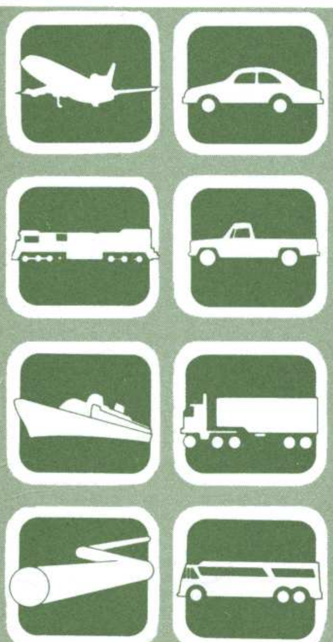
ORNL-5506
Special

Energy Intensity and Related Parameters of Selected Transportation Modes: Passenger Movements

A. B. Rose



OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

Volume Conversions

From \ To	in.^{3}	ft^3	U.S. gal	Imp. gal	liter	bbl
in.^{3}	1	5.787×10^{-4}	4.329×10^{-3}	3.605×10^{-3}	0.01639	1.031×10^{-4}
ft^3	1728	1	7.481	6.2292	28.32	0.1781
U.S. gal	231	0.1337	1	0 8327	3.785	2.381×10^{-2}
Imp. gal	277.4	0.1606	1.201	1	4.545	2.859×10^{-2}
liter	61.02	3.531×10^{-2}	0.2642	0.2200	1	6.29×10^{-3}
bbl	9702	5.615	42	34.972	158.97	1

Mass Conversions

From \ To	lb (avoirdupois)	kg	Short ton	Long ton	Metric ton
lb (avoirdupois)	1	0.4536	5.0×10^{-4}	4.4643×10^{-4}	4.5362×10^{-4}
kg	2.205	1	1.1023×10^{-3}	9.8425×10^{-4}	1.0×10^{-3}
Short ton	2000	907.2	1	0.8929	0.9072
Long ton	2240	1016	1.12	1	1.016
Metric ton	2205	1000	1.102	0.9842	1

Length Conversions

From \ To	cm	in.	ft	yd	m	mile	km
cm	1	0.3937	3.281×10^{-2}	1.0936×10^{-2}	1.0×10^{-2}	6.214×10^{-6}	1.0×10^{-5}
in.	2.54	1	8.333×10^{-2}	2.778×10^{-2}	2.54×10^{-2}	1.578×10^{-5}	2.54×10^{-5}
ft	30.48	12	1	0.333	0.3048	1.894×10^{-4}	3.048×10^{-4}
yd	91.44	36	3	1	0.9144	5.682×10^{-4}	9.144×10^{-4}
m	100	39.37	3.281	1.0936	1	6.214×10^{-4}	1.0×10^{-3}
mile	160,934	63,360	5280	1760	1609	1	1.609
km	100,000	39,370	3281	1093.6	1000	0.6214	1

Energy Conversions

From \ To	ft-lb	kg-m	hp-hr	Metric hp-hr	Btu	kWhr	Joule
Ft-lb	1	0.1383	5.0505×10^{-7}	5.12×10^{-7}	1.285×10^{-3}	3.766×10^{-7}	1.356
kg-m	7.233	1	3.653×10^{-6}	3.704×10^{-6}	9.295×10^{-3}	2.724×10^{-6}	9.80665
hp-hr	1.98×10^{6}	2.7375×10^{5}	1	1.0139	2544	0.7457	2.6845×10^{6}
Metric hp-hr	1.953×10^{6}	270,000	0.9863	1	2510	0.7355	2.648×10^{6}
Btu	778.2	107.6	3.93×10^{-4}	3.985×10^{-4}	1	2.931×10^{-4}	1055
kWhr	2.655×10^{6}	3.671×10^{5}	1.341	1.3596	3412	1	3.6×10^{6}
Joule	0.7376	0.10197	0.3725×10^{-6}	0.3777×10^{-6}	0.9478×10^{-3}	0.2778×10^{-6}	1

1 quad Btu = .4724 million bbl crude per day = .1724 billion barrels crude per year

