R = (GPM \text{ x } O/DST_R\ (1 + FEB_R)/NET_R) \text{ x } 1000$$

where

GPM = switch engine fuel use (gallons per minute)

O/DST = switch time at the origin or destination rail terminal

and FEB_R and NET_R are defined above. Table 2-16 presents the data for this calculation along with the result by region.

- Rail Access Commodity Factors

Once again commodities vary significantly in access cost, time, and energy, so a set of adjustment factors are developed which account for this variation. These factors are based on the data in Table 2-18. When these factors are multiplied by the standard access link class data of Table 2-17 they produce good estimates of commodity access time, cost, and energy consumption.

Table 2-15. Miscellaneous Access Costs

ICC Account	Cost Category
202-221	Roadway Maintenance – Yard Track and Way Track
351-360	Traffic Expenses
	Transportation - Rail Line
371	Superintendance
372	Dispatching trains
373	Station employees
374	Weighing, inspection and demurrage bureaus
376	Station supplies and expenses
377	Yardmasters and clerks
389	Yard supplies and expenses
390-391	Operating joint yards and terminals
410	Stationery and printing
411	Other expenses
414	Insurance
451-462	General Expenses

Table 2-16. Rail Access Energy

Region	Movement Energy, gal/kton		Switch Gal. Per Min.	Origin or Dest. Switch Time, Min.	Switch Energy gal/kton
	25 mi	50 mi			
East	59.3	118.7	1/6	13.7	73.9
South	57.8	114.5	1/6	11.5	59.2
West	64.3	128.5	1/6	12.8	66.6

Table 2-17 Rail Access Link Time, Cost, and Energy

Access Class		Time (hrs)	Cost ($/kton)	Energy (Gal/kton)
Region	Length			
East	25	35.8	2168.73	133.2
	50	37.3	2495.63	192.6
South	25	35.9	2043.15	116.5
	50	37.4	2360.29	173.7
West	25	35.5	2077.12	130.8
	50	36.5	2378.54	195.1

Note that for use in the transportation network model node time, cost, and energy should be subtracted from these access numbers. The transport network model defines a rail trip with a node between the access link and the first rail linehaul link, whereas the cost, time, and energy estimates produced here assume that this node (the origin or destination rail terminal) is included in the access link.

Table 2-18. Commodity Adjustment Factors for Rail Access Links

Commodity	STCC	Net Tons per loaded Car (1)	Car Tare Weight (Tons) (2)	Car, Capital Cost per hour ($) (1)	Fraction Empty Backhaul (1)	Average Consignee/Consignor Terminal Time (Days) (3)	Adjustment Factors		
							Time	Cost	Energy
Field Crops	01	70.6	30.4	.217	.90	4.51	1.0	.86	.89
Forestry & Fishery Products	08,09	--*	---	---	---	---	1.0	1.0	1.0
Metallic ores	10	80.7	28.8	.208	.95	---	1.0	.83	.82
Coal**	11	77.3	26.1	.185	.91	3.95	.7	.70	.72
Crude Petroleum	13	55.1	31.1	.293	1.07	---	1.0	1.17	1.14
Non-Metallic Minerals	14	75.2	28.0	.203	.93	4.46	1.0	.63	.84
Food & Kindred Products	20	46.2	32.6	.230	.88	6.40	1.0	1.15	1.23
Textiles & Apparel	22,23	19.7	32.2	.199	.69	---	1.0	1.48	2.27
Lumber & Furniture	24,25	49.0	31.3	.216	.86	5.70	1.0	1.06	1.16
Pulp, Paper & Allied Products	26	37.8	30.7	.195	.71	5.77	1.0	1.15	1.30
Chemicals	28	65.2	31.2	.254	.99	7.50	1.0	1.02	.98
Petroleum & Coal Products	29	70.0	27.0	.211	1.00	---	1.0	.91	.90
Primary Metal Products	33	63.6	31.1	.206	.82	6.08	1.0	.90	.94
Fabricated Metal Products	34	34.4	31.3	.205	.81	5.41	1.0	1.27	1.49
Non Electrical Machinery	35	23.5	35.4	.213	.69	---	1.0	1.64	2.0
Electrical Machinery	36	16.1	32.6	.201	.70	---	1.0	2.14	2.75
Transport Equipment	37	23.2	33.3	.206	.70	5.59	1.0	1.62	2.0
Misc. Manufactured		64.9	30.2	.212	.91	5.08	1.0	.91	.9
TOFC***		30.6	46.1	.310	.45	---	0.14	1.39	1.7

* No data available - specified at the average.

** One-third of the coal traffic is assumed to be in unit trains which experience no carrier terminal switch cost or energy consumption.

*** TOFC access time is from data collected by Fay Associates (14). Other data are from Reebie (7).

SOURCES

(1) See Table 2-4 for sources
(2) See Table 2-10 for source
(3) From Ref. (7).

- Multiple Track Links

A final consideration for linehaul links deals with route segments which have multiple tracks. In these situations the volume at which a given delay occurs will be much larger than for a single-track link. Comparison of previous estimates (12) of delay as a function of number of trains reveals that a bi-directional, double-track link will handle between 3.5 and 2.75 times as many trains at a given delay as a single-track link. So, the effective speed functions for single-track links are converted to effective speed functions for double-track links by multiplying the volume associated with a given delay by 3.0. Double-track link fuel consumption functions are developed in the same manner. The cost functions are somewhat more complicated. At low annual volumes, the fixed roadway costs dominate the cost per unit while at high volumes delay is most important. A comparison between the volumes transported at the same cost in the range where roadway costs dominate reveals that between 3.5 and 2.5 times as much traffic must be moved on a two-track link to attain the same average cost as one-track link.* So, at all volumes a factor of 3 is used to multiply single-track volume and produce double-track volume at a given cost. Links with three or more tracks use a volume multiple of 5 for speed, fuel consumption, and cost.

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* At a given volume the roadway maintenance costs are only 1.75 to 2.0 times higher for a double-track than they are for a single-track link.

Summary

Rail trips are composed of three elements: access links, linehaul links and nodes. Estimates of time, cost, and energy use were developed for a number of classes of each element. Commodity to commodity variation was accounted for by a set of adjustment factors which apply to each element of the rail trip.

As a preliminary test of the cost component of this analysis, Table 2-19 presents the cost of an average trip which is 511 miles long. The analysis assumes the links are uncongested, and that the trip is completely within one region. The average revenue per ton in 1972 was $8.99. As expected, higher horsepower per trailing ton routes have higher cost than the average revenue, while low horsepower per ton routes have lower cost than revenue. This test also indicates that the costs are in the correct range and that there have been no glaring omissions nor double counting.

Table 2-19. Cost of the Average Rail Trip ($/ton)

Region	Terrain	HP/TT	Access Length 25 mi.	 50 mi.
East	Flat	3.0	$9.83	$10.48
		2.5	9.37	10.02
		2.0	8.96	9.61
		1.7	8.70	9.35
East	Hilly	3.0	9.98	10.63
		2.5	9.47	10.12
		2.0	9.00	9.65
		1.7	8.85	9.50
South	Flat	3.0	9.31	9.94
		2.5	8.90	9.53
		2.0	8.49	9.12
		1.7	8.19	8.82
South	Hilly	3.0	9.57	10.20
		2.5	9.06	9.69
		2.0	8.65	9.28
		1.7	8.34	8.97
West	Flat	3.0	9.51	10.11
		2.5	9.10	9.70
		2.0	8.64	9.24
		1.7	8.39	8.99
West	Hilly	3.0	9.61	10.21

III. HIGHWAY OPERATIONS DATA

Most of the truck operations data relate to the links of the highway network, since the nodes are generally highway intersections or interchanges which take relatively little time to traverse. Accordingly most of this chapter is devoted to development of performance functions for highway linehaul links. Highway node and access functions are taken up near the end of the chapter.

Highway Link Classes

Table 3-1 defines nine classes of highway links which can be identified using the highway network data. These nine classes are sufficient for specifying the link characteristics needed for estimating highway cost, time, and energy functions. Highway links can be further classified by geographic region if this is found to be desirable for future studies.

Consideration was also given to defining classes of highway "superlinks," or parallel coterminal route segments. Table 3-2 tabulates the types of superlinks encountered in the aggregated highway network.

Table 3-1. Highway Link Classes

Physical Type	Toll Status	Terrain Classification		
		Level	Rolling	Mountainous
Divided	Free	D.L. FREE	D.R. FREE	D.M. FREE
	Toll	D.L. TOLL	D.R. TOLL	D.M. TOLL
Undivided	Free	U. LEVEL	U. ROLLING	U. MOUNT

Table entry is the name assigned to the class for model input/output.

Table 3-2. Highway Superlinks

Principal Link		Parallel	No. of
Type	Toll/Free	Link Type	Cases
Divided	Toll	Divided	2
		Undivided	3
	Free	Divided	9
		Undivided	12
Undivided	Free	Undivided	15
			41

The raw data produced during the network aggregation process actually show 186 potential highway superlinks, but most of these can be eliminated because the parallel link is much longer than the principal link, indicating that it is not really a suitable alternative route. In some cases, the parallel link is shorter than the principal link (due to removal of an intermediate node); these cases can also be eliminated, since the capacity of the unparalleled portion of the principal link controls the overall link capacity.

The significant finding of this analysis is the extremely small number of highway superlinks. There are only 11 cases where a divided highway is paralleled by another divided highway, and 15 cases of a divided highway augmented by a parallel undivided through route. In comparison, there are nearly 1300 highway links in the network.

In view of this finding, there is scant justification for defining any classes of highway superlinks. Hence, no parallel link representations are included in the network. In the event that some of the principal links become heavily loaded during network simulations, the file of superlink data can be used to define appropriate new link classes which account for the spare capacity that is actually available.

Highway Capacity Functions

Functions relating average truck speed to the net annual commodity tonnage traversing a link are developed in this section. Two of the important determinants of tonnage capacity -- vehicle size and empty vehicle movements -- are established first, followed by the estimated speed-volume relationships.

- Vehicle Types

Analysis of data compiled by Peat, Marwick, Mitchell & Co. (PMM) in a study for TSC (10) shows that nearly 82% of intercity truck mileage is accounted for by just four basic tractor-semi-trailer combinations. Hence these four vehicle types were used throughout the present study. The relevant PMM data are given in Table 3-3. Specifications for the standard trucks, taken from Winfrey (15), appear in Table 3-4.

- Truck Load Factors

Truck capacity utilization estimates were taken from a recent ICC survey of empty truck mileage (16). The following figures for fully loaded capacity-miles (rather than vehicle-miles) on interstate trips were used:

Vehicle Type	Capacity-miles, % loaded
Van	77.0
Tank	63.2
Weighted Average	75.8

- Highway Tonnage Capacity

Typical tonnage capacities for highway links were calculated using the Highway Capacity Manual (17), following a procedure developed by Stanford Research Institute (SRI) (18). The basic procedure is to compute annual vehicular capacity, under the assumption* that trucks account for 20% of the traffic. Tonnage capacity is then obtained as:

$$Q = V \times \frac{P}{100} \times t \times L$$

where

Q = link capacity, kilotons per year

V = link capacity vehicles per year

P = percent trucks = 20

t = average truck weight capacity, kilotons

L = average truck load factor = 0.758

---

* Additional assumptions: divided highways have 4 lanes, undivided highways have 2 lanes, 18-hour traffic day, 3 peak hours per weekday, 3 peak hours per weekend, capacity based on 100th highest hourly traffic volume during the year. For details and the implications of these assumptions, see (18).

Table 3-3. Distribution of Vehicle-Miles by Truck Type

			% of Commodity Truck-Miles#				
			Box or Irregular		Tank		
Commodity	Density* Factor	% of Total Truck Miles	70 kip**	55 kip	70 kip	55 kip	Total for Commodity
Agriculture	.90	19.7	61.7	14.8	3.5	1.2	81.2
Metallic Ores	1.0	0.2	69.3	11.5	6.8	4.1	91.7
Coal & Coke	.90	0.1	76.4	14.0	--	--	90.4
Petroleum	1.0	5.6	4.0	0.7	74.4	8.9	88.0
Nonmetallic Minerals	1.0	1.5	51.7	11.5	19.9	3.5	86.6
Food Products	.90	11.6	65.3	14.4	3.0	0.3	83.0
Textiles	.75	5.0	62.8	26.7	--	--	89.5
Lumber & Forest Products	.90	4.4	34.0	26.8	--	--	60.8
Pulp & Paper	1.0	2.7	51.2	25.8	--	--	77.0
Chemicals	.90	6.0	36.3	12.3	37.7	4.4	90.7
Rubber & Plastics	.75	3.8	66.6	22.2	--	--	88.8
Stone & Glass	.75	8.8	64.4	17.8	--	--	82.2
Primary Metals	1.0	3.2	74.6	15.9	--	--	90.5
Fabricated Metals	.90	5.7	63.8	23.7	--	--	87.5
Nonelectrical Machinery	1.0	3.3	59.8	25.4	--	--	85.2
Electrical Machinery	1.0	3.7	65.4	22.1	--	--	87.5
Transportation Equipment	.90	8.4	38.8	31.0	--	--	69.8
Instruments	.90	5.8	53.2	20.6	--	--	73.8
Scrap	1.0	0.5	43.0	18.6	--	--	61.6
Total/Avg.	.90	100.0	54.3	18.6	7.8	1.1	81.8

* Fraction of vehicle weight capacity used when fully loaded with this commodity.

** Typical gross vehicle weight when loaded to capacity; 1 kip = 1,000 pounds.

\# All trucks tabulated here have diesel engines.

Source: PMM & Co. (10).

Table 3-4. Specifications for Standard Truck Types

Item	Truck Type Designation 3-S2 Van	2-S2 Van	3-S2 Tank	2-S2 Tank
Tare weight, lb.	30,000	24,000	30,000	24,000
Max payload, lb.	41,000	33,000	41,000	33,000
Max GVW, lb.	71,000	57,000	71,000	57,000
Axles	5	4	5	4
Wheels	18	14	18	14
Assigned % of intercity truck-miles	66.4	22.8	9.5	1.3

Source: Winfrey (15), supplemented by PMM & Co. (10).

Table 3-5. Highway Link Capacity

Physical Type	Terrain	Capacity, ktons/yr
Divided	Level	75,000
	Rolling	48,000
	Mountainous	28,000
Undivided	Level	15,200
	Rolling	9,500
	Mountainous	5,000

From Table 3-4, the average truck weight capacity is found to be approximately 39,070 pounds or 19.5 tons. Final (rounded) values for link tonnage capacity are given in Table 3-5.

- Truck Speed-Volume Curves

Relationships between truck speed and annual link traffic were based on curves of operating speed vs. volume-to-capacity ratio (V/C) presented in the Highway Capacity Manual (17). Some assumptions used are given in Table 3-6. For each highway link class, estimated truck speeds in 1972 at various highway service levels were selected from an Oak Ridge National Laboratory (ORNL) study of intercity truck speeds (11). These were converted to average highway speed (AHS) with the assumed truck speed differential from Table 3-6, and then deflated to 1965 speed levels using the ORNL speed trend data. Operating speed (OS) in 1965 and V/C were then determined simultaneously using the following relationship given in (18) and the appropriate curve from (17):

$$OS = AHS + \frac{DS}{10}\left(1 - \frac{V}{C}\right)$$

where DS is the design speed. Finally, multiplying tonnage capacity by V/C yields the time functions,* shown in Figures 3-1 and 3-2.

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* This procedure is not precisely correct. Since the percentage of trucks in the traffic stream surely drops as annual tonnage decreases, the negative influence of trucks on maximum service volume also lessens. This potential increase in volume which can be serviced at a given speed is assumed to be offset by the aforementioned decrease in truck percentage. The present level of abstraction does not warrant a more detailed analysis.

Table 3-6. Assumptions for Highway Time Functions

Physical Type	Terrain	Design Speed, mph	Alignment, SD%*	Truck Speed Diff., mph**
Divided	Level	70	--	5
	Rolling	60	--	5
	Mountainous	50	--	8
Undivided	Level	60	100	5
	Rolling	50	60	5
	Mountainous	40	0	10

* Percentage of alignment with passing sight distance ≥ 1500 feet.

** Average highway speed minus average truck speed.

Table 3-7. Truck Fuel Efficiency Adjustments for Rolling Grades

Gross Vehicle Weight (kips)	Ratio of MPG on Grade to MPG on Level Road	
	Rolling Terrain Avg. Grade = 2%	Mountainous Terrain Avg. Grade = 4%
24	.812	.650
30	.737	.583
57	.603	.422
71	.603	.418

Source: Winfrey (15)

MPG = miles per gallon

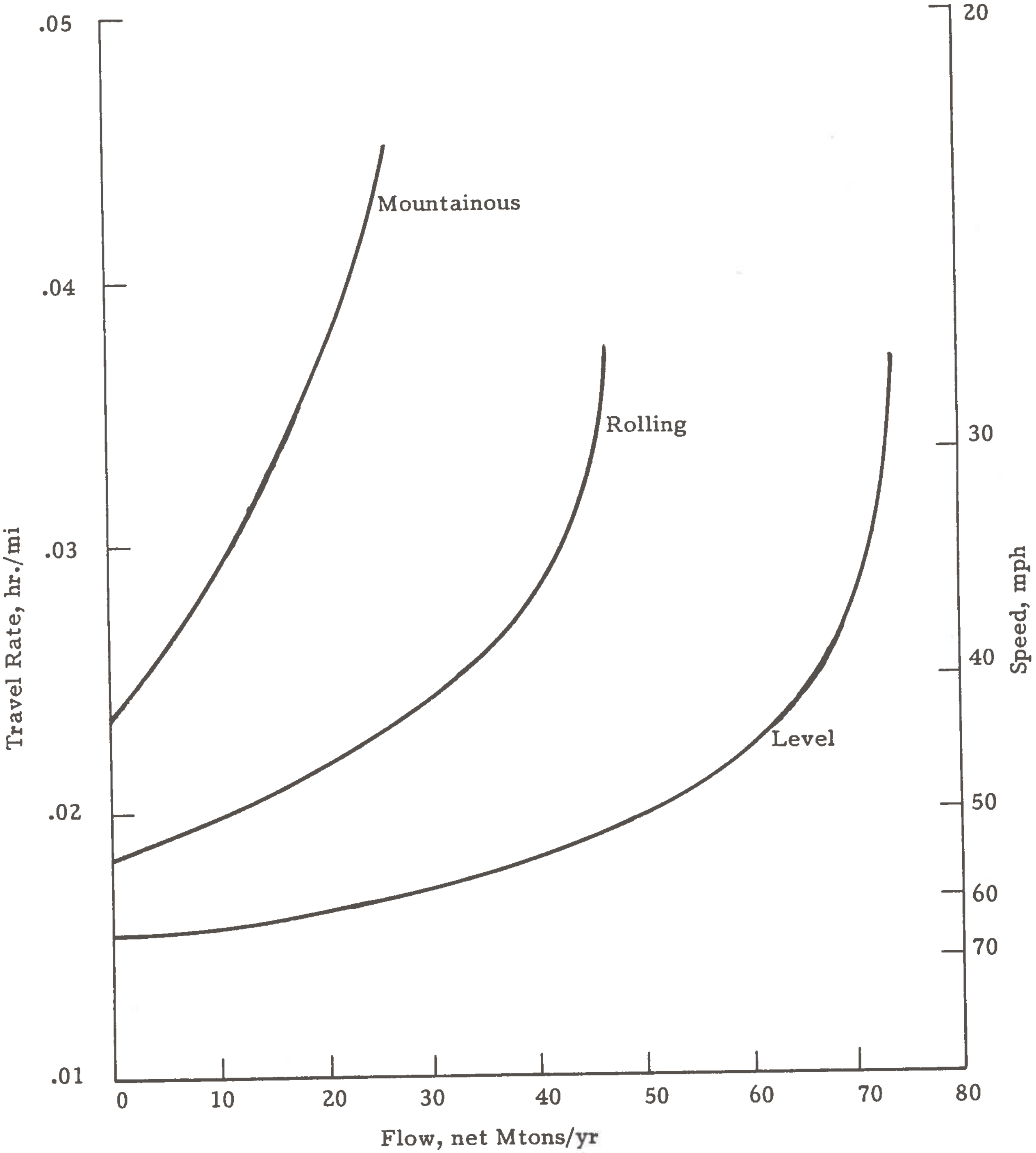

Figure 3-1. Time Functions for Divided Highways

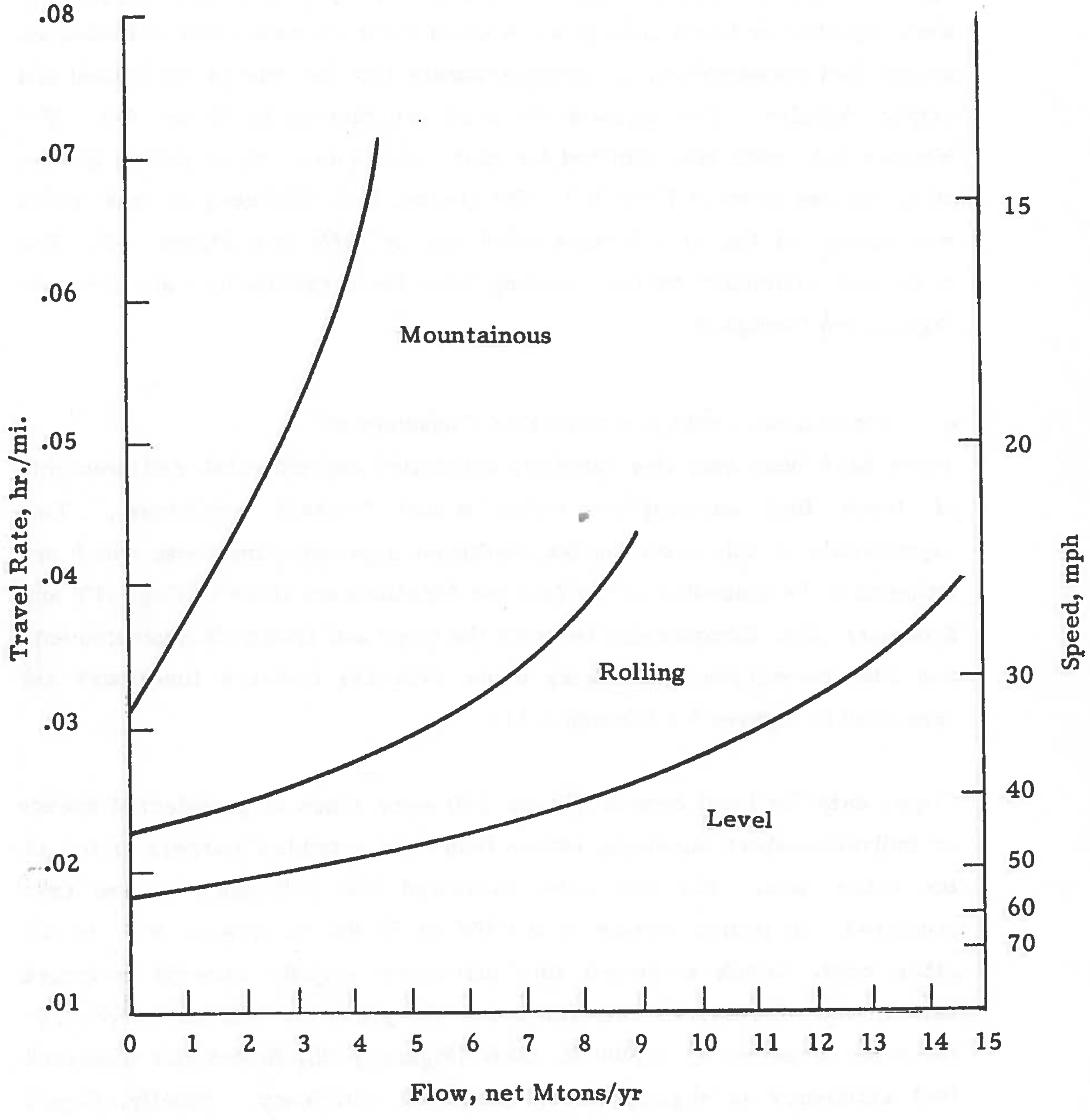

Figure 3-2. Time Functions for Undivided Highways

Highway Energy Functions

- Truck Fuel Consumption Estimates

Basic data on fuel consumption of the standard 3-S2 and 2-S2 vans on level roadways at various speeds were taken from Winfrey (15). Since these data apply to partially loaded vehicles (50 kip and 40 kip GVW, respectively), they were adjusted by linear interpolation using PMM estimates (10) of loaded vs. empty fuel consumption, to obtain separate fuel use curves for loaded and empty vehicles. The adjustments used are plotted in Figure 3-3. The Winfrey data were also adjusted for continuous operations on rolling grades, using factors given in Table 3-7. The greater fuel efficiency of tank trucks was accounted for with factors developed by PMM (see Figure 3-3). The truck fuel efficiency curves resulting from these calculations are shown in Figures 3-4 through 3-7.

- Comparisons with Measured Fuel Consumption

There have been very few carefully controlled experimental measurements of truck fuel consumption under actual linehaul conditions. Two experiments of this nature under conditions approximating those which are intended to be embodied in the fuel use functions are those of Cope (19) and Broderick (20). Comparisons between the Cope and Broderick measurements and fuel consumption estimates made with the fuel use functions* are presented in Figures 3-8 through 3-11.

Cope's data for level terrain (Figure 3-8) were taken at preselected speeds on individual short segments, rather than over extended journeys as for all the other data. For this case, measured fuel efficiency is less than predicted. In rolling terrain at a GVW of 57,000 lb. (Figure 3-9), on the other hand, Cope's measured fuel efficiency slightly exceeds predicted values, while Broderick's data fall below the predicted fuel use curve. For the same situation at 71,000 lb. GVW (Figure 3-10), Broderick's measured fuel efficiency is slightly above predicted efficiency. Finally, Cope's

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* Fuel use functions for partially loaded vehicles were obtained by linear interpolation.

Source: PMM & Co. (10).

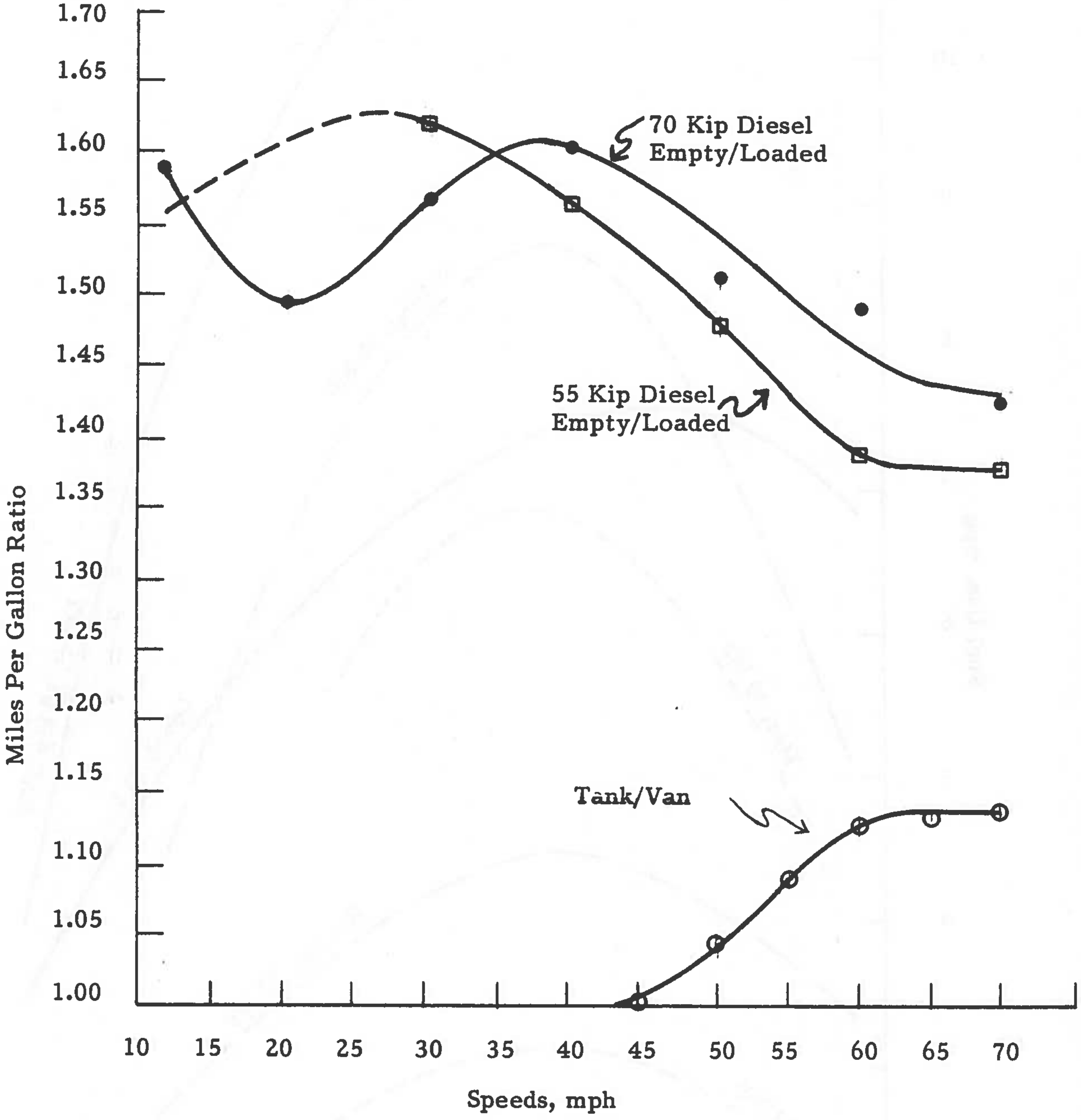

Figure 3-3. Truck Fuel Efficiency Correction Factors

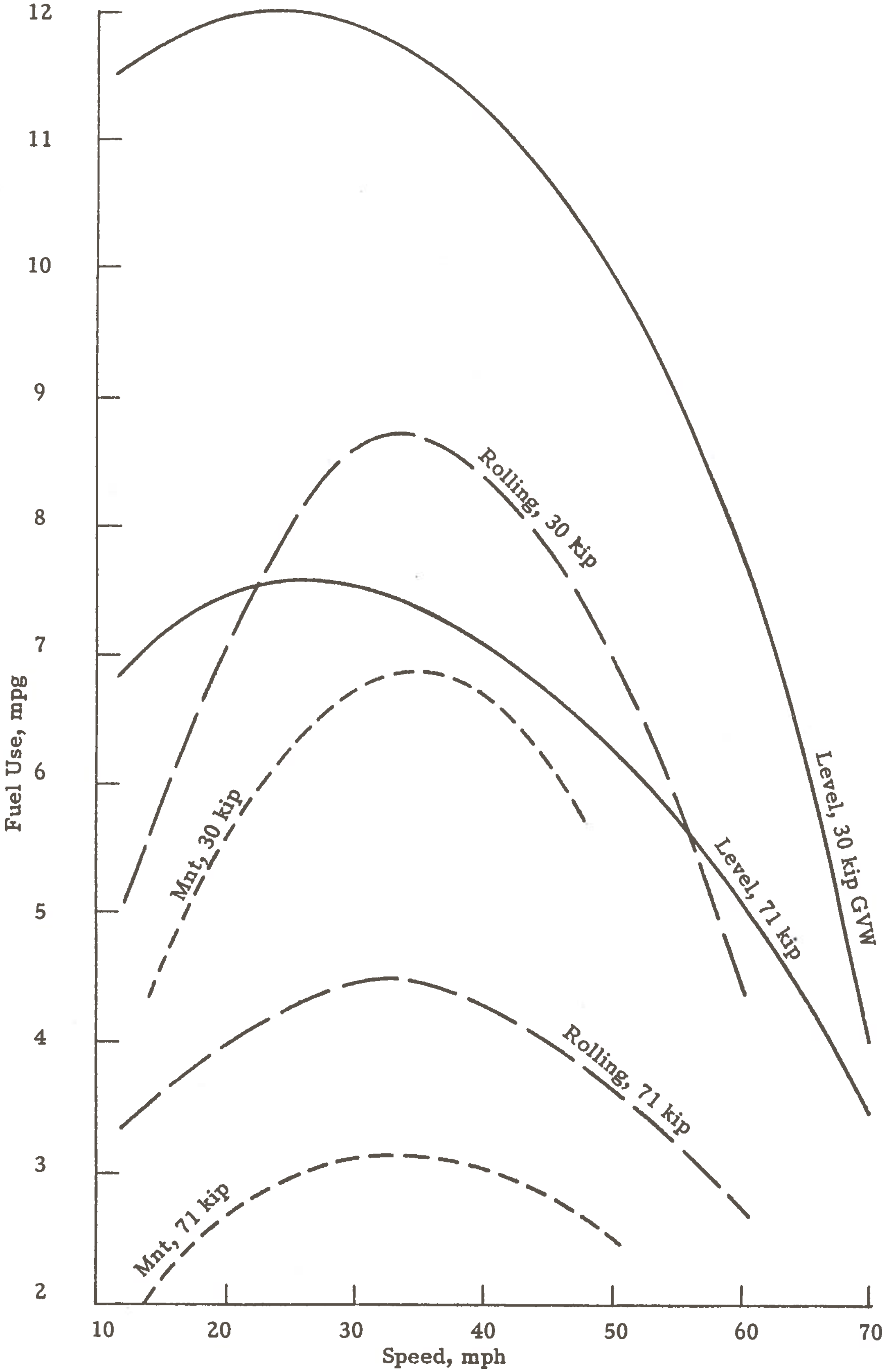

Figure 3-4. Fuel-Use Functions: 3-S2 van

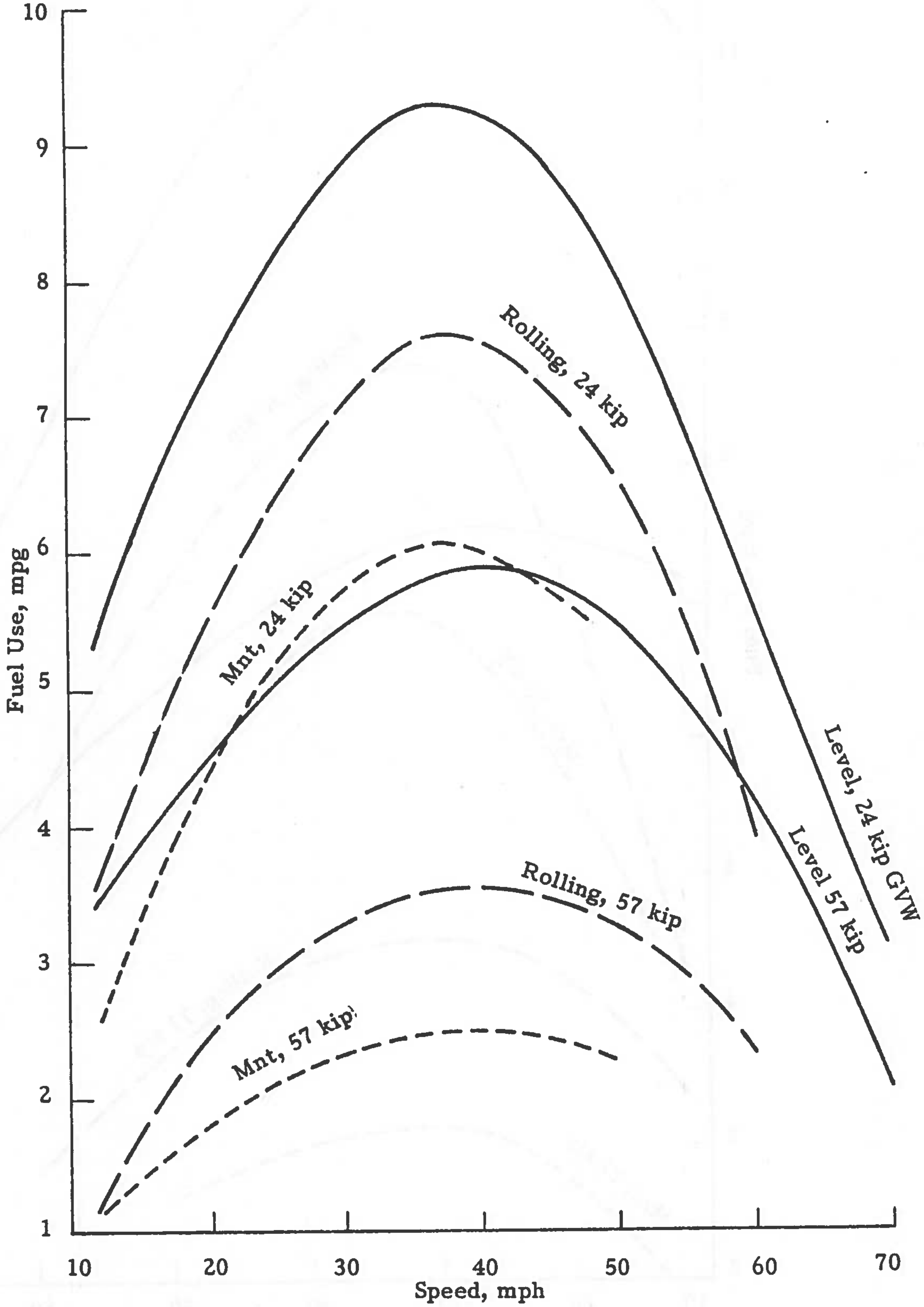

Figure 3-5. Fuel-Use Functions: 2-S2 van

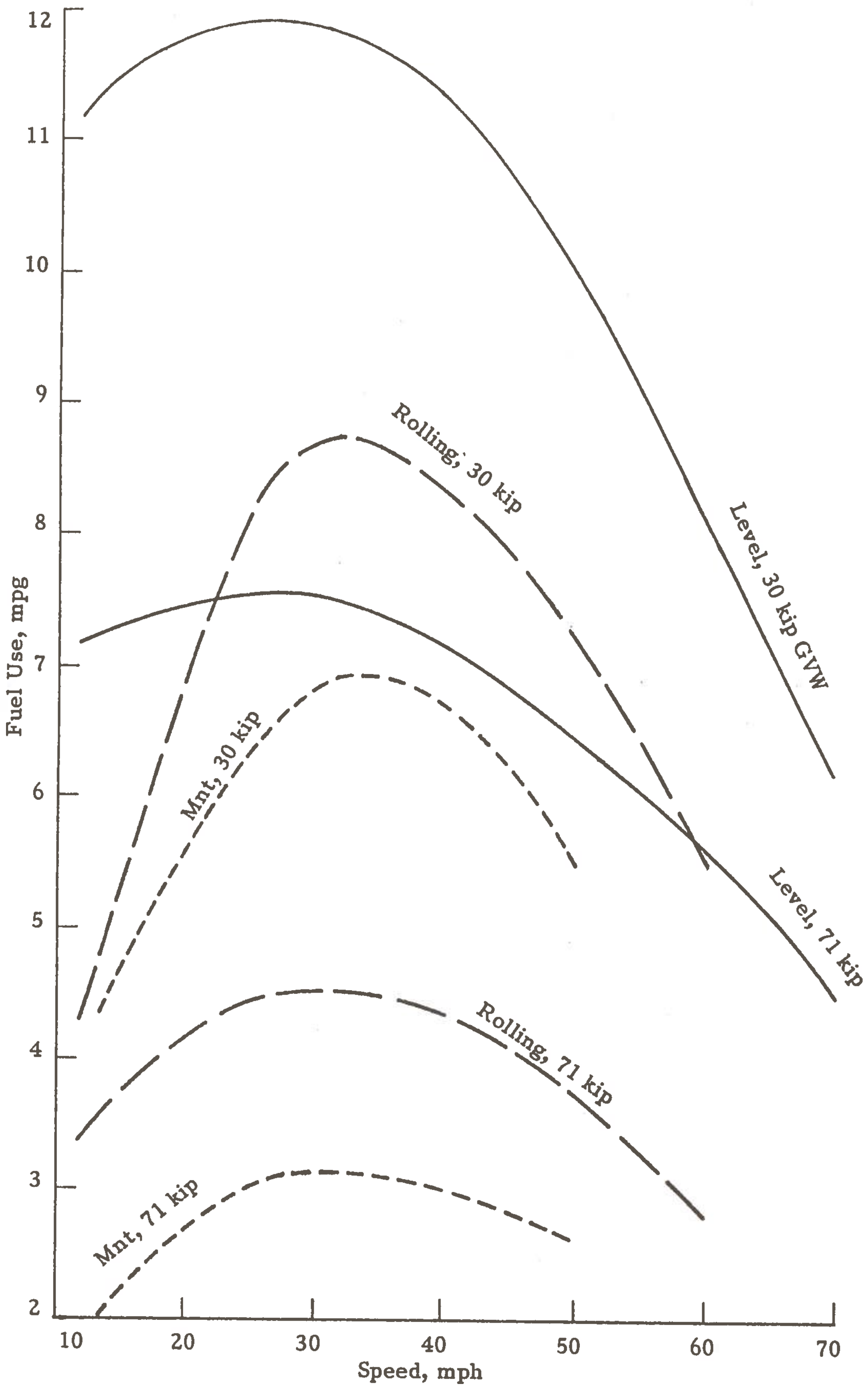

Figure 3-6. Fuel-Use Functions: 3-S2 Tank

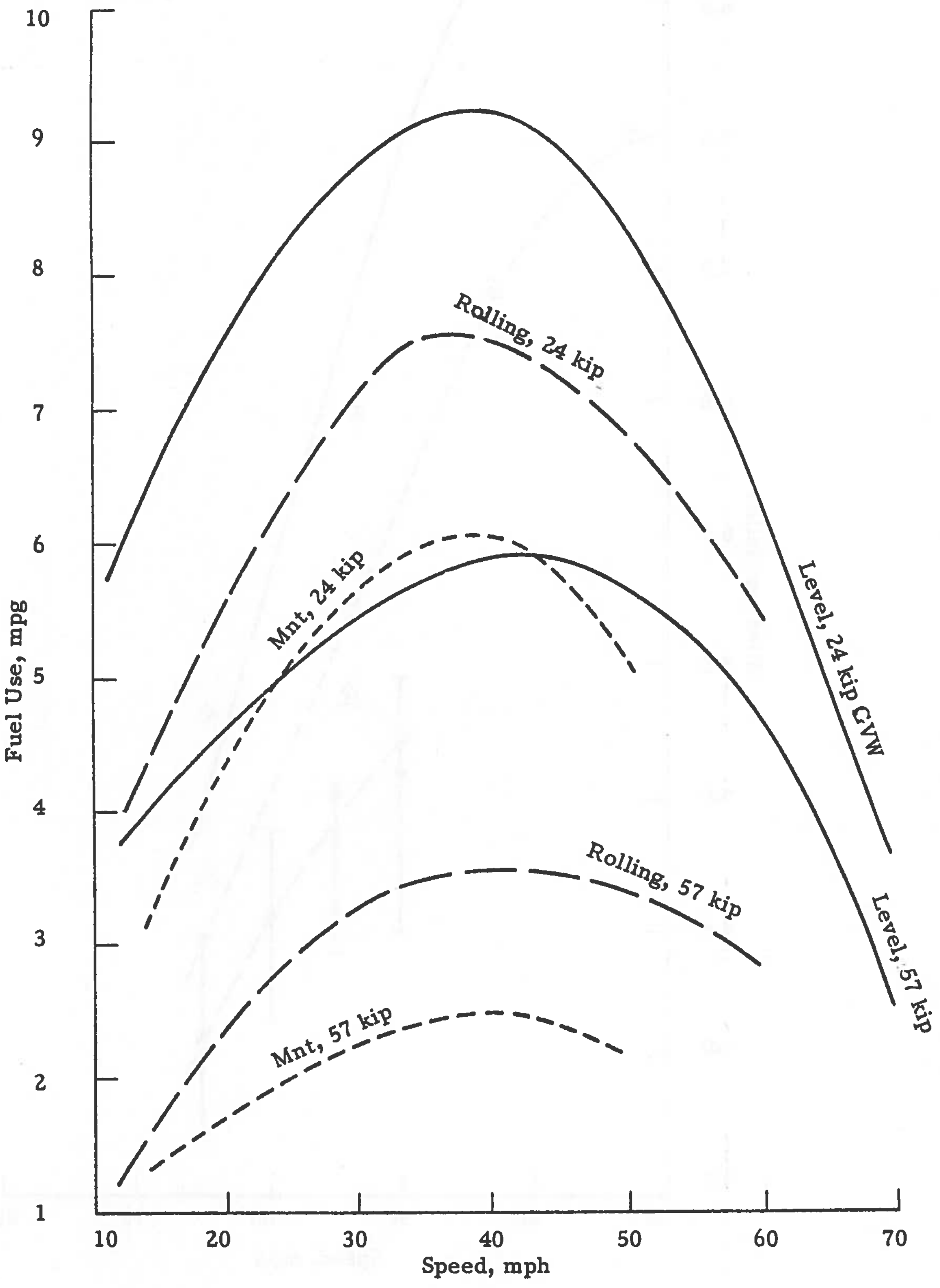

Figure 3-7. Fuel-Use Functions: 2-S2 Tank

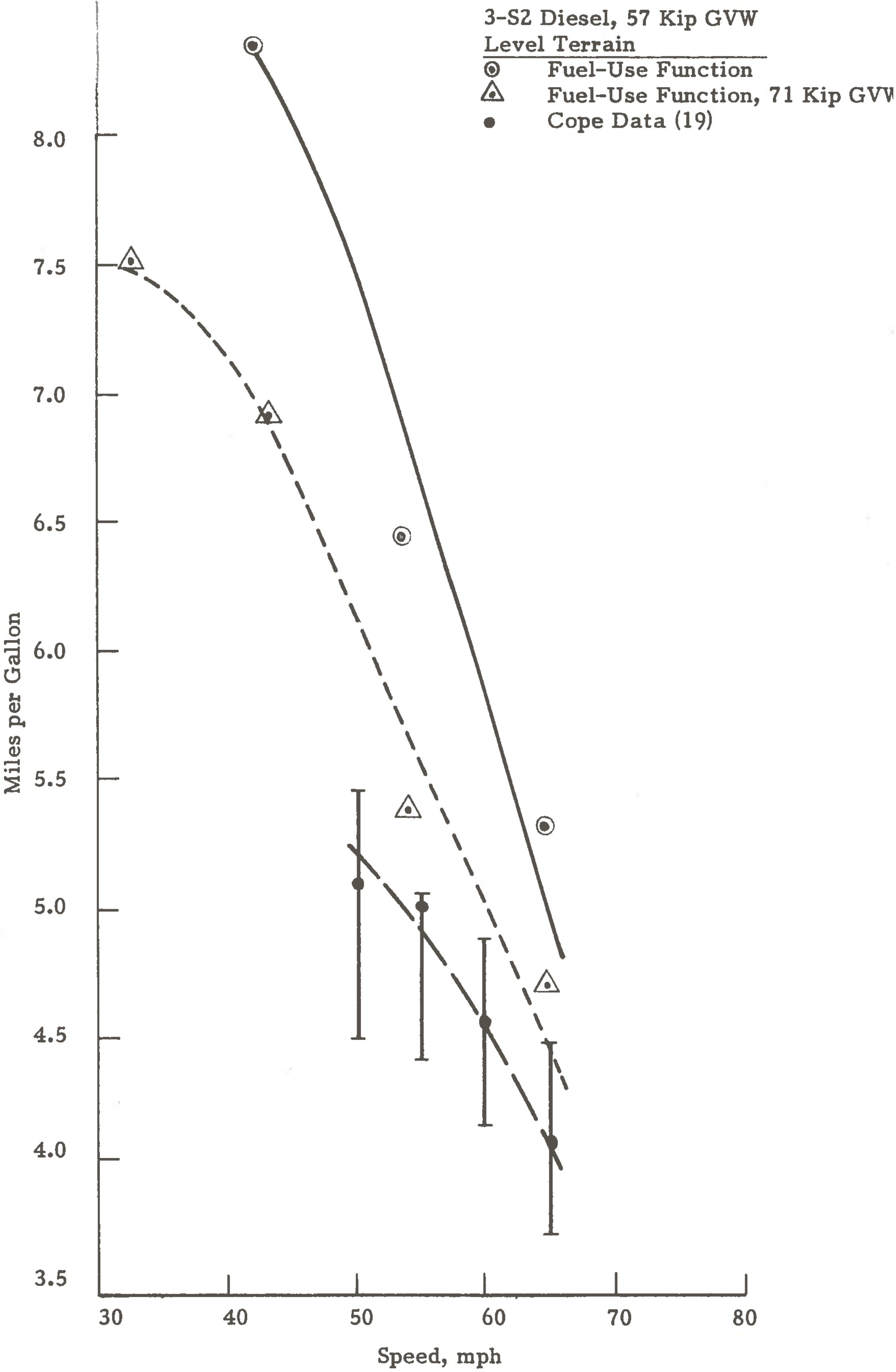

Figure 3-8. Comparison of Predicted and Measured Truck Fuel Consumption in Level Terrain

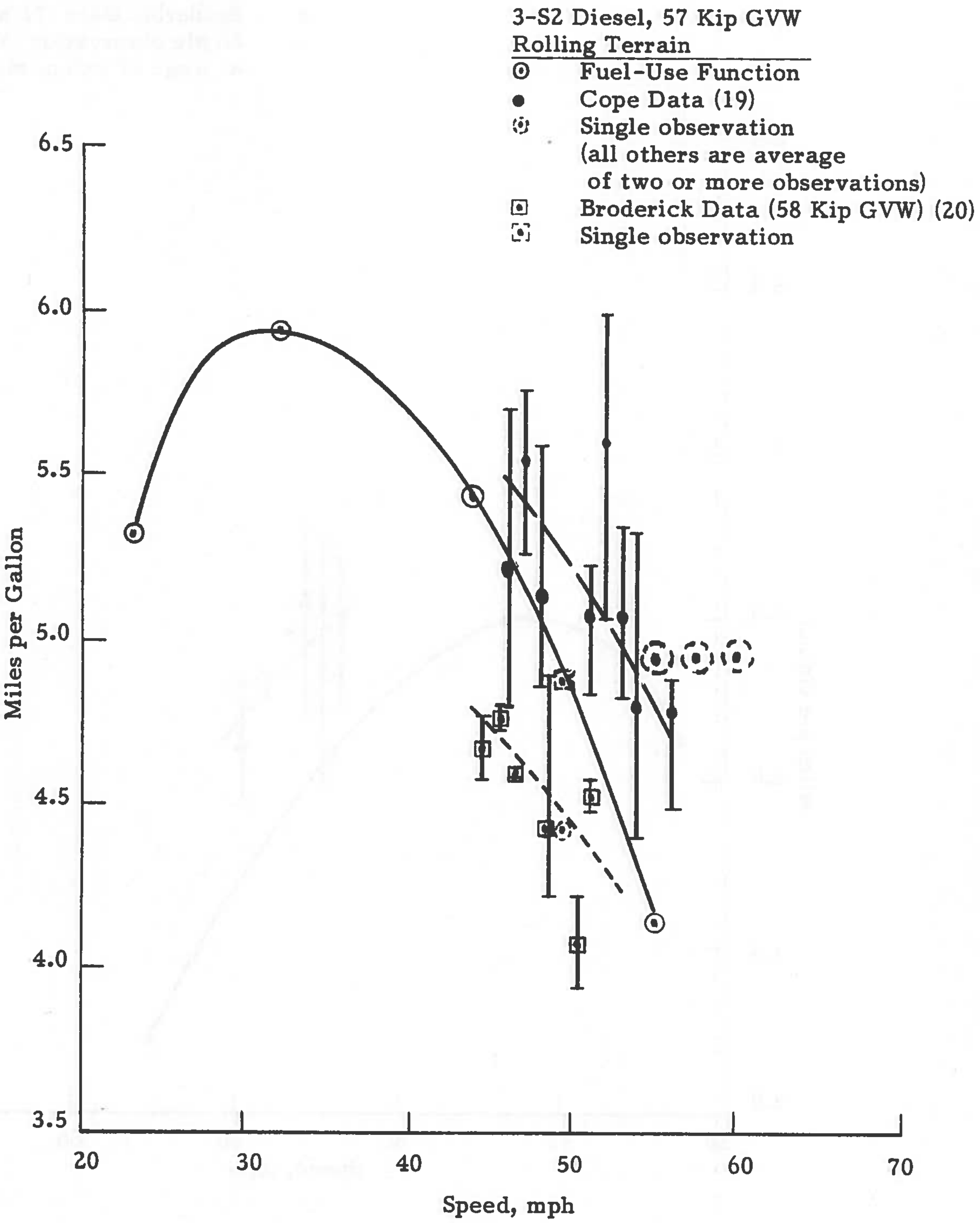

Figure 3-9. Comparison of Predicted and Measured Truck Fuel Consumption in Rolling Terrain

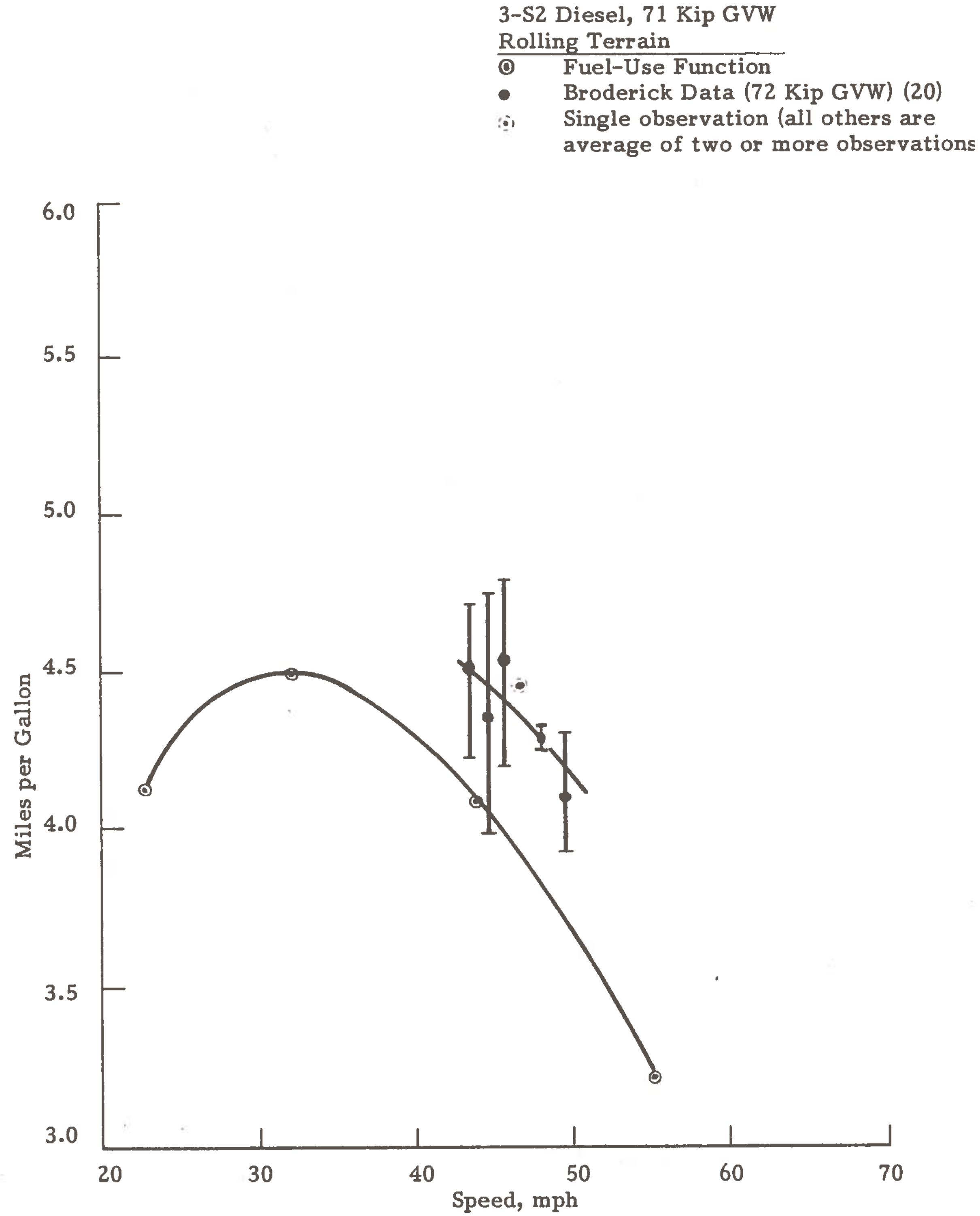

Figure 3-10. Comparison of Predicted and Measured Truck Fuel Consumption in Rolling Terrain

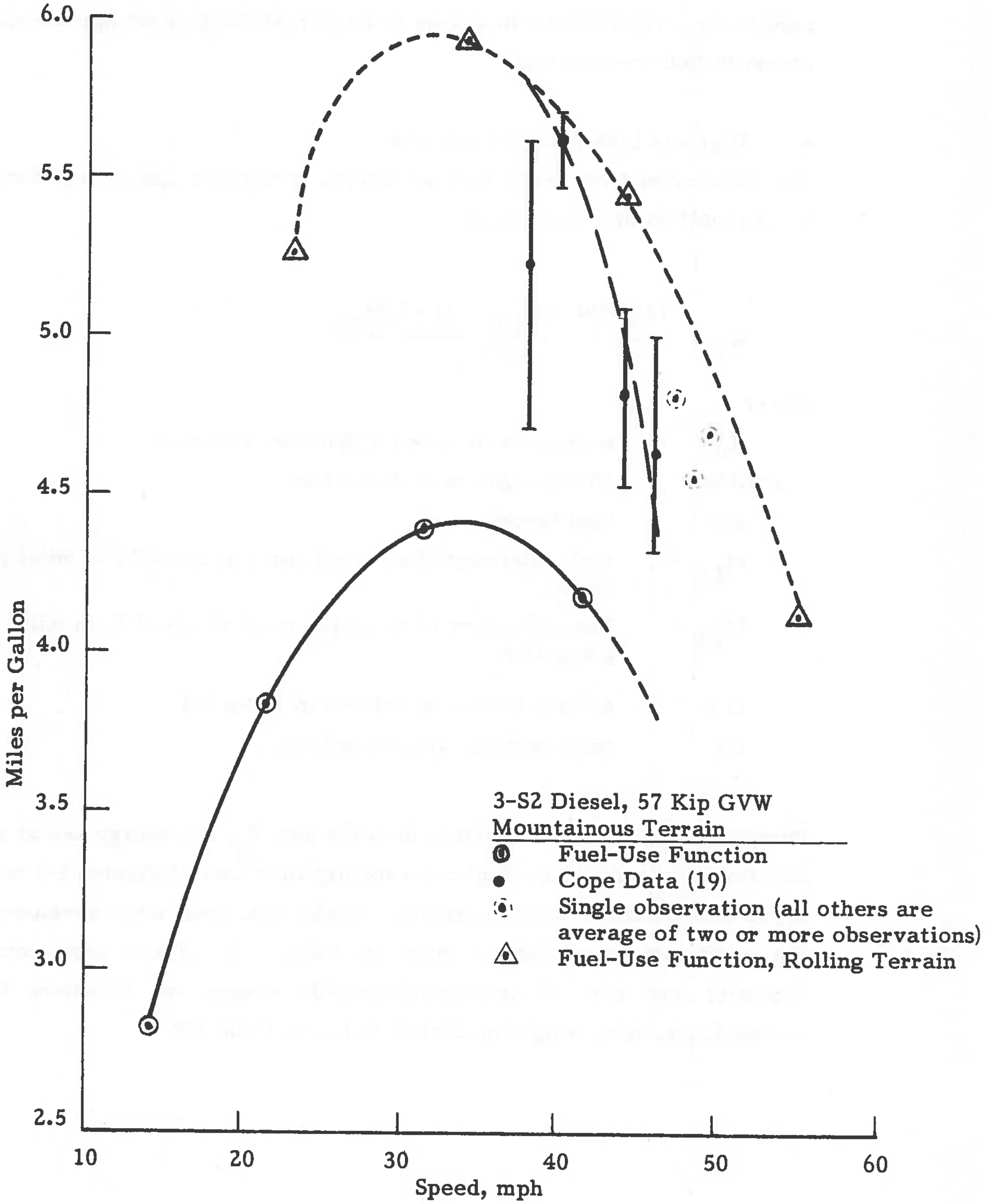

Figure 3-11. Comparison of Predicted and Measured Truck Fuel Consumption in Mountainous Terrain

measurements in what he classifies as mountainous terrain (Figure 3-11) fall between the prediction curves for mountainous and rolling terrain. These results show the fuel use functions to be in reasonably good agreement with observed fuel consumption.

- Highway Link Energy Functions

The conversion from truck fuel use curves to highway link energy functions is straightforward, as follows:

$$E_V = \frac{138{,}690/\ LM_{LV} + (1 - L)M_{EV}}{LDt}$$

where

E_V = energy use at speed V, BTU per ton-mile
138,690 = BTU per gallon of diesel fuel
L = load factor
M_{LV} = fuel efficiency of a loaded truck at speed V, in miles per gallon.