Heat Content for Various Fuels

Fuel oils			Natural gas		
Crude	138,100	Btu/gal	Liquid	95,800	Btu/gal
Residual	149,700	Btu/gal	Wet	1,095	Btu/ft^3
Distillate	138,700	Btu/gal	Dry	1,021	Btu/ft^3
Automotive gasoline	125,000	Btu/gal	Coal		
AVGAS	124,000	Btu/gal	Anthracite	25.4×10^{6}	Btu/short ton
Jet fuel (kerosine)	135,000	Btu/gal	Bituminous	26.2×10^{6}	Btu/short ton
Jet fuel (naphta)	127,500	Btu/gal	Lignite	13.4×10^{6}	Btu/short ton
Diesel oil (#2)	138,700	Btu/gal	(Electrical generation and distribution efficiency)		≈30%
Coal products			Lubricants	144,405	Btu/gal
Crude light oil	130,000	Btu/gal	Waxes	155,643	Btu/gal
Crude coal tar	150,000	Btu/gal	Petroleum coke	143,423	Btu/gal
Crude petroleum	138,100	Btu/gal	Asphalt and road oil	158,000	Btu/gal
Ethane	73,390	Btu/gal	Natural gasoline and cycle products	110,000	Btu/gal
Still gas	142,286	Btu/gal			

1 Btu/gal = 278.7 joule/liter = 2.787×10^{5} joule/m^3

1 Btu/short ton = 942.0 joule/metric ton

ORNL-5506
Special
Companion to ORNL/TM-6700

Contract No. W-7405-eng-26

ENERGY INTENSITY AND RELATED PARAMETERS OF SELECTED TRANSPORTATION MODES: PASSENGER MOVEMENTS

A. B. Rose

Regional and Urban Studies Section
Energy Division

Prepared For

Data Analysis Branch
Nonhighway Transport Systems and Special Projects
Transportation Energy Conservation Division
Office of Conservation & Solar Applications
Department of Energy

Date Published: January 1979

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
Operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy $9.00; Microfiche $3.00

ABSTRACT

A study was undertaken aimed at determining the causes of the divergences among published energy intensity values and at preparing a set of consistent values. This volume presents the findings in relation to the passenger transportation modes. After a brief overview of the important factors to be considered and the potential pitfalls facing users and analysts of energy intensity values, a chapter is devoted to each of the major means of passenger transportation: air, automobile, bus, and rail. In each of these chapters, after a critique of the available data sources, a consistent time series of operational data and energy intensity values is presented for the major sectors of each mode. Engineering simulations and data analysis are also carried out, quantifying the principal determinants of modal energy use to facilitate modification of the current energy intensity values to reflect changing operational and hardware-related parameters. Finally, matrices giving the great-circle distances and modal circuity ratios among the 50 largest standard metropolitan statistical areas are included to facilitate intermodal comparisons.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGMENTS	xvii
ORGANIZATION OF THE REPORT	xix
SUMMARY	S-1
1. INTRODUCTION	1-1
2. THE CONCEPT OF ENERGY INTENSITY	2-1
2.1 Intramodal Energy Intensity Values	2-4
2.2 Intermodal Energy Intensity Values	2-6
2.3 Indirect Energy Consumption	2-7
3. AIR PASSENGER TRANSPORTATION	3-1
3.1 Certificated Route Air Carrier	3-2
3.1.1 Determinants of energy use	3-4
3.1.2 Operational data	3-4
3.2 Supplemental Air Carriers	3-19
3.3 General Aviation Operations	3-20
3.4 Summary Graphs	3-21
4. PASSENGER AUTOMOBILE TRANSPORTATION	4-1
4.1 Determinants of Energy Use	4-1
4.1.1 Vehicle weight	4-2
4.1.2 Vehicle aerodynamics	4-4
4.1.3 Trip length	4-4
4.1.4 Installed options	4-6
4.1.5 Vehicle maintenance	4-7
4.2 Development of Circuities	4-9
4.3 Operational Data	4-10
4.3.1 FHWA estimates	4-10
4.3.2 EPA certification tests	4-11
4.4 Estimates of Automobile Operational Energy Intensity	4-18
4.4.1 Intercity automobile travel	4-18
4.4.2 Urban automobile travel	4-22
5. BUS PASSENGER TRANSPORTATION	5-1
5.1 Intercity Bus	5-2
5.1.1 Determinants of energy use	5-2
5.1.2 Development of circuities	5-5
5.1.3 Operational data	5-8
5.2 Transit Buses	5-10
5.3 School Buses	5-18
5.4 Summary of Graphs and Charts	5-19