M_{EV} = fuel efficiency of an empty truck at speed V, in miles per gallon
D = density factor, as defined in Table 3-3
t = truck weight capacity in tons.

Energy use at speed V translates directly into E_q, the energy use at annual link flow q, via use of the highway capacity functions of Figures 3-1 and 3-2. Eight sets of these vehicle-oriented energy functions were developed, for the combinations of factors given in Table 3-8. These were combined (linearly) into sets of commodity-specific energy use functions for 20 commodities, using weighting factors listed in Table 3-9.

Table 3-8. Highway Vehicle Energy Function Catalog

VehicleType	t, tons	L	Density Factor 1.0	0.90	0.75
3-S2 Van	20.5	0.77	1	5	6
2-S2 Van	16.5	0.77	2	7	8
3-S2 Tank	20.5	0.63	3	-	-
2-S2 Tank	16.5	0.63	4	-	-

L = load factor

Table entry is energy function reference number

Table 3-9. Weighting Factors for Development of Commodity-Specific Highway Energy Functions

Commodity	Highway Vehicle Energy Function 1	2	3	4	5	6	7	8
0. Composite Van	.74	.26						
1. Farm Products, Field Crops			.04	.02	.76		.18	
2. Forest Products, Marine Products					.56		.44	
3. Coal					.85		.15	
4. Crude Petroleum			.89	.11				
5. Metallic Ores	.76	.13	.07	.04				
6. Nonmetallic Minerals	.60	.13	.23	.04				
7. Food & Kindred Products			.04		.79		.17	
8. Textiles, Apparel						.70		.30
9. TOFC			not included					
10. Chemicals & Allied Products			.42	.05	.40		.13	
11. Lumber & Furniture					.56		.44	
12. Machinery (Nonelectrical)	.70	.30						
13. Electrical Machinery	.75	.25						
14. Transportation Equipment					.56		.44	
15. Unidentified Manufactures					.73		.27	
16. Paper & Allied Products	.66	.34						
17. Petroleum & Coal Products	.04	.01	.85	.10				
18. Primary Metal Products	.82	.18						
19. Fabricated Metal Products					.73		.27	
20. Miscellaneous Manufactures						.76		.24

The 120 functions (20 commodities x 6 link types) resulting from the calculations outlined above were plotted, and for each link type a base energy function representing the energy use curves for several commodities was defined. These base functions are shown in Figures 3-12 and 3-13. Commodity adjustment factors are given in Table 3-10. In most cases, a single commodity adjustment was used to represent several energy functions lying relatively close to each other.

Table 3-10. Highway Energy Function Commodity Adjustment Factor

Link Type	Terrain	Commodities	Function Adjustment Type*	Function Adjustment Value
Divided	Level	2,8,11,14,20	M	1.19
		15,19	M	1.06
		5,6,18	M	.95
	Rolling	2,8,11,14,20	M	1.13
		15,19	A	+85
		5,6,18	M	.96
	Mountainous	2,8,11,14,20	M	1.11
		15,16,19	A	+85
		3,5,6,18	M	.96
Undivided	Level	2,8,11,14,20	A	+230
		15,19	M	1.04
		5,6,13,18	A	-85
	Rolling	2,8,11,14,20	M	1.15
		15,19	A	+95
		5,6,18	M	.96
	Mountainous	2,8,11,14,20	M	1.13
		12,15,16,19	M	1.04
		3,5,6,18	M	.96

* M = multiplicative adjustment
A = additive adjustment

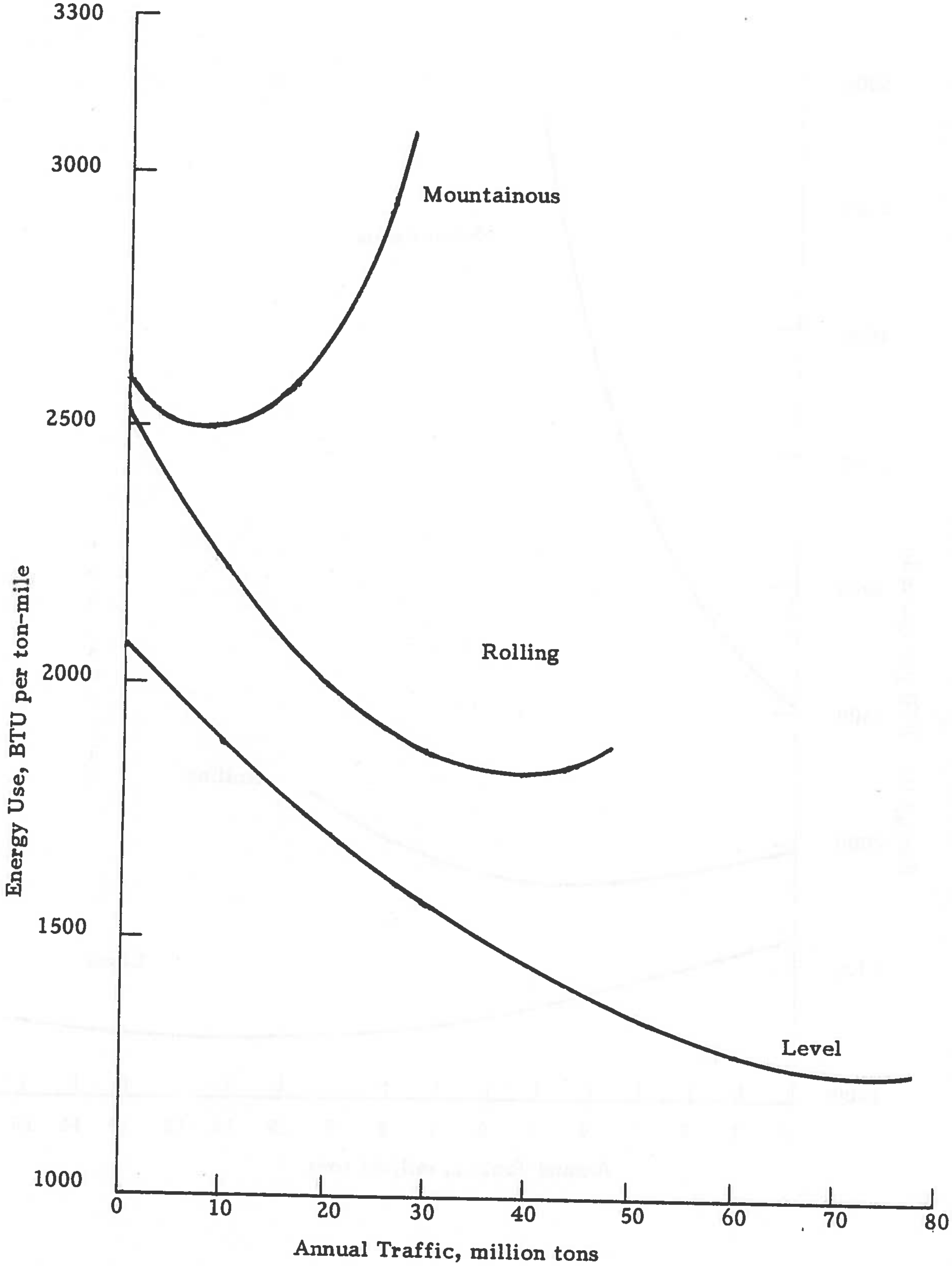

Figure 3-12. Energy Functions for Divided Highways

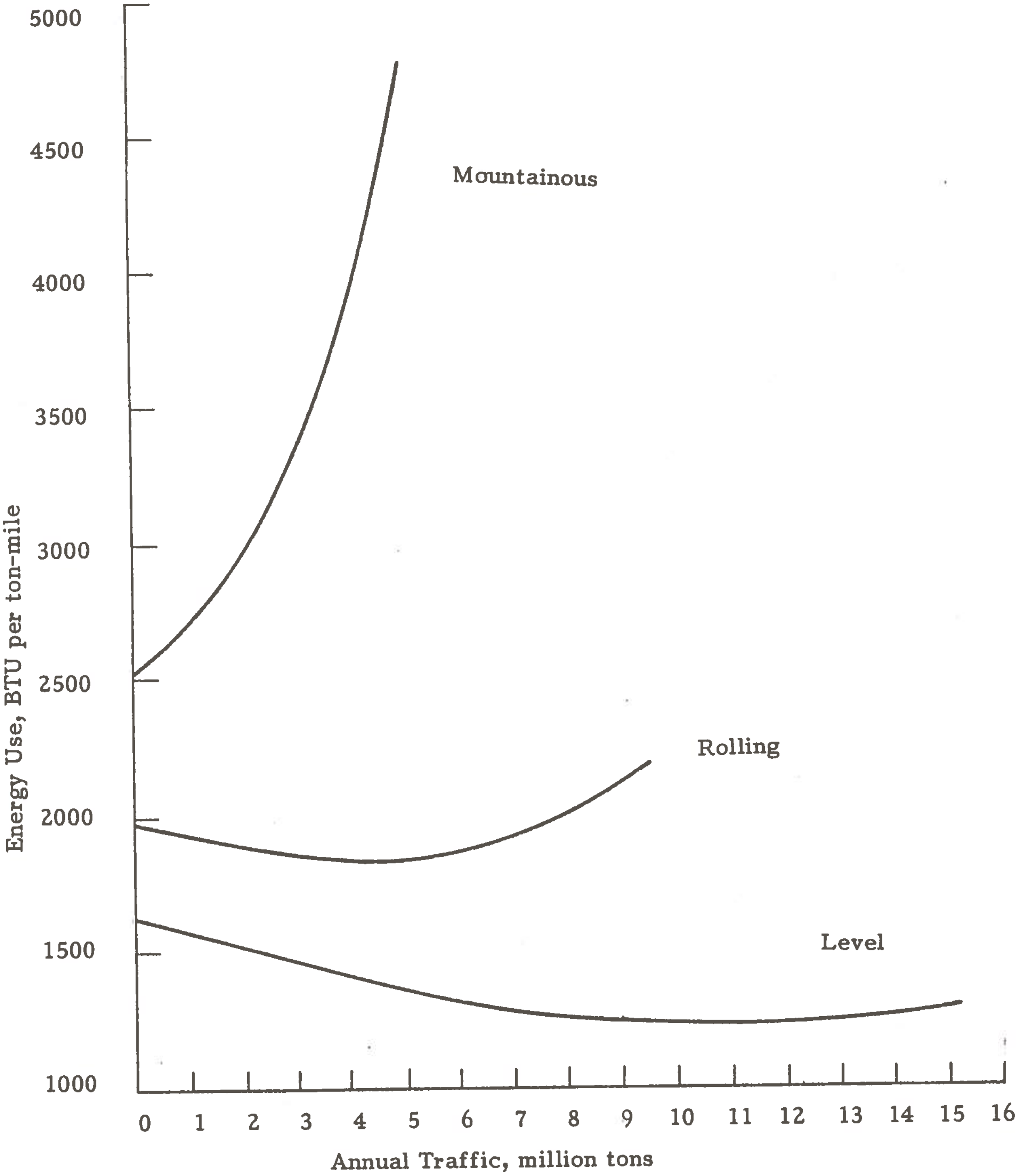

Figure 3-13. Energy Functions for Undivided Highways

Highway Cost Functions

- Truck Operating Costs

Operating costs for the standard vehicles were computed with the TSC truck cost model (see Volume 2 of this report). Assumptions and input data are listed in Table 3-11. Model runs were made at various values of fuel consumption. The resulting vehicle operating costs are given in Table 3-12.

Both fuel consumption and vehicle utilization rate vary with speed, which, in turn, varies with annual traffic (as per Figures 3-1 and 3-2). These relationships were used to develop cost vs. volume functions for the eight baseline vehicle combinations given in Table 3-8. At a selected volume level, the highway link time and energy functions were entered to determine speed and fuel use, respectively. Given fuel use, cost was obtained from Table 3-12 by linear interpolation. This cost, which is based on annual vehicle utilization of 110,000 miles, was then adjusted to reflect a utilization rate based on assumed annual driving time (excluding stops) of 8 hours per day, 5½ days per week, 50 weeks per year, or 2,200 hours per year. Annual utilization at speed V is thus 2200 x V (e.g., at V=50 mph, utilization is 2200 x 50 = 110,000 miles). Finally, the adjusted cost, in ¢/mile, was divided by average vehicle capacity utilization in tons, to produce ¢/ton-mile. The process described above can be summarized in mathematical form as follows:

$$C_V = \frac{c_{eV}\ 110{,}000/(2200\ V)}{LDt}$$

where

C_V = truck transportation cost at speed V, ¢/ton-mile

c_{eV} = vehicle operating cost at fuel efficiency e corresponding to speed V, ¢/mile (Table 3-12)

110,000 = annual vehicle mileage on which c_{eV} is based

2200 = assumed annual operating hours

L = vehicle load factor

D = density factor, as in Table 3-3

t = truck weight capacity, tons

Table 3-11. Truck Cost Model Input Data

Value	Description
15%	Interest rate
10%	Investment tax credit
51%	Marginal income tax rate
--	Double declining balance depreciation method
80%	Portion of equipment cost financed
60 months	Term financed
$2,000	Annual insurance cost (including cargo insurance)
$20,000	Annual driver wages, including vacation replacement
$2,500	Annual driver expenses
$0.30/gal.	Fuel cost, less tax
$0.11/gal.	Fuel tax
$10,100	Trailer purchase price
72 months	Trailer economic life and tax life
$2,400	Trailer salvage value
10%	Trailer salvage value assumed for tax calculations
$1,200	Cost of full set of trailer tires
150,000 miles	Trailer tire life
1.08¢ /mi.	Trailer maintenance cost
$8,000	Annual overhead cost
$36,000	Tractor purchase price
60 months	Tractor economic life
48 months	Tractor tax life
$8,000	Tractor salvage value
10%	Tractor salvage value assumed for tax calculations
$2,000	Cost of full set of tractor tires
120,000 miles	Tractor tire life
7.6¢/mile	Use related tractor maintenance cost
$200	Annual time related tractor maintenance cost
110,000 miles	Annual truck utilization
$1,200	Annual license and permit cost
$100	Annual third structure tax
$300	AnnuaL federal highway use tax

Note: These values are for the 3-S2 van. Some minor adjustments were made for the other standard vehicles.

Table 3-12. Estimated Truck Operating Costs (1972)

Fuel Efficiency, mi./gal.	Estimated Operating Cost, ¢/mile			
	3-S2 Van	2-S2 Van	3-S2 Tank	2-S2 Tank
1	89.0	86.4	96.3	88.9
2	68.5	65.9	75.8	68.4
3	61.7	59.1	69.0	61.6
4	58.3	55.7	65.5	58.1
5	56.2	53.6	63.5	56.1
6	54.9	52.3	62.1	54.7
7	53.9	51.3	61.1	53.7
8	53.2	50.6	60.4	53.0
9	52.6	50.0	59.8	52.4
10	52.1	49.5	59.4	52.0
11	51.8	49.2	59.1	51.7
12	51.5	48.9	58.8	51.4

Source: Output from TSC Truck Cost Model, using inputs given in Table 3-11.

- Highway Link Cost Functions

Following a process identical to that used to develop link energy functions, the baseline vehicle cost functions were combined linearly to estimate commodity specific cost functions, using the weighting factors given in Table 3-9. The functions for the composite van were selected as the prototypes for the highway links. These are plotted in Figures 3-14 and 3-15.* Commodity specific adjustments of these functions are given in Table 3-13.

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* During model calibration runs, it was found desirable to change the assumed truck fuel price in 1972 from 30¢/gal. to 12¢/gal. This corresponds to a cost decrease of 1.3 mills per thousand BTU's, based on 138,690 BTU/gal. The cost functions were adjusted by determining BTU/ton-mile at various link flows with the aid of the highway link energy functions. The cost functions plotted in Figures 3-14 and 3-15 do not include this adjustment.

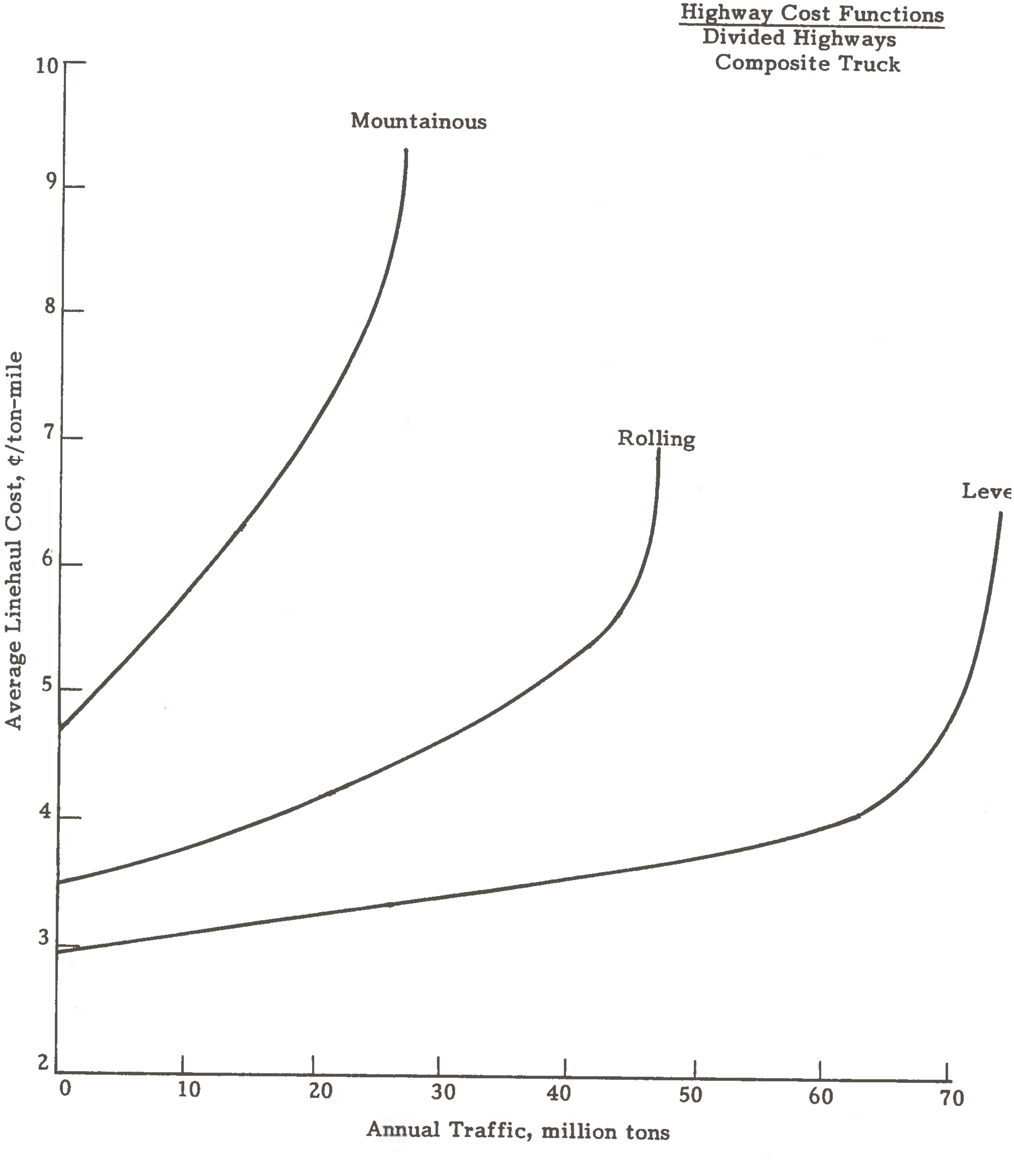

Figure 3-14. Cost Functions for Divided Highways

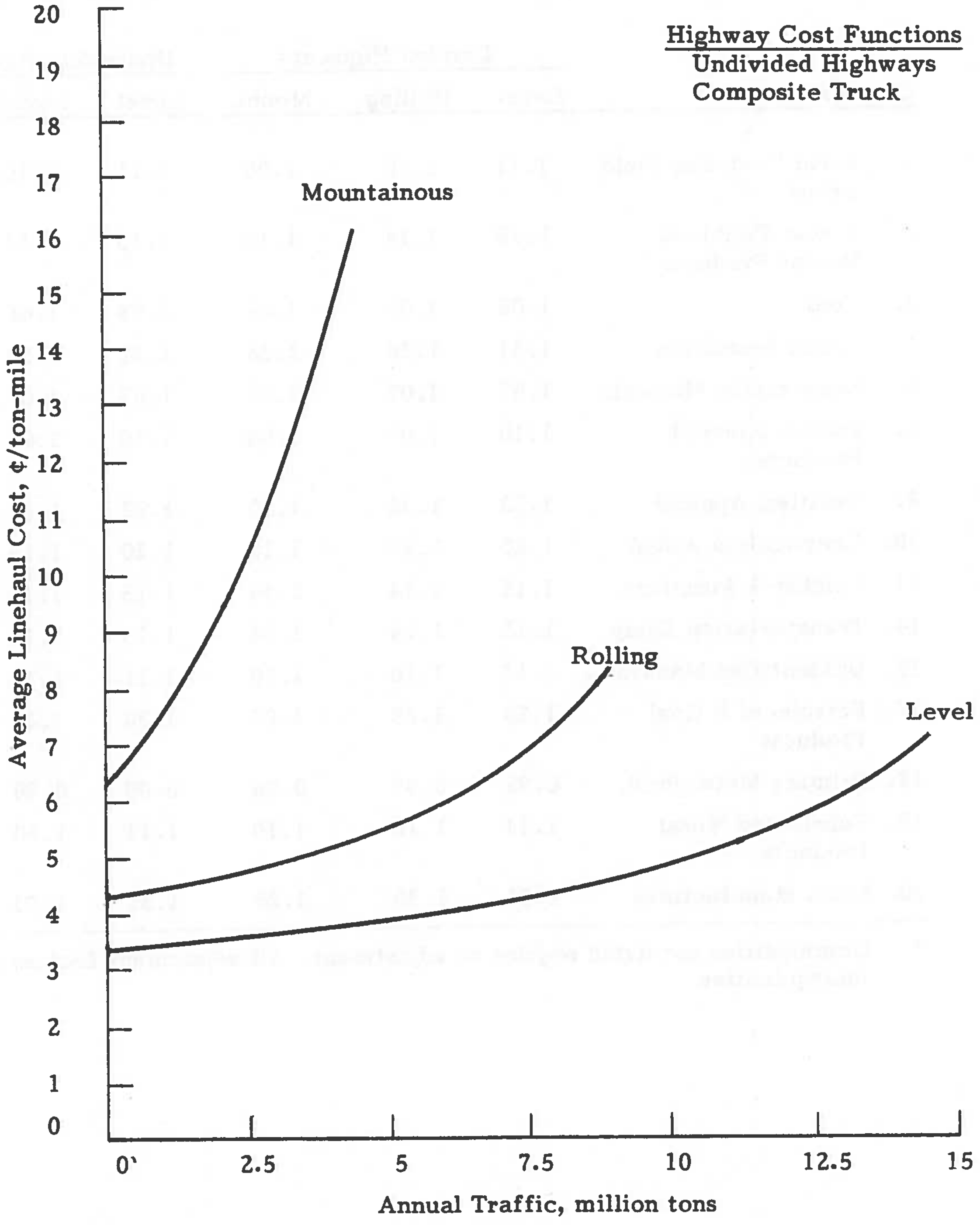

Figure 3-15. Cost Functions for Undivided Highways

Table 3-13. Highway Cost Function Commodity Adjustment Factors

	Divided Highways			Undivided Highways		
Commodity*	Level	Rolling	Mount.	Level	Rolling	Mount.
1. Farm Products, Field Crops	1.11	1.10	1.09	1.11	1.10	1.09
2. Forest Products, Marine Products	1.15	1.14	1.14	1.15	1.14	1.14
3. Coal	1.08	1.08	1.07	1.08	1.08	1.06
4. Crude Petroleum	1.31	1.30	1.28	1.32	1.30	1.27
6. Nonmetallic Minerals	1.07	1.07	1.07	1.07	1.07	1.06
7. Food & Kindred Products	1.10	1.09	1.08	1.10	1.09	1.08
8. Textiles, Apparel	1.33	1.32	1.30	1.33	1.32	1.30
10. Chemicals & Allied	1.20	1.19	1.18	1.20	1.19	1.17
11. Lumber & Furniture	1.15	1.14	1.14	1.15	1.14	1.14
14. Transportation Equip.	1.15	1.14	1.14	1.15	1.14	1.14
15. Unidentified Manufac.	1.11	1.10	1.10	1.11	1.10	1.10
17. Petroleum & Coal Products	1.30	1.28	1.27	1.30	1.28	1.25
18. Primary Metal Prod.	0.98	0.98	0.98	0.98	0.98	0.98
19. Fabricated Metal Products	1.11	1.10	1.10	1.11	1.10	1.10
20. Misc. Manufactures	1.31	1.30	1.28	1.31	1.30	1.27

* Commodities not listed require no adjustment. All adjustment factors are multiplicative.

- Toll Highways

Toll highways and bridges were located on a plot of the highway network using state highway maps and data obtained from the International Bridge, Tunnel & Turnpike Association (21, 22). This information was compared with the link toll status listed in the highway network data, and corrections to the toll-miles field in the link data were entered as necessary. The approximate toll on each link was computed as:

$$T = \frac{10\ cd}{15\ s}$$

where

T = estimated link toll cost, mills per ton-mile
c = average toll on this highway for 5-axle trucks, cents per mile, as reported in (21, 22)
d = total toll-miles included in link
15 = average truck payload, tons
s = total link length (Note: $d \leq s$)

The resulting frequency distribution of link toll costs is presented in Figure 3-16. Based on this distribution, an average effective toll of 3 mills per ton-mile was selected to represent the extra cost of traversing a link with toll mileage. Cost functions for the three classes of toll links were obtained by adding this value to the cost functions for divided highways.

Highway Node Functions

- Node Classes

Nodes are classified on the basis of "turn penalty" values coded in the original FHWA network, which are used to simulate urban area congestion. Four penalty values, which vary with urban area population, are used. There are 68 nodes in the network with non-zero turn penalties coded for at least one approach direction, and 55 of these are "supernodes." In the original data, penalty values may vary by approach direction, but such distinctions were ignored; the maximum value coded for any approach direction was used. This is a particularly appropriate simplification in light of the prevalence of supernodes among the penalized nodes, and in view of the relatively small travel time penalties.

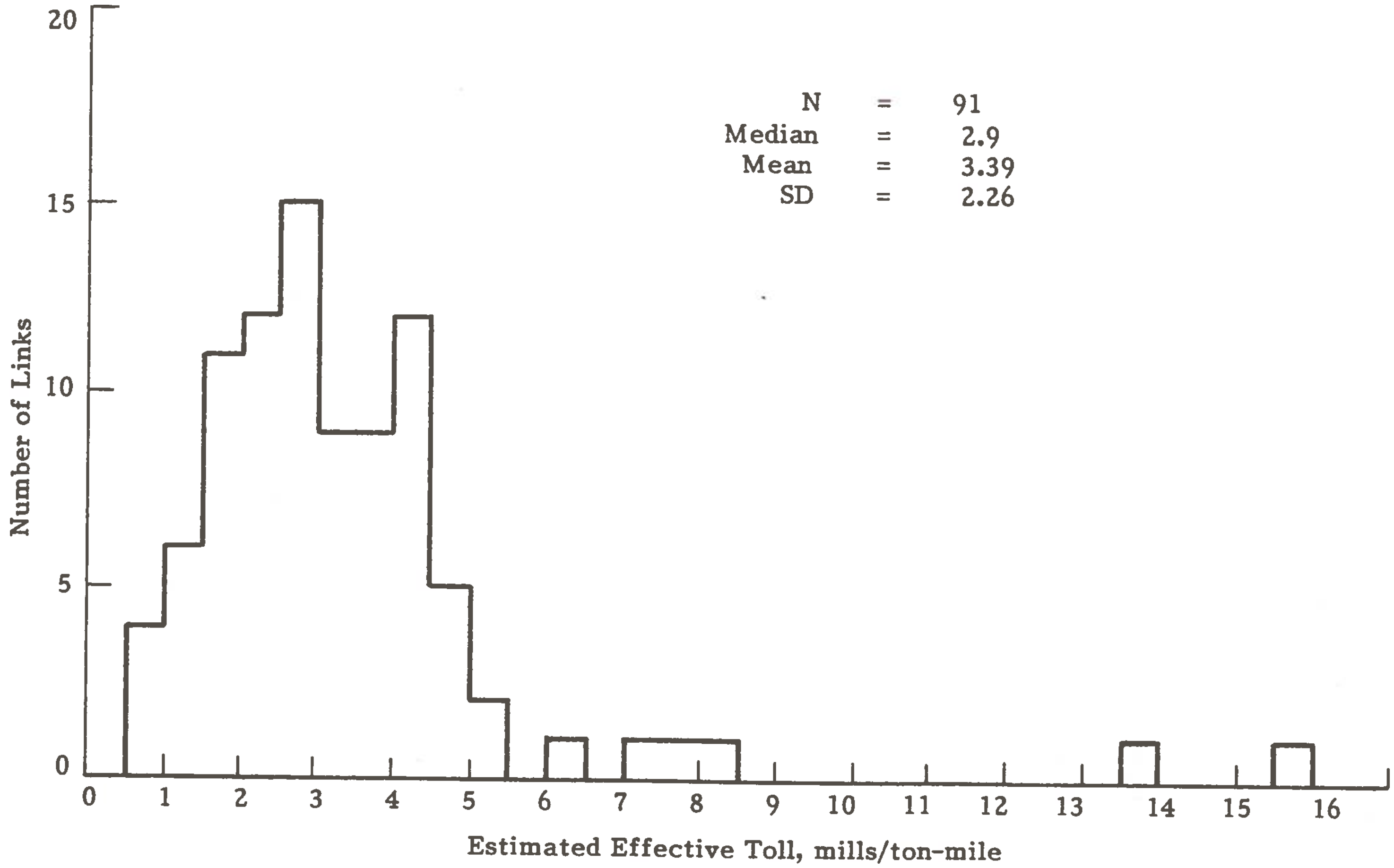

Figure 3-16. Distribution of Highway Link Toll Costs

For supernodes, which represent areas where network detail has been collapsed into a single node, there are data available on the number and mileage of highway links of each type which are implicitly "contained" in the supernode. However, the actual travel distance incurred in passing through supernodes is already accounted for in the lengths of the incident links. Hence, there is no need to define supernodes as separate node classes.