	Page
6. RAIL PASSENGER TRANSPORTATION	6-1
6.1 Intercity Rail	6-2
6.1.1 Determinants of energy use	6-3
6.1.2 Development of circuities	6-4
6.1.3 Operational data	6-8
6.2 Rail Transit Operations	6-8
6.3 Commuter Rail	6-15
Appendix A — U.S. DOMESTIC TRAVEL, SOURCE DATA, 1972 and 1976	A-1
Appendix B — INTERCITY MODAL CIRCUITIES SOURCE DATA	B-1
Appendix C — AIR PASSENGER SOURCE DATA	C-1
Appendix D — CONVERSION FACTORS	D-1
BIBLIOGRAPHY	E-1

LIST OF FIGURES

Figure		Page
S.1	Certificated Route Air Carrier Energy Intensity	S-1
S.2	Summary of Certificated Route Air Carrier Energy Intensity, 1976	S-2
S.3	Summary Breakdown of Aircraft Efficiency Improvement, 1971-1976	S-3
S.4	Automobile Fuel Economy and Standards, 1967 to 1985	S-4
1.1	U.S. Energy Consumption and Production, 1976	1-2
3.1	Percent Distribution of U.S. Airline Operating Statistics by City-Pair Distance	3-3
3.2	Variation of Passenger Load Factors with Flight Stage Length, 1976	3-5
3.3	Aircraft Departures and Passengers Per Department vs Flight Stage Length, 1976	3-5
3.4	Relationship between Energy Efficiency and Stage Length for Various Aircraft	3-6
3.5	Summary of Certificated Route Air Carrier Energy Intensity, 1971	3-10
3.6	Summary of Certificated Route Air Carrier Energy Intensity, 1972	3-11
3.7	Summary of Certificated Route Air Carrier Energy Intensity, 1973	3-12
3.8	Summary of Certificated Route Air Carrier Energy Intensity, 1974	3-13
3.9	Summary of Certificated Route Air Carrier Energy Intensity, 1975	3-14
3.10	Summary of Certificated Route Air Carrier Energy Intensity, 1976	3-15
3.11	Summary Breakdown of Aircraft Efficiency Improvement, 1970-76	3-18
3.12	Certificated Route Air Carrier Passenger-Miles, 1971-77	3-21