An error may be introduced by not explicitly differentiating supernodes from regular nodes, in that link types encountered on the actual path through the supernode may differ from the link type of the incident link. In view of the relatively short distances involved and the relatively small differences in travel speeds across link types, however, the resulting errors in travel time should be small, and on average should cancel.

In summary, highway nodes were placed into five classes, according to the maximum node turn penalty coded for any approach direction, as follows:

	Turn Penalty	
Class	Code *	Minutes
PEN00	0	0
PEN05	1	5
PEN07	2	7
PEN11	3	11
PEN18	4	18

- Node Time, Energy, and Cost

Performance functions for nodes were derived from the link functions for divided highways in level terrain. Assuming an average speed of 45 mph, the node transit times in the FHWA network data were converted to distance. Energy and cost per ton-mile values were obtained from the link functions, entered with a flow volume consistent with the assumed speed. The resulting node disutilities are given in Table 3-14.

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* Data code used in FHWA network.

Table 3-14. Highway Node Time, Energy, and Cost

Node Class	Time, hr.	Energy, BTU/ton	Cost, $/kton
PEN00	0	0	0
PEN05	.0833	4,690	150
PEN07	.117	6,560	210
PEN11	.183	10,300	330
PEN18	.300	16,900	540

Highway Access

Highway access links represent travel between the shipper's or consignee's loading dock or yard over local and intraregional streets and highways to the primary highway system. Platform activities at motor carrier terminals and equivalent private trucking facilities are also included.

- Access Link Classes

Highway access links are grouped into three classes, based on the approximate access travel distance, as follows:

Access Class	Avg. Distance, mi.
HA25	25
HA50	50
HA75	75

- Access Time, Energy, and Cost

Access performance functions were based on travel over undivided highways in level terrain at an average speed of 30 mph. The average load factor assumed, based on ICC data (16), was 0.60. Platform time and cost were based on the following estimates made by TSC:

Type of Service	Avg. Time, days	Avg. Cost, $/ton
Motor Carrier, TL	0.12	0.0542
Motor Carrier, LTL	0.46	3.0342
Private, TL	0	0.0424

Due to the approximate equality of motor carrier and private platform costs, the motor carrier values were used to estimate time and cost for TL operations.

During model calibration runs, it was found that truck access costs were overestimated. Hence a calibration factor of 0.65 was applied to the sum of roadway and terminal costs estimated as outlined above. This adjustment was not applied, however, to commodities 5 and 6 (metallic ores and nonmetallic minerals), since these bulk goods utilize heavy equipment which is subject to faster than normal deterioration. Also, a 50% vehicle load factor was used for these commodities.

Final highway access assumptions and time, energy, and cost estimates are presented in Table 3-15.

Table 3-15. Highway Access Time, Energy, and Cost

Commodities	Avg. % LTL	Cost Calibration Factor#	Disutility Component	Access Class HA25	 HA50	 HA75
Composite*	0		Time, hr.	3.7	4.5	5.4
			Energy, BTU/ton	40,000	80,000	120,000
		0.65	Cost, $/ton	1.33	2.63	3.73
5, 6**	0		Time	3.7	4.5	5.4
			Energy	47,850	95,700	143,550
		1.00	Cost	2.45	4.85	7.25
7, 8, 11, 15, 16, 20	50		Time	7.8	8.6	9.5
			Energy	40,000	80,000	120,000
		0.65	Cost	2.30	3.60	4.90
12, 13, 19	25		Time	5.7	6.5	7.4
			Energy	40,000	80,000	120,000
		0.65	Cost	1.80	3.10	4.40

* Includes all commodities not specifically listed.

** Load factor = 50% (all others use 60% load factor).

\# The effect of this factor is already included in the costs tabulated.

IV. WATERWAY OPERATIONS DATA

Inland waterway capacity, energy use, and cost estimates were based on data compiled by the Corps of Engineers as part of the Inland Navigation Systems Analysis (INSA) program (5). Extensive use was also made of models, data, and model outputs related to the TSC Waterway Cost Model (23).

Inland Waterway Locks

- Node Classes and Lock Time Functions

Locks are represented as nodes in the waterway network. They are grouped into node classes according to river system, lock chamber size, and lock capacity and transit time characteristics.

Lock capacity and transit time were estimated with TSC's LOKCAP model (13), which uses queueing theory to predict locking time and delay for individual locks. Inputs to LOKCAP, including tow size distributions and locking times, were derived from data collected by the Corps of Engineers Performance Monitoring System (PMS)* in 1975. LOKCAP runs for 130 locks were used in this study.

The results of the lock classification and capacity analysis are presented in Table 4-1. The final three columns in the table provide parameter estimates for the lock time functions. The following hyperbolic function is used:

$$t = 2T_0 - T_1 + \frac{Q(T_1 - T_0)}{Q - q}$$

where

---

* See reference (5), Volume 5, chapter 5.

Table 4-1. Lock Classes and Time Functions

	Locks Included					Time Functions		
		Dimensions, feet						
		Chamber A		Chamber B		Q	T_0	T_1
Class	River	Length	Width	Length	Width	Kilotons	Min.	Min.
UM600.110	Mississippi	600	110			50,000	65	100
UM.LD26	Mississippi	600	110	360	110	70,000	100	150
IL600.110	Illinois	600	110			50,000	75	125
	Ohio	600	110					
	Tennessee	600	110					
	Cumberland	800	110					
AK600.110	Arkansas	600	110			45,000	40	60
	Monongahela	600	84					
	GIWW*	797	75					
	Alabama/Coosa	655	84					
	Bl. Warrior/Tombigbee/Mobile	600	110					
		520	95					
	Ouichita/Black	655	84					
OH12+6.110	Ohio	1200	110	600	110	120,000	50	70
	Mississippi	1200	110	600	110			
		1200	110	358	110			
OH.NAVPASS	Ohio	(LD52, LD53)				195,000	40	60
OH.GALLPLS	Ohio	600	110	360	110	60,000	70	110
OH600+360	Ohio	600	110	360	56	60,000	50	75
	Tennessee	600	110	360	60			
		600	110	400	60			
		600	110	292	60			
	Atchafalya/Old	1200	75					
MN360.56	Monongahela	360	56			40,000	60	90
	Allegheny	360	56					
	Ouichita/Black	300	55					
MN720.XX+	Monongahela	720	84	720	84	100,000	38	60
		720	56	360	56			
		720	110	360	56			
TNUM.360+	Tennessee	360	60			30,000	80	125
	Mississippi	400	56					
XX400+.75+	Clinch/Emory	400	75			35,000	30	50
	Cumberland	400	84					
	GIWW*	425	75					
	Ap/Ch/Fl**	505	82					
KW2X360.56	Kanawha	360	56	360	56	60,000	80	120
	Mississippi	400	56	400	56			
GIWW.XXXX	GIWW*	750	75			55,000	40	60
		1158	75					
		1204	75					
		1200	56					
		640	75					
		1198	84					
		800	75					
KY145.XX	Kentucky	145	38			4,500	55	90

* Gulf Intracoastal Waterway
** Apalachicola/Chattahoochee/Flint

t = lock transit time, including delay time
q = annual lock traffic, net kilotons
Q = theoretical lock capacity, kilotons
T_0 = lock transit time at $q=0$
T_1 = lock transit time at $q=0.5Q$

Parameters Q, T_0, and T_1 are provided directly in the LOKCAP output. The parameter values shown in Table 4-1 are the average or representative values selected for each lock class. To illustrate the types of functions used, several of the functions in Table 4-1 are plotted in Figure 4-1.

- Lock Energy Functions

Energy functions for locks were derived from the lock time functions and from the results of a run of the TSC Waterway Cost Model (23). Modern towboats use one gallon of diesel fuel per horsepower per day while underway, and half that amount while performing maneuvering operations such as station-keeping at locks. Average towboat horsepower was determined for each river from Waterway Cost Model output. The cost model also provided observations of average tow cargo load at various traffic levels for each lock class. Tow energy use at locks was calculated as follows:

$$E = 138{,}690 \quad \frac{0.5HP}{24} \quad \frac{t}{q}$$

where

E = locking energy use, BTU per ton
0.5 = towboat fuel consumption, gal./hp-day
HP = average towboat horsepower
t = locking time, hours
q = average tow cargo load, tons

The above equation permits conversion of the lock time function parameters from time units to energy use. Results, along with other pertinent data, are given in Table 4-2. Some representative functions are plotted in Figure 4-2.

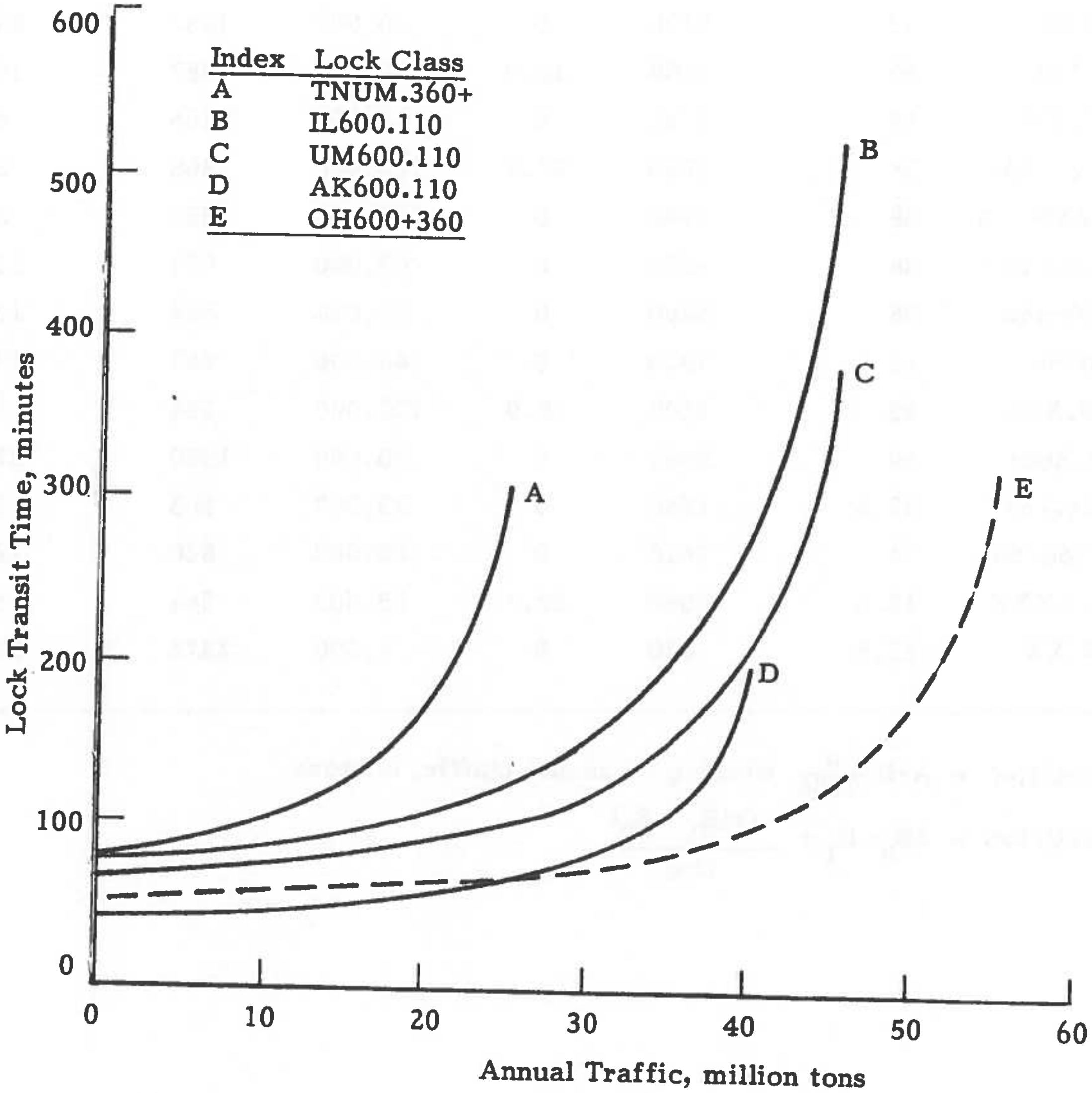

Figure 4-1. Lock Time Functions

Table 4-2. Lock Energy Functions

		Avg. Tow Cargo Load*		Energy Function**		
Class	Fuel use gal/tow-hr	A	B	Q K tons	E_0 BTU/ton	E_1 BTU/ton
UM600.110	55	6410	47.2	50,000	1289	1675
UM.LD26	55	8190	0	70,000	1552	2328
IL600.110	40	5000	40.0	50,000	1387	1926
AK600.110	19	3780	0	45,000	465	697
OH12+6.110	38	5060	32.3	120,000	868	880
OH.NAVPASS	38	5940	0	195,000	591	887
OH.GALLPLS	38	6320	0	60,000	973	1529
OH.600+360	38	5460	0	60,000	804	1207
MN360.56	12	1920	0	40,000	867	1300
MN720.XX+	13	2100	18.0	100,000	544	601
TNUM.360+	40	5480	0	30,000	1350	2109
XX400+.75+	12.5	1540	0	35,000	563	938
KW2X360.56	16	3610	0	60,000	820	1230
GIWW.XXXX	12.5	2050	22.3	55,000	564	644
KY145.XX	12.5	670	0	4,500	2372	3881

* tons/tow $= A+B \frac{q}{1000}$ where q = annual traffic, kilotons

** BTU/ton $= 2E_0 - E_1 + \frac{Q(E_1 - E_0)}{Q-q}$

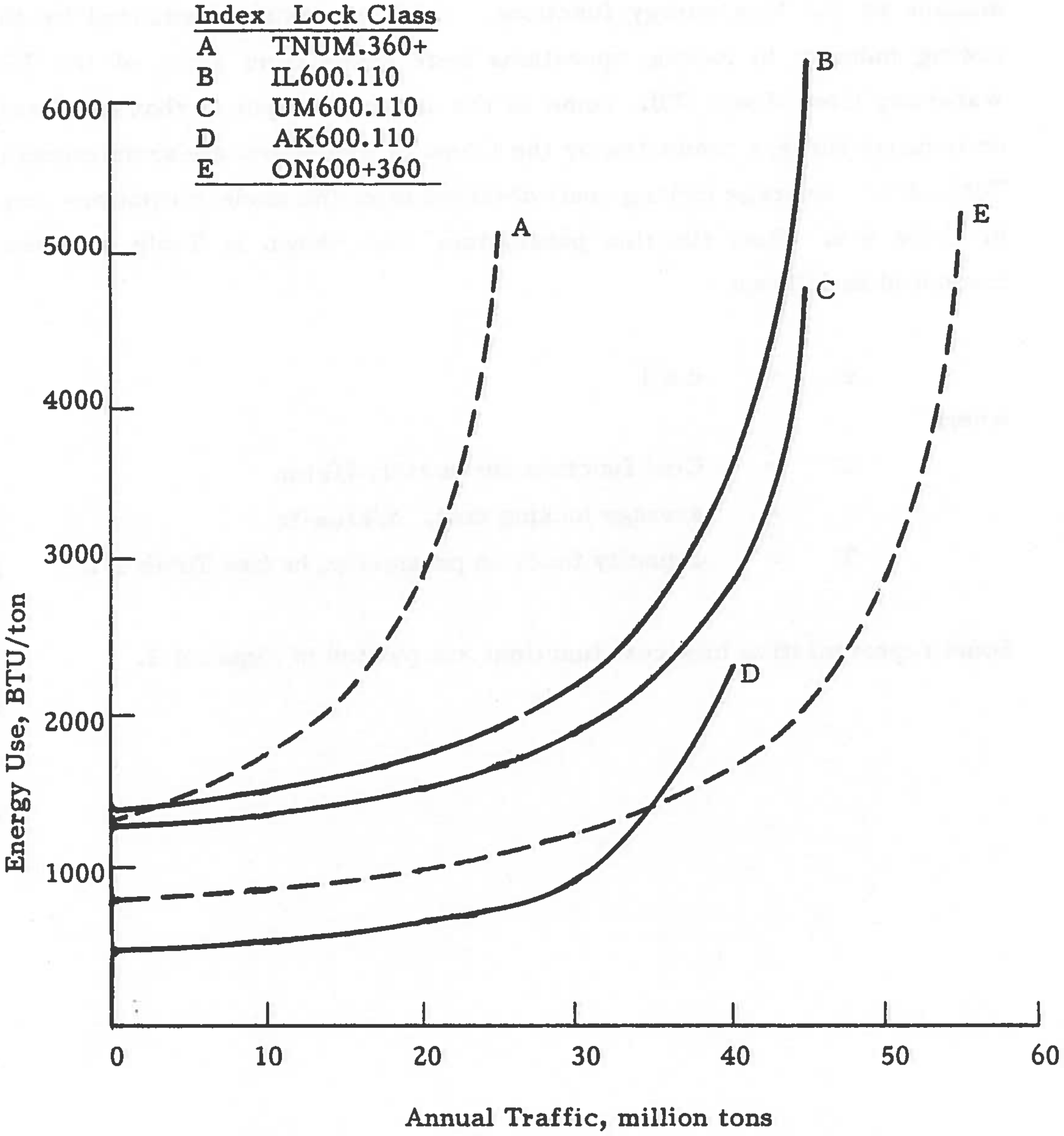

Figure 4-2. Lock Energy Functions

- Lock Cost Functions

Cost functions for inland waterway locks were derived in much the same manner as the lock energy functions. Data on costs experienced by the towing industry in locking operations were taken from a run of the TSC Waterway Cost Model (23). Some of the unit costs input to that run, based on industry surveys conducted by the Corps of Engineers, are summarized in Table 4-3.* Average locking costs obtained from the model output are given in Table 4-4. Cost function parameters, also shown in Table 4-4, were computed as follows:

$$C = c \times T$$

where

C = Cost function parameter, \$/kton

c = average locking cost, \$/kton-hr

T = capacity function parameter, hr (see Table 4-1)

Some representative lock cost functions are plotted in Figure 4-3.

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* A complete listing of model inputs may be found in (23), Appendix A.

Table 4-3. Towboat and Barge Operating Costs

A. Towboat Costs

Towboat Horsepower	Max Tow Size*	Labor Cost ($/hr)	Other Cost ($/hr)	Total Variable Cost ($/hr) **		Annual Fixed Cost ($)
				Operating	Maneuvering	
300	2	15.70	3.63	20.83	20.09	54,600
600	4	15.70	3.63	22.33	20.83	54,600
1,200	8	26.30	11.10	43.40	40.40	117,000
1,800	12	28.80	13.70	51.50	47.00	152,000
2,500	14	34.30	18.30	65.08	58.85	222,000
3,300	17	39.30	22.60	78.46	70.16	293,000
4,300	23	39.50	26.90	87.88	77.15	358,000
5,000	26	41.10	29.40	95.46	82.98	396,000
5,700	28	42.30	31.80	102.66	88.38	437,000
7,000	33	42.90	36.00	113.94	96.42	524,000
8,400	36	45.30	40.80	128.10	107.10	611,000
9,000	38	45.30	42.30	132.60	110.16	646,000
10,100	40	45.30	44.90	140.72	115.40	706,000

* Number of jumbo barges. Tow size may also be limited by channel characteristics.

** Sum of previous two columns plus fuel cost (based on 12¢/gal. and fuel consumption of 1.0 gal./hp/day while operating and 0.5 gal/hp/day while maneuvering).

B. Barge Costs

Barge Class	Capacity (tons)	Variable Cost ($/hr)	Annual Fixed Cost ($)
Open Hopper Jumbo	1700	.55	19,300
Covered Hopper Jumbo	1700	.66	22,900
Tank Barge Jumbo	1700	1.75	37,900

Table 4-4. Lock Cost Functions

		Average Locking Cost ($/kton-hr)		Cost Function*		
Lock Class	No. of Locks	mean	Std.dev.	Q ktons	C_0 $/kton	C_1 $/kton
UM600.110	23	17.26	.21	50,000	18.70	28.80
UM.LD26	1	16.92	--	70,000	28.20	42.30
IL600.110	24	16.92	1.35	50,000	21.20	35.20
AK600.110	32	16.39	7.30	45,000	10.90	16.40
OH12+6.110	10	15.59	1.35	120,000	13.00	18.20
OH.NAVPASS	2	18.58	1.46	195,000	12.40	18.60
OH.GALLPLS	1	15.49	--	60,000	18.10	28.40
OH.600+360	7	17.03	1.65	60,000	14.20	21.30
MN360.56	12	25.22	12.21	40,000	25.20	37.80
MN720.XX+	4	14.33	.37	100,000	9.10	14.30
TNUM.360+	4	22.07	1.55	30,000	29.40	46.00
XX400+.75+	5	31.91	12.99	35,000	16.00	26.60
KW2X360.56	4	16.86	2.85	60,000	22.50	33.70
GIWW.XXXX	7	17.09	3.95	55,000	11.40	17.10
KY145.XX	6	46.29	.04	4,500	42.40	69.40

* $\$/\text{kton} = 2C_0 - C_1 + \frac{Q(C_1 - C_0)}{Q - q}$ where q = annual traffic, kilotons

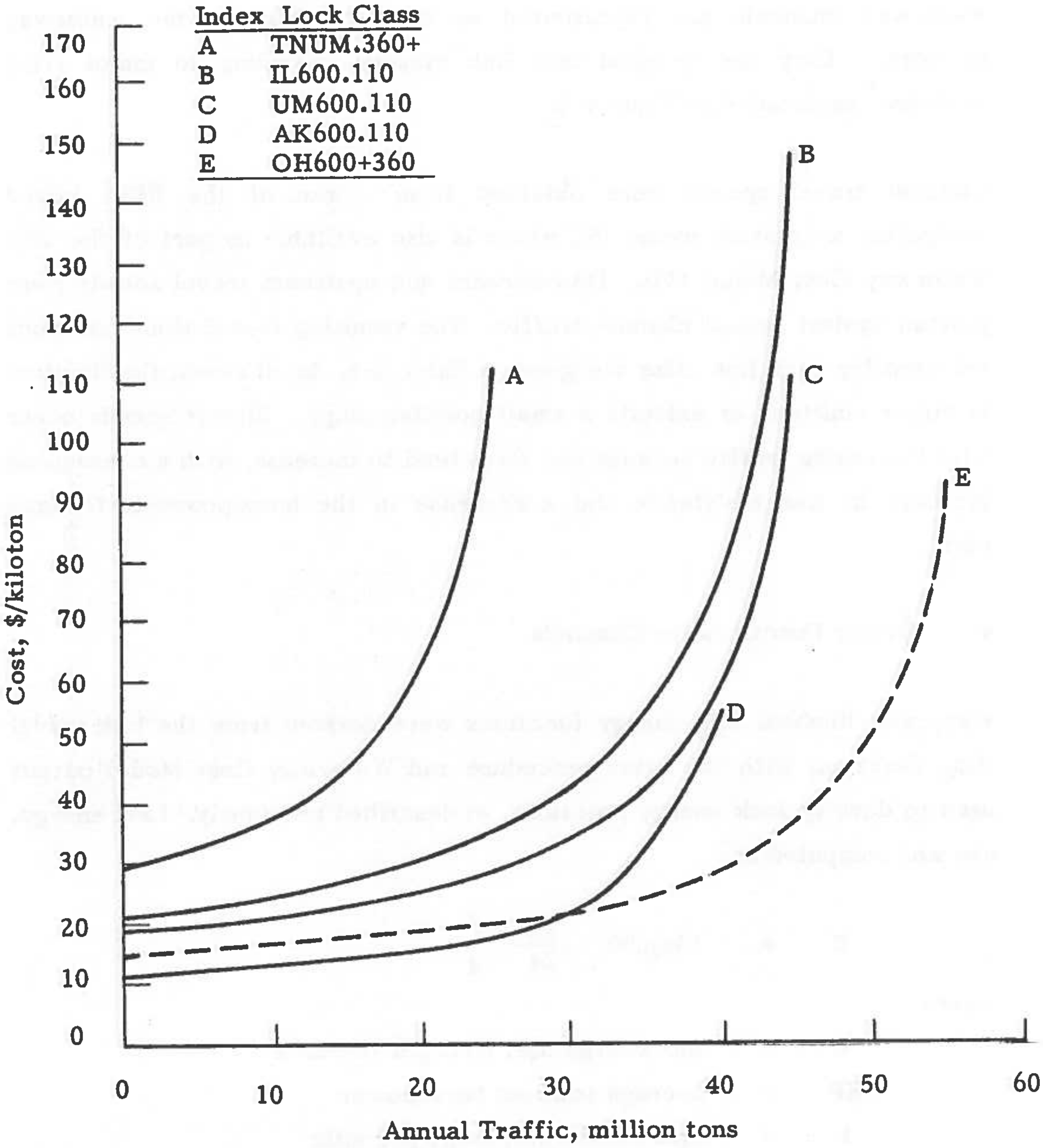

Figure 4-3. Lock Cost Functions

Inland Waterway Channels

- Link Classes and Travel Time Functions

Waterway channels are represented as linehaul links in the waterway network. They are grouped into link classes according to major river systems,* as detailed in Table 4-5.

Channel travel speeds were obtained from a run of the INSA inland navigation simulation model (5), which is also available as part of the TSC Waterway Cost Model (23). Downstream and upstream travel speeds were plotted against annual channel traffic. The resulting travel time functions selected for each link class are given in Table 4-5. In all cases, the function is either constant or exhibits a small positive slope. Slower speeds occur with increasing traffic because tow sizes tend to increase, with a consequent increase in tow resistance and a decrease in the horsepower-to-tonnage ratio.

- Energy Functions for Channels

Waterway linehaul link energy functions were derived from the link travel time functions with the same procedure and Waterway Cost Model output used to develop lock energy functions, as described previously. Link energy, use was computed as :

$$E = 138{,}690 \frac{HP}{24} \frac{t}{q}$$

where

E = link energy use, BTU per ton-mile
HP = average towboat horsepower
t = link travel rate, hours per mile
q = average tow cargo load, tons.

---

* This grouping corresponds to that defined for use with the TSC Waterway Cost Model; see (23), Appendix A, for detailed data. The White, Green and Barren, and Pearl rivers were excluded, since they lie entirely within single BEAR's.

Table 4-5. Waterway Linehaul Link Classes and Time Functions

Link Class	Rivers Included	Downstream Travel Rate (hr/mi)* A	Bx1000	Upstream Factor **
LWR.MISS.R	Lower Mississippi	.04	.678	1.5
UPR.MISS.R	Upper Mississippi	.128	0	1.25
ARKANSAS.R	Arkansas	.155	0	1.46
OHIO.RIVER	Ohio	.10	.457	1.0
L.MONONGHL	Lower Monongahela	.132	0	1.0
U.MONONGHL	Upper Monongahela	.132	0	1.0
ALLEGHENY	Allegheny	.139	0	1.0
TENNESSEE	Tennessee	.115	.171	1.0
CLINCH/EMY	Clinch/Emory	.128	0	1.0
CUMBERLAND	Cumberland	.128	0	1.0
KANAWHA.R	Kanawha	.146	0	1.0
KENTUCKY.R	Kentucky	.139	0	1.0
ILLINOIS.R	Illinois Waterway	.135	0	1.0
GIWW.WEST	Gulf Intracoastal Waterway (West)	.155	0	1.0
GIWW.EAST	Gulf Intracoastal Waterway (East)	.132	0	1.31
BW/TOMB/MO	Black Warrior/Tombigbee/Mobile	.155	0	1.0
ALABA/COOS	Alabama/Coosa	.146	0	1.0
MISSOURI.R	Missouri	.110	0	2.05
AP/CHAT/FL	Apalachicola/Chattahoochee/Flint	.114	0	1.65
ATCHAF/OLD	Atchafalaya/Old	.106	0	2.13
RED.RIVER	Red	.135	0	1.0
OUACHTA/BL	Ouachita/Black	.146	0	1.0
P.ALLEN.RT	Morgan City-Port Allen Route	.135	0	1.0

* Travel Rate = A+Bq where q = annual link traffic, million tons.

** Ratio of upstream travel rate to downstream travel rate. In most cases, no differential was observable in the simulation model output. The small downstream current in slackwater pools is apparently counteracted by reduced draft due to a tendency toward movement of empty barges upstream.

Pertinent data and the resulting channel energy functions appear in Table 4-6.

- Channel Cost Functions

Towing industry costs for linehaul channel operations were obtained from the same source as the locking costs. The average cost for each river was used in all cases. Cost values selected for inclusion in the database are listed in Table 4-6.

Ports

Waterway ports were grouped into node classes according to the relative amount of fleeting activity occurring, as revealed in a simulation of the inland waterway system conducted for the Corps of Engineers (24). Some results from that simulation and the node classes defined for ports are presented in Table 4-7.

The only time, cost, and energy use incurred at port nodes are those relating to fleeting activities. Since most tows do not stop at every port, most of the ports were placed into a class with zero time, cost, and energy use. Port costs associated with waterway access are included in the access link data, as described later.

Fleeting costs were derived from analysis of output from the TSC Waterway Cost Model (23), which indicated that fleeting type activities at ports incur an average cost of \$0.25 per ton. It was assumed that cargo would be delayed awaiting a tow for 24 hours, and that a fleeting stop would delay a tow for 3 hours. The statistically average tow in the model consists of 7 barges and a 2000 horsepower towboat, with a net load of 5600 tons. With fuel consumption of 0.5 gal per horsepower per day, energy use for the 3-hour fleeting operation amounts to 3000 BTU/ton. Port time, energy use, and cost estimates based on this analysis are given in Table 4-8.

Table 4-6. Waterway Linehaul Link Energy and Cost Functions

Link Class	Fuel Use gal/tow-hr	Avg. Tow Cargo Load * A	B	Downstream Energy Use (BTU/ton-mi)** C	D	Upstream Factor #	Downstream Cost (Mills/ton-mi.)
LWR.MISS.R	191	5960	58	178	.678	1.5	2.75
UPR.MISS.R	111	5960	58	277	0	1.25	3.40
ARKANSAS.R	45	4950	0	195	0	1.46	3.90
OHIO.RIVER	75	5440	25	191	0	1.0	2.75
L.MONONGHL	26	2190	35	187	0	1.0	3.15
U.MONONGHL	26	2190	35	187	0	1.0	3.15
ALLEGHENY	23	2240	0	198	0	1.0	2.75
TENNESSEE	78	6450	0	193	.286	1.0	3.15
CLINCH/EMY	41	3260	0	223	0	1.0	3.00
CUMBERLAND	41	3260	0	223	0	1.0	3.00
KANAWA.R	33	3600	0	187	0	1.0	3.00
KENTUCKY.R	25	670	0	719	0	1.0	5.50
ILLINOIS.R	82	6190	0	248	0	1.0	3.15
GIWW.WEST	25	3070	0	175	0	1.0	3.60
GIWW.EAST	27	3070	0	164	0	1.31	3.80
BW/TOMB/MO	25	3280	0	164	0	1.0	3.15
ALABA/COOS	25	960	0	527	0	1.0	5.00
MISSOURI.R	73	3530	0	315	0	2.05	5.50
AP/CHAT/FL	25	970	0	379	0	1.65	9.40
ATCHAF/OLD	25	2100	0	175	0	2.13	7.50
RED.RIVER	25	910	0	514	0	1.0	6.30
OUACHTA/BL	25	910	0	556	0	1.0	5.50
P.ALLEN.RT	25	1600	0	293	0	1.0	3.60

* tons/tow = A+Bq where q = annual traffic, million tons.

** BTU/ton-mile = C+Dq.

\# Ratio of upstream energy use and cost to downstream energy use and cost.

Table 4-7. Node Classes for Waterway Ports

Node Class	Port Name	Loaded Bgs Shp.	Loaded Bgs Rcv.	Barges Fleeted	% Tows Stopping	Notes
MAJR.FLEET	New Orleans	300	709	1274	86	Major Fleeting Ports: over 1000 barges fleeted, and over 70% of passing tows stopping.
	Baton Rouge	746	711	1129	81	
	Cairo	138	140	2160	72	
	St. Louis (L/D27 Pool)	385	157	1332	76	
	Paducah	108	12	1367	89	
	Kentucky R./Ohio R.	361	427	1332	100	
INMD.FLEET	Old R./Mississippi R.	17	0	1010	54	Intermediate: 50% to 70% tows stopping.
	St. Louis (L/D 26 Pool)	1	0	919	56	
	Gallipolis, Ohio	26	482	639	70	
MINR.FLEET	Arkansas R./Mississippi R.	0	2	75	53	Other fleeting ports.
	Cumberland R./Ohio R.	71	0	535	41	
	Pittsburgh	8	54	160	35	
	Mobile	0	28	148	35	
	Morgan City, La.	31	8	202	21	
THRU+ACCES	All other ports	--	--	--	--	Zero time and cost.

Note: Traffic data based on 1975 simulation run, 30 days; see (24).
At all other junction ports, pickup and delivery activity exceeded fleeting activity, or only a small percentage (10 to 30%) of passing tows stopped.

Table 4-8. Port Time, Cost, and Energy Functions

Node Class	Avg. % Tows Stopping	Time (hr)	Energy Use (BTU/ton)	Cost ($/kton)
-	100	27	3000	250
MAJR.FLEET	90	24	2700	225
INMD.FLEET	60	16	1800	150
MINR.FLEET	30	8	900	75
THRU+ACCESS	0	0	0	0

Waterway Access

Waterway access links were classified according to the approximate distance from the BEAR economic center to the waterway, in 25-mile increments. The access link classes were assigned names WA025, WA050, ..., WA200; the last three characters correspond to the average access distance.

The waterway portion of access impedance follows closely the estimates for fleeting activities derived above. The average time was increased to 36 hours, to account for delays associated with the loading and unloading process. Tow energy use remained at 3000 BTU/ton, to account for access-related fleeting. TSC Waterway Cost Model output indicates that average operating costs at non-fleeting ports are about $100/kiloton.

Access to port facilities was assumed to be by truck, at a speed of 30 mph and requiring 1 hour of additional terminal time. Rail access was assumed for coal and metallic ores, and pipeline access for petroleum. Access cost and energy use data were derived from the functions developed for the assumed access mode. Costs were increased by $0.75 per ton to account for terminal and transfer charges. Access functions are given in Table 4-9.

The following exceptions, found to be required during model calibration, are incorporated in the data:

- Commodity 2, Forest and Marine Products, is dominated by Marine Products, so distance-related energy use and cost were reduced by 50%, and no $.75 terminal charge was added.
- Savings by using rail rather than truck for coal and metallic ores (commodities 3 and 5) were assumed to be offset by the specialized transfer facilities required, so the standard access impedances were used.

Table 4-9. Waterway Access Functions

Function/Commodity	Average Access Distance, miles							
	25	50	75	100	125	150	175	200
Time, hours	38	39	40	41	42	43	44	45
Crude Petroleum	54	73	91	110	128	147	165	184
Petroleum Products	52	68	84	100	116	132	148	165
Energy use, KBTU/ton	34.3	65.6	97.0	128	160	191	222	254
Forest & Marine Products	18.6	34.3	50.0	65.5	81.5	97.0	112.5	128.5
Crude Petroleum	6.1	9.2	12.3	15.4	18.5	21.6	24.7	27.8
Petroleum Products	9.2	15.4	21.6	27.8	34.0	40.2	46.4	52.6
Group A *	40.3	77.6	115	152	189	227	264	301
Group B *	36.2	69.4	103	136	169	202	235	269
Group C *	32.8	62.5	92.3	122	152	182	211	241
Cost, $/ton	2.25	3.65	5.05	6.45	7.85	9.25	10.55	11.95
Forest & Marine Products	.80	1.50	2.20	2.90	3.60	4.30	4.95	5.65
Coal	1.50	2.90	4.30	5.70	7.10	8.50	9.80	11.20
Crude Petroleum	.90	.96	1.01	1.07	1.12	1.17	1.23	1.28
Petroleum Products	.91	.97	1.04	1.10	1.16	1.22	1.28	1.35
Group D *	2.40	3.96	5.51	7.07	8.62	10.17	11.75	13.25
Group E *	2.46	4.07	5.68	7.29	8.90	10.42	12.15	13.75
Group F *	2.71	4.57	6.44	8.30	10.16	12.05	13.85	15.75
Group G *	1.50	2.90	4.30	5.70	7.10	8.50	9.80	11.20
Nonmetallic Minerals	2.35	3.85	5.34	6.84	8.34	9.84	11.35	12.85

* Group A: Textiles & Apparel, Lumber & Furniture, Transportation Equipment, Miscellaneous
Group B: Unidentified Manufactures, Fabricated Metal Products
Group C: Nonmetallic Minerals, Primary Metal Products
Group D: Farm Products, Food & Kindred Products, Unidentified Manufactures, Fabricated Metal Products

- Reflecting the prevalence of waterside plants and relatively inexpensive transfer, the $.75/for terminal charge was not applied to the following commodities:

3	Coal
10	Chemicals
18	Primary Metal Products

Admittedly, the above adjustments are somewhat ad hoc in nature and could stand considerable analytical refinement. Time and data resources did not permit this. However, these adjustments are relatively minor and are intuitively reasonable.

V. PIPELINE OPERATIONS DATA

Linehaul Link Classes

Pipelines were grouped into link classes according to the approximate diameter of a single pipeline with a flow capacity equivalent to that of all the pipelines represented by a network link. This equivalent pipeline concept was used by Debanne (6) in defining the pipeline network.

In the original network data, pipeline "capacities" are expressed in terms of trillion BTU (TBTU) per year. These capacities were converted to millions of barrells (MBBL) per day, using a factor of 5.8 million BTU per barrel, for 26 links with known diameters ranging from 6 inches to 48 inches. The results followed closely a curve of economic capacity* vs pipeline diameter reported by Kearney (25), which is shown here in revised format as Figure 5-1. Hence this figure was used to determine pipeline diameters from the Debanne network data. Based on the resulting frequency distribution of pipeline diameters, link classes were defined as in Table 5-1.

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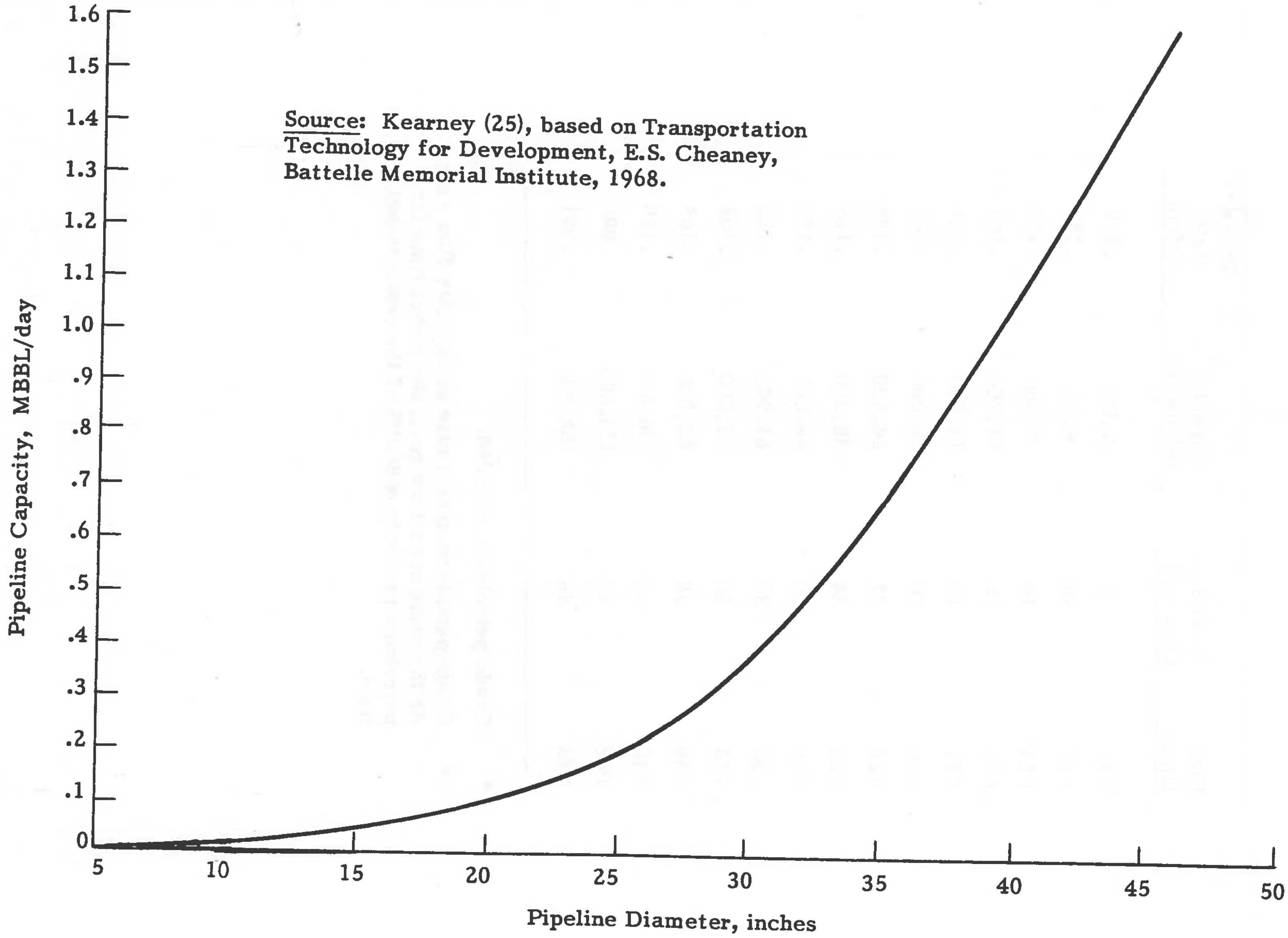
* The capacities shown in the curve are described as minimum cost petroleum pipeline flow rates in reference (25).



<u>Source</u>: Kearney (25), based on Transportation Technology for Development, E.S. Cheaney, Battelle Memorial Institute, 1968.

Figure 5-1. Economic Flow Capacities for Petroleum Pipelines

Table 5-1. Pipeline Capacities

Link Class	Maximum Dia. (in.)	Capacity* (ktons/yr)	Travel** Rate (hr/mi)
P06	6	1,000	.300
P10	10	4,000	.215
P14	14	8,000	.185
P16	16	11,000	.168
P18	18	14,000	.156
P20	20	18,000	.148
P22	22	24,000	.138
P24	24	30,000	.128
P28	28	44,000	.120
P32	32	61,000	.112
P34	34	71,000	.108
P36	36	82,000	.105
P40	40	106,000	.100
P42	42	120,000	.098
P48	48	168,000	.091

* Crude petroleum, rounded.

** Crude petroleum travel rate at capacity flow rate. At the same mass flow rate, the travel time for petroleum products is 86.9% of the crude travel time.