Figure		Page

3.13 Certificated Route Air Carrier Passenger Load Factors, 1971-77 3-22

3.14 Certificated Route Air Carrier Aircraft-Miles, 1971-77 3-22

3.15 Certificated Route Air Carrier Fuel Consumption, 1971-77 3-23

3.16 Certificated Route Air Carrier Energy Intensity, 1971-77 3-23

3.17 Breakdown of Cumulative Fuel Economy Improvements for Four-Engine, Wide-Body Aircraft, 1971-76 3-24

3.18 Breakdown of Cumulative Fuel Economy Improvements for Three-Engine, Wide-Body Aircraft, 1973-76 3-24

3.19 Breakdown of Cumulative Fuel Economy Improvements for Four-Engine, Narrow-Body Turbofan Aircraft, 1971-76 3-25

3.20 Breakdown of Cumulative Fuel Economy Improvements for Four-Engine, Narrow-Body Turbojet Aircraft, 1971-76 3-25

3.21 Breakdown of Cumulative Fuel Economy Improvements for Three-Engine, Narrow-Body Aircraft, 1971-76 3-26

3.22 Breakdown of Cumulative Fuel Economy Improvements for Two-Engine, Narrow-Body Aircraft, 1971-76 3-26

4.1 Automobile Engine Heat Balance During Cruising 4-3

4.2 Component Breakdown of Engine Load for a Standard-Size Automobile 4-3

4.3 Variation of Fuel Economy with Trip Length 4-5

4.4 Factory Installations of Popular Options in New Automobiles by Model Year 4-6

4.5 EPA Urban and Highway Driving Cycles 4-12

4.6 Regression Lines of EPA Certification Fuel Economy vs On-Road Fuel Economy 4-19

5.1 Principal Communities in the United States Served by Intercity Buses 5-1

5.2 Componential Breakdown of Energy Use for Steady-State Cruise Conditions 5-4

Figure		Page

Figure		Page
5.3	Variation of Energy Intensity with Cruising Speed	5-4
5.4	Summary of Over-the-Road Test Results on the Effects of Speed on Intercity Bus Fuel Consumption	5-6
5.5	Variation of Bus Transit Energy Intensity with Passenger Trip Length	5-17
5.6	Variation of Bus Energy Intensity 1970-76	5-19
5.7	Variation of Intercity Bus Energy Intensity, 1970-1976	5-19
5.8	Bus Energy Intensity and VMT Summary, 1972	5-20
5.9	Bus Energy Intensity and VMT Summary, 1973	5-20
5.10	Bus Energy Intensity and VMT Summary, 1974	5-21
5.11	Bus Energy Intensity and VMT Summary, 1975	5-21
5.12	Bus Energy Intensity and VMT Summary, 1976	5-22

LIST OF TABLES

Table		Page
S.1	Certificated Air Carrier Energy Intensity, 1971-77	S-2
S.2	Regression Equations Relating EPA Certification to Actual On-Road Fuel Economies	S-5
S.3	Energy Use Effects of Popular Options	S-6
S.4	Summary of Bus Energy Intensities, 1970-1977	S-8
S.5	Summary of Rail Energy Intensities, 1972-1977	S-9
2.1	Variations of Energy Intensity Estimates for Urban Passenger Transportation Modes	2-2
2.2	Variations of Energy Intensity Estimates for Intercity Passenger Transportation Modes	2-2
2.3	Indirect Energy Use as Percent of Direct Energy Use by Mode, 1971	2-7
3.1	Air Carrier Percent of All Intercity Passenger Transportation Statistics, 1976	3-1
3.2	Distribution of Air Carrier Service vs Flight Stage Length, 1976	3-7
3.3	Summary of Certificated Air Carrier Energy Intensity 1971-1976	3-9
3.4	Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1971	3-10
3.5	Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1971	3-10
3.6	Certificated Air Carrier Operating Statistics and Energy Intensites, by Carrier Type, 1972	3-11
3.7	Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1972	3-11
3.8	Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1973	3-12
3.9	Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1973	3-12

Table		Page
3.10	Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1974	3-13
3.11	Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1974	3-13
3.12	Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1975	3-14
3.13	Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1975	3-14
3.14	Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1976	3-15
3.15	Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1976	3-15
3.16	Fuel Efficiency Improvements Due to Increased Load Factors and Operational Improvements, by Aircraft Class, 1971-1976	3-17
3.17	Supplemental Air Carrier Operating Statistics, 1975-1976	3-19
3.18	Estimates of General Aviation Activity and Energy Intensity, 1970-1976	3-20
4.1	Energy Use Effects of Popular Options	4-7
4.2	Fuel Economy Improvement vs Cost of Maintenance Action	4-8
4.3	Percent Fuel Economy Improvement after Maintenance Action	4-8
4.4	Intercity Automobile Circuities, 1972	4-9
4.5	Intercity Automobile Circuities, 1976	4-9
4.6	FHWA Estimates of Automotive Fleet Fuel Efficiency, 1970-1976	4-11
4.7	Sales Fractions vs Inertia Weight, 1970-1978	4-15
4.8	City-Highway Sales-Weighted Passenger Car Fuel Economy by Inertia Weight Class, 1970-1978	4-16
4.9	Weight Class Distribution for Light-Duty Trucks, 1975-1978	4-17

Table		Page

4.10	Sales-Weighted Fuel Economy for Light-Duty Trucks, 1975-1978	4-17
4.11	EPA Certification vs. Actual On-Road Fuel Economy, Model Years 1974-1977	4-19
4.12	Intercity Automobile Energy Intensity for 1972 Model Year Automobiles and Travel Characteristics	4-20
4.13	Intercity Automobile Energy Intensity, 1976	4-21
4.14	Estimated Urban Automobile Energy Intensity	4-23
4.15	Average Route Speeds for Central Business Districts and Test Procedures	4-24
5.1	Selected Characteristics of Intercity Travelers by Mode, 1972	5-2
5.2	Average Trip Lengths and Circuities for All Intercity Buses, 1972	5-7
5.3	Percent of All Intercity Bus Operations Performed by Class I Carriers, 1970-76	5-8
5.4	Operating Statistics and Energy Intensities of Intercity Buses, 1970 through 1976	5-9
5.5	Bus Transit Statistics Expressed as Percent of All Mass Transit, 1976	5-11
5.6	Stock of Transit Buses Owned and Leased, 1970-77	5-12
5.7	VMT, Energy Use, and Energy Intensity of Trolley Coaches, 1970-77	5-12
5.8	VMT, Energy Use, and Energy Intensity of Conventional Transit Buses, 1970-77	5-13
5.9	VMT, Energy Use, and Energy Intensity for All Transit Bus Operations, 1970-76	5-13
5.10	Variations in Energy Intensity Among Systems, 1970, 1973, and 1975	5-14
5.11	Passenger-Trips on Bus Transit Systems, 1970-1976	5-16
5.12	School Bus Operational Data, 1970 through 1976	5-18