Pipeline Time Functions

The standard continuity equation of fluid mechanics relates pipeline flow rate, cross-sectional area, and fluid velocity, as follows:

$$Q = A \times V$$

where

Q = flow rate, cubic feet per second
A = pipeline cross-sectional area, square feet
V = fluid velocity, feet per second

Pipeline capacity limitations arise from the pumping energy input required to overcome friction loss, which is proportional to the square of the velocity.

Relationships between pipeline energy consumption and flow velocity developed by PMM (10) are shown in Figure 5-2. Line AA in the figure is the PMM estimate of average pipeline operating velocities, based on discussions with petroleum industry representatives. For the TSC database, pipeline capacity was defined as the flow rate corresponding to the fluid velocity occurring when energy consumption is four times greater than the energy consumption at the average operating velocity. Figure 5-2 was used to make these calculations. The resulting capacities, expressed in kilotons of crude petroleum,[*] appear in Table 5-1.

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[*] Petroleum densities are reported in (10) as 6770 BBL/kton for crude and 7788 BBL/kton for products.

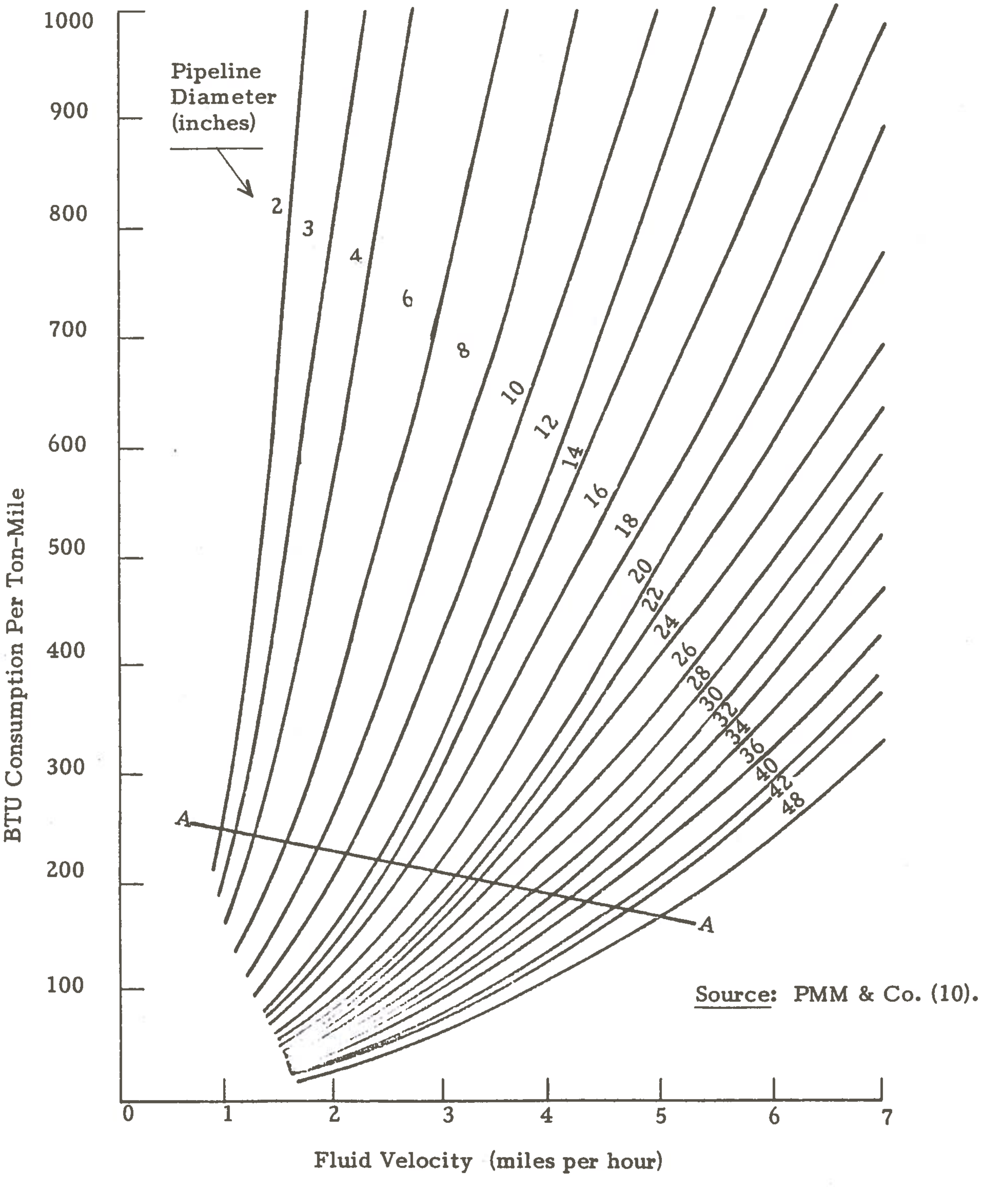


Figure 5-2. Energy Consumption in Crude Petroleum Pipelines

Flow velocities at any flow rate may be computed directly with the continuity equation. With all constants and conversion factors incorporated, the equation for crude petroleum is:

$$Q = 6.635\ D^2V$$

where

Q = flow rate, kilotons per year
D = pipeline diameter, inches
V = flow speed, mph

The corresponding equation for petroleum products pipelines is:

$$Q = 5.768\ D^2V$$

Pipeline Energy Functions

Figure 5-2 shows energy use as a function of flow velocity for crude pipelines, and Figure 5-3 provides the same information for products pipelines. The equations given above were used to map these functions into a family of energy use vs. flow rate curves.

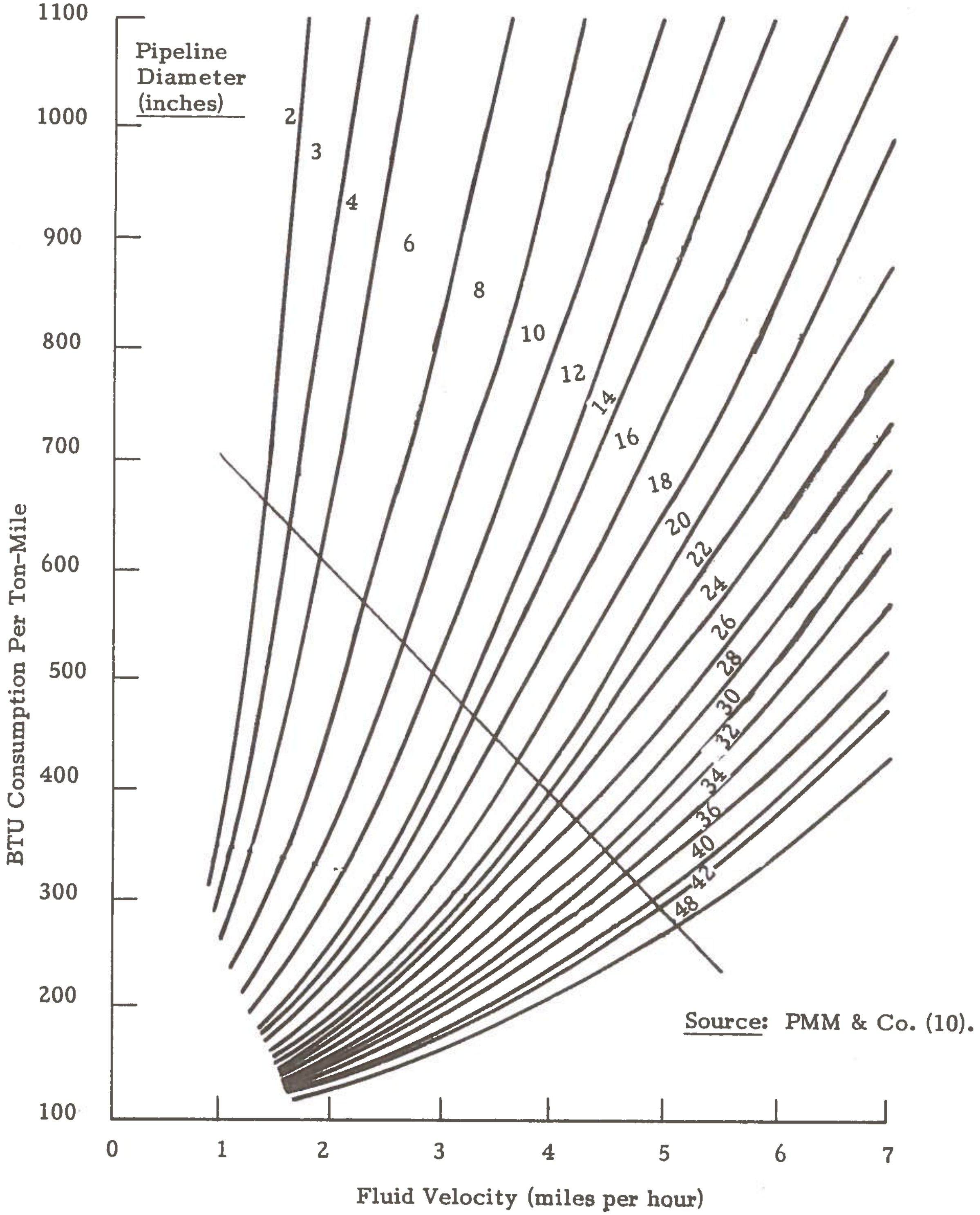
The following mathematical function was fitted to the crude pipeline energy use curves:

$$E = \frac{Yq}{Q-q}$$

where

E = energy use, BTU/ton-mile
q = annual flow, kilotons
Q = capacity parameter, kilotons
Y = energy use at flow q = Q/2

Parameter estimates are given in Table 5-2. Comparison of energy use in crude and products lines at various flow levels provided estimates of adjustment factors for products pipelines; these are also given in Table 5-2.



Source: PMM & Co. (10).

Figure 5-3. Energy Consumption in Petroleum Products Pipelines

Pipeline Cost Functions

Estimates of fully allocated costs for crude petroleum pipelines were taken from a Kearney study (25). These estimates covered flow rates up to the economic capacities depicted earlier in Figure 5-1, and in general show costs decreasing at a diminishing rate. To estimate costs over the increasing cost flow regions between economic capacity and physical capacity, it was assumed that:

(1) Variable cost is 30% of fully allocated cost at economic capacity: and

(2) Variable costs increase in the same ratio as energy use for flows exceeding economic capacity.

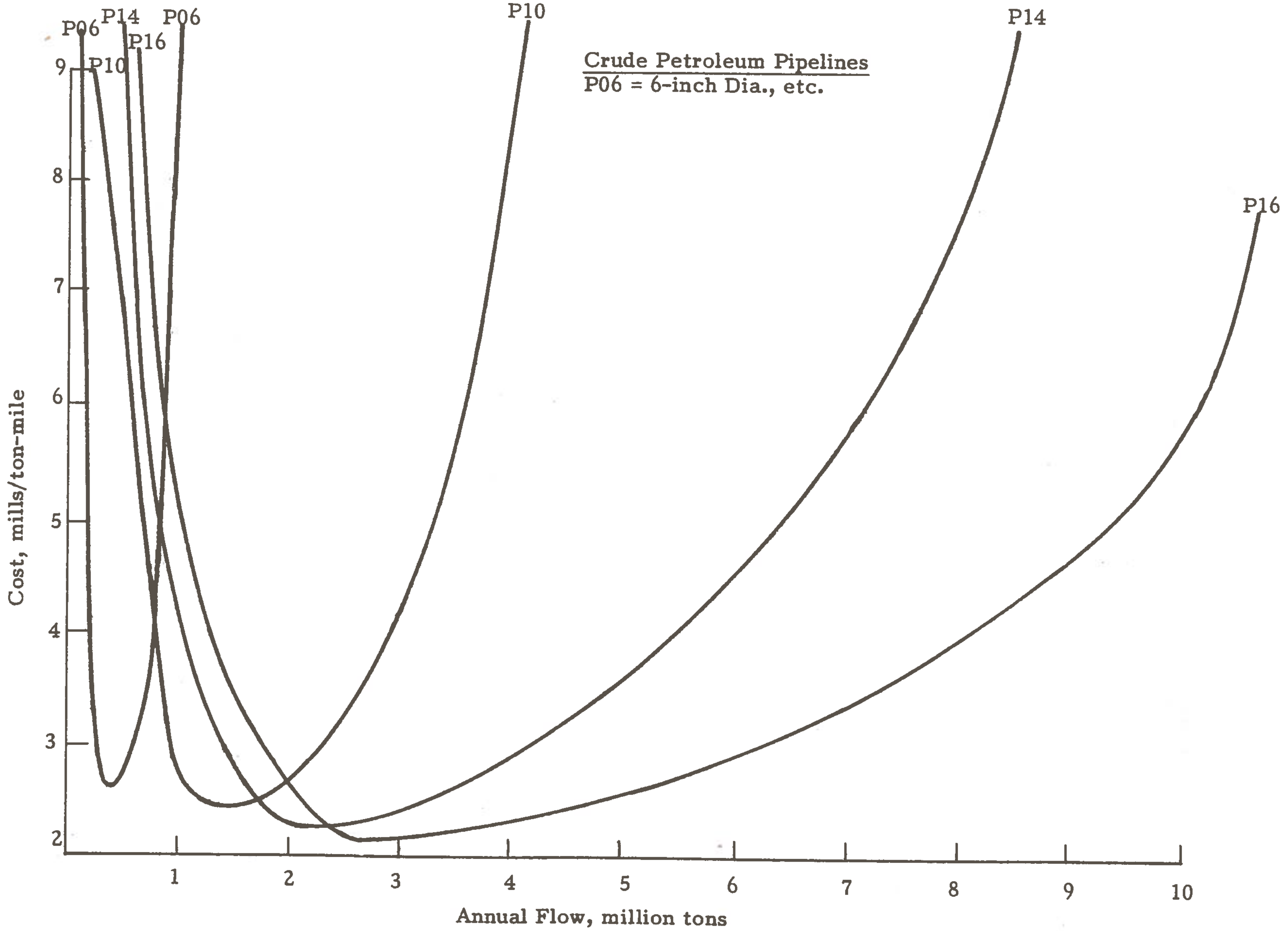
The pipeline cost functions resulting from these estimates appear in Figures 5-4 to 5-6.

Table 5-2. Pipeline Energy Functions

Link Class	Parameters for Crude Pipelines* Q kilotons/yr	Y BTU/ton-mi.	Adjustment for Products Type **	Factor
P06	1,300	575	A	125
P10	6,000	800	A	125
P14	13,000	725	A	130
P16	19,000	750	A	125
P18	26,000	740	A	135
P20	34,000	720	A	130
P22	45,000	750	A	125
P24	57,000	745	A	115
P28	80,000	660	A	130
P32	110,000	625	M	1.6
P34	140,000	680	M	1.6
P36	168,000	710	M	1.6
P40	220,000	720	M	1.6
P42	250,000	715	M	1.6
P48	350,000	690	M	1.6

* BTU/ton-mi $= \frac{Yq}{Q-q}$ where q = annual flow in kilotons

** A = additive factor, M = multiplier


Crude Petroleum Pipelines
P06 = 6-inch Dia., etc.
P06
P14
P16
P06
P10
P10
P14
P16
Cost, mills/ton-mile
9
8
7
6
5
4
3
2
1
2
3
4
5
6
7
8
9
10
Annual Flow, million tons

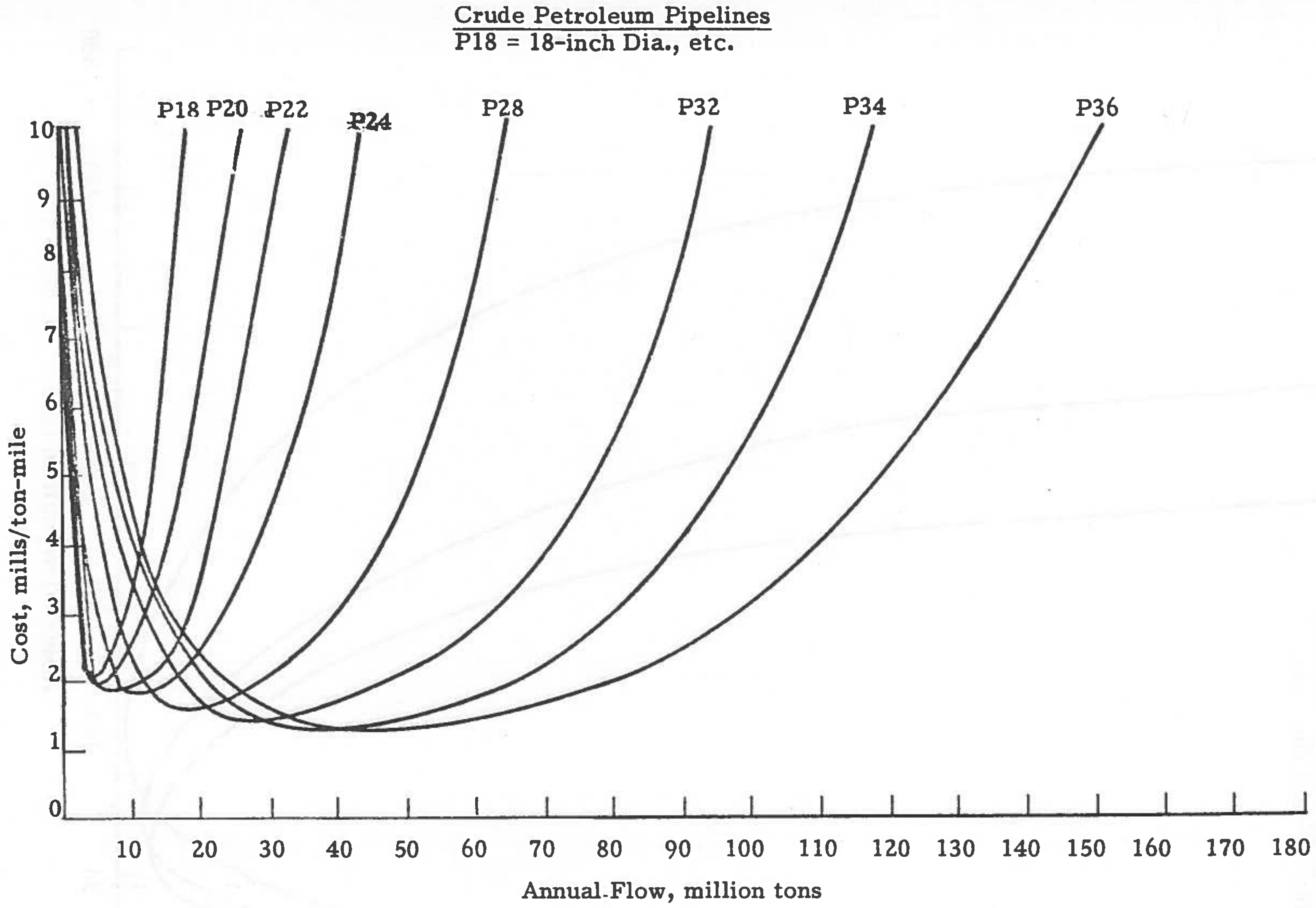


Figure 5-5. Pipeline Cost Functions

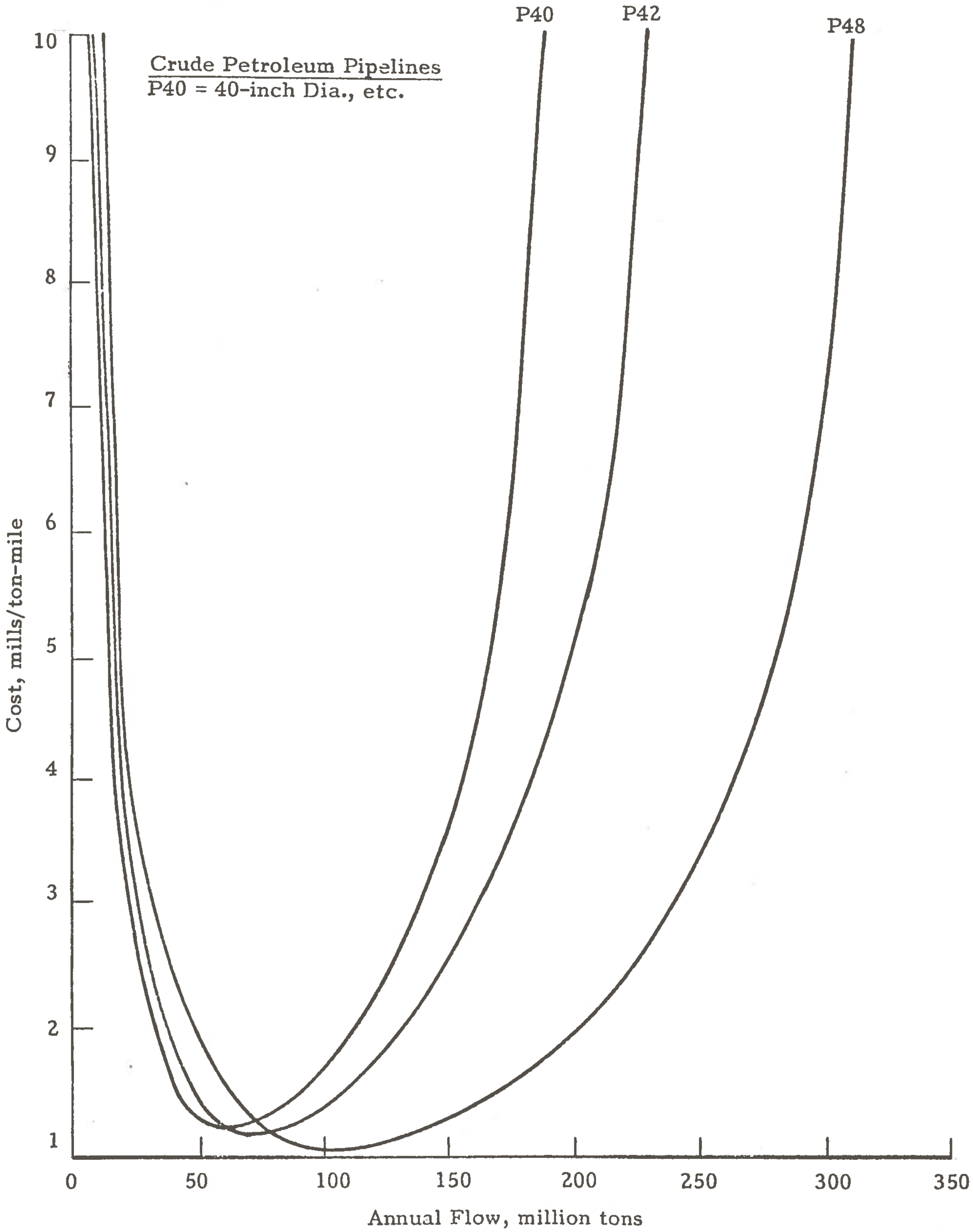


Figure 5-6. Pipeline Cost Functions

Costs for petroleum products were estimated assuming an average energy-use multiplier of 1.5 and applying this to 30% of the crude pipeline cost. This produces an average adjustment factor (multiplicative) of 1.15 for petroleum products.

Pipeline Access

Pipeline access link classes were defined according to the approximate distance from the BEAR economic center to the pipeline node accessed. Recognizing the somewhat gross nature of the pipeline network and the propensity of the petroleum industry to minimize their subregional distribution costs, access time, energy use, and cost were calculated using a distance equal to half of the approximate access distance. Functions for a 16-inch pipeline flowing at economic capacity were used, yielding the following average access impedances:

Travel Rate = .738 hr/mile
Energy Use = 124 BTU/ton-mile
Cost = 2.16 mills/ton-mile

The pipeline access functions are given in Table 5-3.

Table 5-3. Pipeline Access Functions

Access Link Class	Time (hr)	Energy Use (BTU/ton)	Cost $/kiloton
PA010	4	620	11
PA025	9	1,550	27
PA050	19	3,100	54
PA075	28	4,650	81
PA100	37	6,200	108
PA125	46	7,750	135
PA150	55	9,300	162
PA175	65	10,850	189
PA200	74	12,400	216
PA250	92	15,500	270
PA300	110	18,600	324
PA500	185	31,000	540
Product/Crude Ratio	.869	2.0	1.15

VI. COMMODITY TRAFFIC DATA

The preceding five chapters have concentrated on the supply-side elements of the TSC freight network and operations database, emphasizing data and procedures used to estimate modal service characteristics. The present chapter describes the transportation demand data included in the system.

Commodities

Commodity flow data, developed by TSC (26), consists of movements of 19 commodities between 171 BEA regions. Commodity groups are listed in Table 6-1. For the most part, a commodity corresponds to a single Standard Transportation Commodity Classification (STCC) code. Exceptions and the reasons therefor are noted in (26).

Commodity 9, TOFC or piggyback traffic, does not appear in the original TSC data, but was created expressly for this study. Further details concerning TOFC are provided later.

• Time Value

The commodity characteristic of primary importance in this study is the value to the shipper of savings in transit time. Estimates of this value for each commodity are given in Table 6-1. Initial estimates were taken from a TSC report (27). The imputed values shown in the table are those which were required to achieve an acceptable calibration * of the TSC Freight Energy Model. In most cases, the imputed travel time value is significantly higher than the standard in-transit inventory value. These high travel time values were found to be needed in order to get the model to replicate the observed truck vs. rail (and, in some cases, rail vs. water) modal split. That is, a high time value allows the extra cost of using motor carrier to be overcome by the substantial motor carrier service advantage.

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* Model calibration results are presented in Volume 1. Adjustments in the value of travel time were the principal means used to calibrate the model.

Table 6-1. Commodity Characteristics

Code	STCC Code	Description	Time Value ($/ton-day)*		Transport Modes**			
			TSC Est.	Imputed	RR	HWY	WTR	PPL
1	01	Farm Products, Field Crops	.07	1.47	X	X	X	
2	08,09	Forest Products, Marine Products	.25	.45	X	X	X	
3	11	Coal	.01	.01	X	X	X	
4	13	Crude Petroleum	.01	.01	X	X	X	X
5	10	Metallic Ores	.01	.16	X	X	X	
6	14	Nonmetallic Minerals	.01	.01	X	X	X	
7	20	Food and Kindred Products	.23	1.98	X	X	X	
8	22,23	Textiles and Apparel	2.04	3.64	X	X	X	
9	#	TOFC	--	1.50	X			
10	28	Chemicals and Allied Products	.48	1.88	X	X	X	
11	24,25	Lumber and Furniture	.27	2.37	X	X	X	
12	35	Machinery (Nonelectrical)	2.89	1.89	X	X	X	
13	36	Electrical Machinery	2.81	1.31	X	X		
14	37	Transportation Equipment	1.43	.63	X	X		
15	##	Unidentified Manufactures	--	1.80	X	X	X	
16	26	Paper and Allied Products	.33	1.53	X	X	X	
17	29	Petroleum and Coal Products	.04	.74	X	X	X	
18	33	Primary Metal Products	.32	1.62	X	X	X	
19	34	Fabricated Metal Products	1.01	2.41	X	X	X	
20	21,30,31, 32,38,39	Miscellaneous Manufactures	.97	3.27	X	X	X	

* TSC estimates (27) are based on commodity value and an average effective inventory charge of 25%/year. Imputed values are those used in the final network model calibration runs and all subsequent runs.

** Modes declared allowable in unconstrained network model runs. See text.

\# Trailer on Flat Car rail traffic, derived from selected rail commodities. See text.

\#\# Composition varies by origin/destination, due to Census Bureau disclosure rules; see ref. (26).

At first glance, the discrepancies between the inventory-based and imputed values of travel time are somewhat troubling. It must be recalled, however, that the transportation network model uses transit time as a surrogate for the complete set of transportation service variables, which might include loss and damage, transit time variability, shipment size, stockout probability, and other characteristics of the individual shipper's overall physical distribution system. Reliable data on all of these variables are simply not available at the systems level, nor is it presently feasible from a computational standpoint to include them all in the network model. Consequently, the implicit assumption is that freight transportation service quality is correlated with transit time. Hence the imputed time value represents the shipper's sensitivity to service quality, not merely his direct valuation of transit time.

- Transport Modes

Allowable mode choices for each commodity are displayed in the last four columns of Table 6-1. These choices are available in all model runs which are unconstrained, i.e., where the model is completely free to select modes and routes solely on the basis of relative cost and service. In most cases a three way choice between rail, highway, and waterway is possible. Crude petroleum, of course, also has the pipeline mode available. For calibration and baseline runs, TOFC traffic (less than 1% of total interregional tonnage) is assigned only to the rail mode.

A seeming anomaly is that commodity 17, petroleum and coal products, is not permitted to move by pipeline. This is due to a discrepancy in the commodity flow data, in which only 1.6% of this tonnage is recorded as moving by pipeline. In order to maintain a marginally tolerable split of this traffic among the other three modes, thereby avoiding severe distortions* in their reported flow statistics, it was found necessary to prohibit pipeline movements of this commodity. Fortunately, the initial model applications did not depend very much on high accuracy in either the pipeline or petroleum products market segments.

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* Waterway traffic totals are particularly sensitive to modal allocations of petroleum products.

Finally, commodities 13 and 14, electrical machinery and transportation equipment, were not allowed to move by water carrier. Calibration of the truck/rail modal split for these commodities required use of a time value low enough to produce a small but measurable amount of waterway traffic, whereas the traffic flow data show virtually no waterway movements. Since truck/rail competition for these two commodities was of interest in initial model applications, it was decided to delete the waterway alternative. The constraint thereby introduced is small, since together these commodities comprise only 1%of the tonnage reported in the commodity flow data.

In considering the above discussion of commodity characteristics, it is important to note that special conditions or restrictions involve only 2.6% of interregional shipment tonnage. In all other cases, the model is completely free to allocate shipments to any physically compatible transport mode, subject only to consideration of network coverage and relative cost and service.

Commodity Flow

Base year commodity flow estimates and forecasts for future years were prepared by TSC. A complete account of data sources and projection methods is given in (26). Some important aspects of the flow data and projections are summarized below.

- 1972 Flows

Bulk commodity flows in 1972 were developed for TSC by Jack Faucett Associates (28). Data for processed and manufactured goods were taken from the 1972 Census Commodity Transportation Survey (CTS).

Bulk commodity flows, which account for 80% of the intercity tonnage carried by rail, water, and pipeline, were derived from a number of sources. Rail traffic was taken from the 1972 One Percent Waybill Sample and the 1972 ICC Quarterly Commodity Statistics. Inland waterway flows were obtained from the Army Corps of Engineers 100% survey of water carrier traffic. Pipeline flows were estimated from information compiled by the Federal Energy Administration and the National Petroleum Council.

Commodity flows into and out of each BEA region were compared with independent estimates of regional production and consumption. Any resulting irreconcilable discrepancies were used to estimate inter-BEA truck movements, especially where outside data sources indicate the existence of such movements. This undoubtedly understates trucking activity, but there is no comprehensive source of data on bulk truck flows.

Where two or more segments of a multimodal shipment are included in the bulk commodity flow data, they appear as separate, rather than integrated, flows. For example, a multimodal flow of iron ore from Duluth to Pittsburgh would show up as a rail move within the Duluth BEA (from mine to port), a waterway movement from Duluth to Cleveland, and a rail move from Cleveland to Pittsburgh. This obviates the need to include intermodal transfer connections in the network data, since all such existing transfers are already implicitly included in the flow data. * This also, however, inhibits the utility of the current version of the database for addressing questions pertaining to intermodalism in bulk commodity movements.

Manufactured goods are probably underrepresented in the 1972 commodity flow data, due to certain problems inherent in the CTS. First, the CTS only includes shipments from manufacturing facilities, excluding imports and shipments from facilities such as warehouses, agricultural assemblers, merchandisers, and mineral processing plants. Second, in multimodal moves the mode responsible for the longest length of haul is credited with the entire shipment. This is not a particularly serious problem in the present context, since the minor modes involved in a multimodal move are normally used for access to the major linehaul mode, and thus are represented in the access link data structure. This aspect of the flow data would, however, make it difficult to calibrate the transportation network model if intermodal transfer links were included in the network, although it does not otherwise inhibit addressing intermodalism issues.

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* In an earlier CACI study using this flow data and permitting rail/water transfers, the network model allocated an insignificant amount of traffic to multimodal routes.

A third problem with the CTS arises from Census disclosure practices, which cause commodity detail to be suppressed for many flows. All such flows are grouped together as commodity 15, unidentified manufactures. Although the commodities which are included in this group are known for each origin region, it is not possible to distinguish the commodity mix for any component flow.

- 1990 Flows

Commodity flow forecasts for the year 1990 were based strictly on OBERS Series E projections of regional economic activity (29). Special industry analyses, alternative economic scenarios, western coal development, industry and population relocation trends, high agricultural exports, and similar foreseeable influences were not incorporated. As such, the forecasts should be interpreted as "baseline projections" subject to adjustment to account for the excluded factors.

The projection process, described completely in (26), may be summarized as follows:

<u>Step 1</u> -- Multiply base year shipments by industry growth rate in origin region.

$$X_{kijt} = X_{kij72} r_{kit}$$

where

X_{kijt} = flow of commodity k from region i to region j in year t

X_{kij72} = flow of commodity k from region i to region j in 1972

r_{kit} = growth rate for industry k in region i between 1972 and t

<u>Step 2</u> -- Adjust raw projected flows to insure that total national shipments grow at the same rate as total gross product originating.

$$Q_{kijt} = X_{kijt} \frac{q_{kt}}{\sum\limits_{i}\sum\limits_{j} X_{kijt} / \sum\limits_{i}\sum\limits_{j} X_{kij72}}$$

where

Q_{kijt} = adjusted flow of commodity k from i to j in year t

q_{kt} = rate of growth of national product originating in industry k

Step 3 — Assign projected flows to modes according to base year mode splits.

$$Q_{kijtm} = Q_{kijt} \frac{X_{kij72m}}{X_{kij72}}$$

where subscript m denotes transportation mode.

In summary, base year flows were expanded by the forecast growth in industrial production in the origin region, constrained by the expected national growth in gross product originating within the industry. The distribution of destinations for the flow of each commodity from each origin region and the base year modal shares for each flow were maintained in the forecasts. Methods used to deal with transshipment and disclosure problems are detailed fully in (26).

Table 6-2 displays the total interregional tonnage, by commodity, included in the 1972 and 1990 flow data. The projection methodology yields flows in 1990 which are, on average, 44% higher than base year flows, which corresponds to a compound growth rate of 2% per year. In general, bulk commodities exhibit less than average growth while manufactures grow more rapidly than the average.

Also shown in Table 6-2 are several categories of commodity flow excluded from this study (although they are included in the TSC data and projections). Intra-BEA traffic is the largest such category. This traffic is excluded because the TSC national freight network is generally rather sparse within a single BEAR, and because there is no satisfactory algorithm known for assigning this "local" traffic to elements of the interregional network. The remaining categories are excluded because their respective networks are not presently included in the TSC freight network and operations database. In that the present database strains the available computer resources, including these additional networks will require either further network aggregation or moving the TSC Freight Energy Model to a larger computer.

Table 6-2. Commodity Flow Summary

	Total Flow, kilotons		Growth
Commodity	1972	1990	%
Included Traffic			
1. Farm Products	165,115	184,773	11.9
2. Forest and Marine Products	8,358	9,367	12.1
3. Coal	428,710	520,406	21.4
4. Crude Petroleum	321,911	417,219	29.6
5. Metallic Ores	67,374	95,205	41.3
6. Nonmetallic Minerals	91,713	155,063	69.1
7. Food and Kindred Products	174,257	230,410	32.2
8. Textiles and Apparel	12,776	18,279	43.1
10. Chemicals	108,874	223,559	105.3
11. Lumber and Furniture	50,394	78,652	56.1
12. Machinery (Nonelectrical)	15,901	26,257	65.1
13. Electrical Machinery	8,705	21,384	145.7
14. Transportation Equipment	16,517	28,292	71.3
15. Unidentified Manufactures	286,542	466,230	62.7
16. Paper and Allied Products	54,055	97,722	80.8
17. Petroleum Products	82,168	127,386	55.0
18. Primary Metal Products	96,677	112,633	16.5
19. Fabricated Metal Products	27,756	52,945	90.8
20. Miscellaneous Manufactures	90,572	172,833	90.8
Total	2,108,376	3,038,612	44.1
Excluded Traffic			
Alaska, Hawaii, and Unknown	11,804	0	--
Intraregional (Origin = Destination)	752,762	1,096,888	45.7
Coastwise and Lakewise Waterway Traffic	317,788	464,890	46.3
Air Freight and Nonpetroleum Pipeline Traffic	6,543	10,900	66.6
Total excluded traffic	1,088,896	1,572,678	44.4
Total	3,197,272	4,611,291	44.2

Totals may not match column sums due to rounding.

Shipments

Commodity flows are input to the transportation network model as a set of shipment records, which specify the commodity, origin region, destination region, annual kilotons, and (optionally) the fraction of the flow to be carried by each mode.* Computer resources required for a model run are directly proportional to the number of shipment records to be processed. Reasonable computer costs can be attained if the number of shipments is in the 5,000-10,000 range. The 1972 commodity flow data as described above, however, consists of 134,860 records. Processing all of these would cause the computer cost for each run to exceed the acceptable level by a factor of ten (or, put another way, would allow a single run for one set of conditions in place of analysis of ten different options). Stratified sampling of the flow data, as described below, resolved this dilemma.

To avoid expending computer resources on marginally useful processing, all modal shipments smaller than one kiloton were discarded. This reduced the number of records to 57,612, while producing a loss of only 0.65% of the total tonnage.

TOFC shipments (commodity 9) were next added to the flow data. For lack of better information, TOFC traffic was assumed to be a constant portion of all rail shipments of selected commodities. Table 6-3 shows the percentages of various commodity flows reassigned to TOFC. This simple procedure guarantees that the correct amount of TOFC traffic will appear in the rail statistics, but does not guarantee that the actual spatial distribution of TOFC flows will be reproduced. This step produced 6997 TOFC shipments accounting for 17,646 kilotons of rail traffic.

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* This expected modal split may be wholly or partially observed by the model, or may be completely ignored, in selecting shipment routings. See Volume 2 for details.

Table 6-3. TOFC Share of Selected Commodity Traffic

	Commodity	Net Tons per Car	TOFC % of Rail Tons
7.	Food and Kindred Products	46.2	9.3
14.	Transportation Equipment	23.2	18.6
16.	Paper and Allied Products	37.8	11.4
18.	Primary Metal Products	63.6	6.8
19.	Fabricated Metal Products	34.4	12.5
20.	Miscellaneous Manufactures	64.9	6.6
	Average	56.0	7.7

Based on AAR data showing a five year (1972-1976) average of 0.141 TOFC carloads per selected commodity carload and an average TOFC carload of 30.6 tons. Attempts to estimate TOFC carloads as a linear function of selected commodity carloads produced results which were not statistically significant.

Table 6-4. Distribution of Flow Sizes (1972)

	Shipment Records		Total Flow	
Flow Size (ktons)	Number	%	kilotons	%
10,000 - 100,000	12	0.02	179,002	8.54
1,000 - 10,000	270	0.52	658,935	31.46
100 - 1,000	2,590	4.94	686,348	32.77
10 - 100	14,953	28.55	451,993	21.58
1 - 10	34,550	65.97	118,335	5.65
Total	52,375	100.00	2,094,613	100.00

The shipment set at this point consisted of 64,609 modal flows totaling 2,094,613 kilotons. Combining all flows with the same commodity, origin, and destination yielded 52,375 multimodal shipment records. Fortunately, the shipment size distribution is highly skewed; as Shown in Table 6-4, about 5% of the shipment records contain 70% of the flow tonnage, while 66% of the records provide only 5% of the tonnage. In recognition of this flow concentration, the following sampling plan was implemented:

1. The shipment size distribution for each commodity-mode combination was examined and the largest shipments were selected for direct inclusion in the final shipment list.

2. Sample sizes (by commodity and mode) were selected for the remaining tonnage, in proportion to the tonnage and the importance of the commodity for initial model applications, subject to constraining the total number of shipment records to about 10,000.

3. Random samples were drawn from the flow records and the sampled flow quantities were expanded by the ratio $(Q_{km} - X_{km})/q_{km}$, where Q_{km} is the total tonnage for commodity k and mode m, X_{km} is the tonnage included in the large shipments and q_{km} is the total sampled tonnage.

The sampling plan is displayed in detail in Table 6-5. The resulting set of shipment records contains 10,974 single-mode flows which combine into 10,152 multimodal records. Note that only 822 of the unique commodity-orgin-destination combinations appearing in the final shipment data feature flow by more than one mode. This is only 8% of the total records, hence the flow data are quite compatible with the all-or-nothing modal assignment logic of the transportation network model.

Shipments for 1990 were generated in exactly the same manner as for 1972. In this case, the final data set consists of 11,220 single-mode flows which combine to 10,408 multimodal records.

Table 6-5. Shipment Sampling Plan (1972)

		Input		Large Shipments			Small Shipments		
Comm	Mode*	Shpmts	Ktons	No.	Ktons	% of Ktons	No.	Ktons	Scaled
1	1	1803	93970	135	56403	60.0	120	2490	37567
1	2	248	41302	68	24832	60.1	15	1262	16470
1	3	195	29842	33	26930	90.2	15	219	2912
2	1	126	700	41	422	60.3	10	30	278
2	3	24	7658	10	7067	92.3	5	137	591
3	1	647	354313	159	319178	90.1	40	2723	35135
3	2	2	470	2	470	100.0			
3	3	106	73927	29	66683	90.2	10	1061	7244
4	1	43	6740	43	6740	100.0			
4	3	64	38315	64	38315	100.0			
4	4	131	276856	131	276856	100.0			
5	1	265	60962	45	54898	90.1	20	655	6064
5	3	55	6412	10	5807	90.6	5	23	605
6	1	1345	71905	174	50389	70.1	90	1567	21516
6	3	163	19808	50	17859	90.2	10	161	1949
7	1	3638	69503	272	34795	50.1	250	2336	34708
7	2	4687	88813	242	44424	50.0	350	3818	44388
7	3	7	7485	7	7485	100.0			
8	1	121	1126	23	797	70.7	10	28	330
8	2	1193	11011	108	5512	50.1	90	423	5500
9	1	6997	17646	1105	12355	70.0	440	401	5291
10	1	2237	49664	208	24849	50.0	155	1852	24816
10	2	2551	45182	135	22611	50.0	210	1912	22571
10	3	67	13243	30	11930	90.1	5	185	1313
11	1	1983	27587	151	13805	50.0	145	1037	13782
11	2	1747	21645	159	12992	60.0	140	864	8653
11	3	2	35	2	35	100.0			
12	1	706	3092	72	1239	40.1	60	174	1853
12	2	2194	11202	188	4484	40.0	200	728	6718
12	3	3	5	3	5	100.0			
13	1	461	2181	72	1092	50.1	40	110	1089
13	2	1055	5596	126	2807	50.2	110	317	2789
14	1	630	7101	68	3567	50.2	45	304	3534
14	2	747	7369	57	3691	50.1	65	408	3678
14	3	3	39	3	39	100.0			
15	1	5514	127378	292	63714	50.0	420	5469	63664
15	2	6784	137538	526	82580	60.0	550	5176	55008
15	3	75	18717	33	16894	90.3	5	341	1825
16	1	2343	27400	148	10963	40.0	170	1277	16437
16	2	1900	22281	127	11157	50.1	160	977	11125
16	3	3	112	3	112	100.0			
17	1	496	17659	59	12372	70.1	35	367	5287
17	2	577	19712	64	13851	70.3	45	634	5861
17	3	70	43365	70	43365	100.0			
17	4	16	1301	16	1301	100.0			
18	1	996	35993	57	18106	50.3	70	1241	17887
18	2	1944	53946	128	32380	60.0	140	1717	21566
18	3	43	3561	20	3223	90.5	5	77	338
19	1	674	6845	44	3427	50.1	60	358	3419
19	2	1871	18686	129	9369	50.1	170	1018	9317
19	3	11	68	11	68	100.0			
20	1	1855	25010	115	12518	50.1	145	968	12492
20	2	3167	61504	173	36915	60.0	300	2365	24589
20	3	4	781	4	781	100.0			
				6044			4930		

The critical assumption in the shipment generation process is that the spatial distribution and mode choices of the shipments in the sample are the same as those in the low-volume shipment population. If this is true, then statistics such as average trip length, modal shares, cost, transit time, and energy use will be unaffected by the sampling procedure. The principal type of error introduced is in the commodity mix represented in the traffic on network elements adjacent to access links, particularly in the outlying portions of the network. Some inaccuracies in individual access link flow volumes can also be expected. Recall, however, that these statements apply only to that 30% of the commodity flow affected by the sampling procedure. Experience thus far with the TSC Freight Energy Model indicates that the advantages gained in being able to make additional runs and test more options outweigh the marginal accuracy losses introduced by sampling.

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