Table		Page
6.1	Historical Trends of Intercity Rail Service, 1929-1977 . . .	6-2
6.2	Percent Components of Energy Use for Several Train Consists, New York to Albany, 1977	6-4
6.3	Percent Components of Energy Use for Several Electric Train Consists, New York to Washington, 1977	6-5
6.4	Variations in Energy Intensity for Various Train Consists, New York to Albany, 1977	6-6
6.5	Variations in Energy Intensity for Additional Amtrak Consists	6-7
6.6	Amtrak Intercity Rail Circuities, 1972	6-7
6.7	Operating Statistics and Energy Efficiencies of the Amtrak Intercity Rail System, 1972-77	6-9
6.8	Stock of Rail Transit Cars Owned and Leased, 1970-77	6-10
6.9	VMT, Energy Use, and Energy Intensity of Heavy Rail Transit Systems, 1970-77	6-11
6.10	VMT, Energy Use, and Energy Intensity of Light Rail Transit Systems, 1970-77	6-12
6.11	VMT, Energy Use, and Energy Intensity of Rail Transit Systems, 1970-77	6-14
6.12	Passengers on Rail Transit Systems, 1970-76	6-15
6.13	Operational Statistics and Energy Intensities of Commuter Railroads, 1972-77	6-16
A.1	95% Confidence Intervals for 1972 and 1976 (National Travel Surveys)	A-3
A.2	U.S. Aggregate Domestic Travel Data, 1972	A-4
A.3	U.S. Aggregate Domestic Travel Data, 1976	A-5
A.4	Domestic Air Travel Data, 1972	A-6
A.5	Domestic Air Travel Data, 1976	A-7
A.6	Domestic Auto/Truck Travel Data, 1972	A-8
A.7	Domestic Auto/Truck Travel Data, 1976	A-9

Table		Page
A.8	Domestic Bus Travel Data, 1972	A-10
A.9	Domestic Rail Travel Data, 1972	A-12
A.10	Person-Trips Outside the U.S. Deleted from 1972 Data	A-14
B.1	Mean Automobile Circuities by Distance Category	B-2
B.2	Mean Bus Circuities by Distance Category	B-3
B.3	Mean Passenger Rail Circuities by Distance Category	B-4
B.4	City-Pair Great-Circle Distances	B-5
B.5	City-Pair Circuities, Automobile	B-8
B.6	City-Pair Circuities, Bus	B-11
B.7	City-Pair Circuities, Rail	B-16
C.1	Passenger-Miles and Number of Trips by Trip Length, 1975	C-2
C.2	Top 100 City Pairs Ranked by Number of Passengers, 1972	C-4
C.3	Top 100 City Pairs Ranked by Passenger-Miles, 1976	C-6
D.1	Energy Use- and Production- Related Figures	D-1
D.2	Alternative Fuel Equivalents	D-2
D.3	Energy Unit Conversions	D-3
D.4	Distance and Velocity Conversions	D-3
D.5	Force Conversions	D-4
D.6	Energy Intensity and Efficiency Conversions	D-4
D.7	Volumetric and Flow Rate Conversions	D-5
D.8	Nomenclature and Powers of Ten	D-6
Condensed Conversion Tables		Inside Front Cover

Acknowledgements

I am pleased to express my gratitude to the individuals who shared their knowledge expertise and efforts with me in carrying out this project. Ken Reed and Chris Wallace's energy and determination in data reduction and puzzling over contradicting data sources, often at odd hours, resulted in large portions of the tabular content of this publication. I also wish to thank Sydney Berwager, Ken Chomitz, Margaret Fels, David Greene, and Charles Lave for their speedy review of a draft of this work and their many helpful comments.

Of the many studies and references utilized in the preparation of this work, I would like to single out two which were particularly helpful. Both are special studies performed for Oak Ridge National Laboratory and a limited number of copies will be made available on special request. The *Survey and Analysis of Energy Intensity Estimates for Urban Transportation Modes*, by K. Chomitz and C. Lave laid the groundwork for, and was extremely helpful in, preparing the sections on urban transportation systems. The evaluation of the quality of available urban transportation data provided therein must be one of the best available. R. K. Mittal in his *Energy Intensity of Various Transportation Modes* identified many of the better data sources, past studies, and analysis techniques. Dr. Mittal's work, in many ways, has influenced the direction this study has taken.

Work on this project was supported by Philip Patterson and Richard Alpaugh of the Transportation Energy Conservation Division of the Department of Energy.

ORGANIZATION OF THE REPORT

The report is written in two parts, each of which is designed to stand on its own. The user more interested in ready references or quick facts will find these in the Summary section and will need to use the actual body of the report only for clarification of specific points. He should, however, also read Chapter 2, "The Concept of Energy Intensity," as it contains important points on the general use and validity of energy intensity values.

The more interested reader will find four more detailed chapters, each of which deals with a particular form of passenger transportation in greater detail. The major categories dealt with in the chapters are air, automobile (including light trucks), bus, and railroad passenger transportation systems. Each of these chapters, except that on automobiles, in turn is subdivided into a definite hierarchical structure:

X. A brief chapter introduction

X.1 Discussion of the intercity aspect of the transportation form. This level of division is not necessary in the automobile chapter.

X.1.1 Determinants of Energy Use — Engineering analyses are carried out and data presented when available aimed at quantifying the principal modal determinants of energy use. These sections are primarily designed to aid in the assessment of the impacts of changes in operational or hardware parameters on modal energy use.

X.1.2 Development of Circuities — A short section is devoted to development of passenger-mile-weighted circuity ratios* because of the importance of circuity ratios in the execution

*A circuity ratio is defined as the ratio between the actual modal trip length and the great-circle (straight-line) distance between two points.

of intermodal comparisons and assessment of the impacts of modal shift strategies. This section is not provided in the air chapter as all air-carrier statistics are already reported on a great-circle mile basis.

X.1.3 Operational Data — This section presents a critique of the available data sources, a time series of basic operational data, and a time series of calculated energy intensity estimates.

X.2, X.3 Data and analysis pertaining to other aspects of the transportation form. General aviation, school buses, and transit operations fall into this category.

X.4 Summary Graphs and Tables — in the air and bus chapters.

The relative sizes and makeups of the sections vary considerably from chapter to chapter as necessitated by the availability of data.

SUMMARY

Although this section is designed to stand alone in conjunction with Chapter 2, "The Concept of Energy Intensity," even the casual user should refer to the appropriate section in the report proper before utilizing any values in calculations which are included in the appropriate chapters of the report. The brevity of this section has dictated the omission of many caveats, amplifying analyses, and explanations. The following pages present the aggregate energy intensities for each of the major forms of passenger transportation treated in the report.

Air Passenger Transportation

From the analytical point of view, the air mode is the most satisfying of the modes treated in the report. Large volumes of high-quality data available from the Civil Aeronautics Board are readily analysed to yield quantitative insights into the operations of the certificated air carriers.

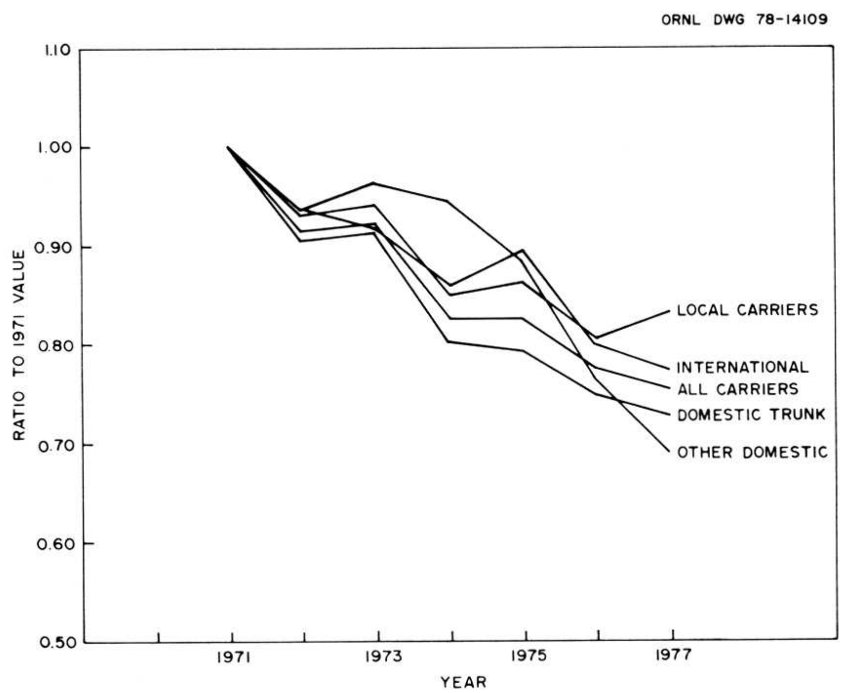


Fig. S.1. Certificated Route Air Carrier Energy Intensity in Btu Per Passenger-mile, 1971-1977, Normalized to 1971 Values.

Table S.1. Certificated Air Carrier Energy Intensity, 1971—77

	Domestic		International		Total	
	Btu/PM	% load factor	Btu/PM	% load factor	Btu/PM	% load factor
1971	8920	48.6	6540	56.6	8290	50.5
1972	8130	52.6	6080	60.3	7590	54.5
1973	8200	52.2	6020	58.4	7650	53.6
1974	7240	55.9	5630	56.8	6870	56.1
1975	7180	55.0	5860	54.4	6870	54.9
1976	6760	56.2	5230	58.6	6440	56.7
1977[a]	6580	56.6	5070	59.9	6260	57.2

[a]Based on data for first three quarters.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970—1977.

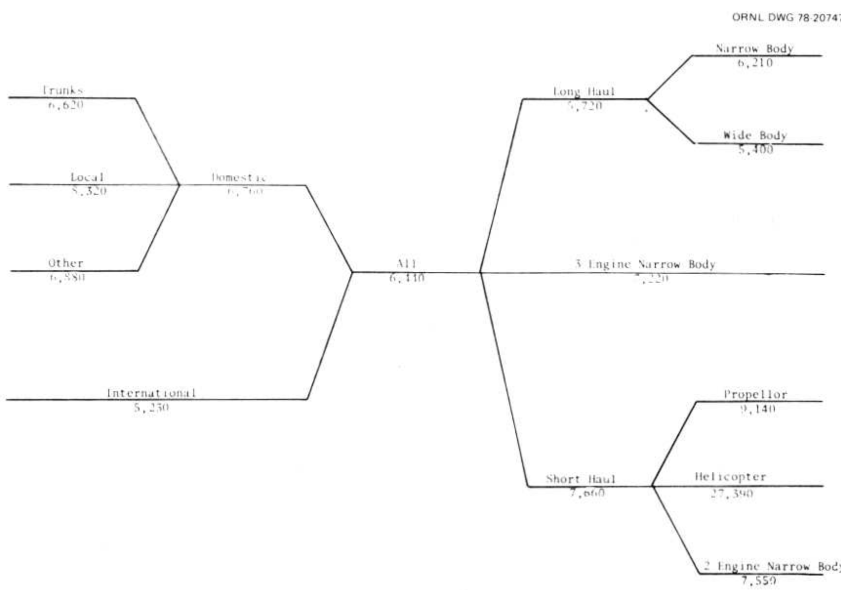


Fig. S.2. Summary of Certificated Route Air Carrier Energy Intensity, 1976. Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970-1977.

The outstanding feature of certificated air carrier operations has been the close to 30% increase in passenger miles flow between 1971 and 1976, which was accompanied by a decrease of equal magnitude in energy intensity. Besides increased load factors and the use of more efficient aircraft types, improved maintenance and more efficient operating procedures played a substantial role in achieving this decrease in intensity.

As a proxy for other factors, the flight stage length may be thought of as the single most important determinant of aircraft energy intensity. With decreasing flight stage lengths, one may expect to find decreased efficiency of the aircraft, use of smaller, less efficient aircraft, stronger effects of operational inefficiencies, and decreased load factors.

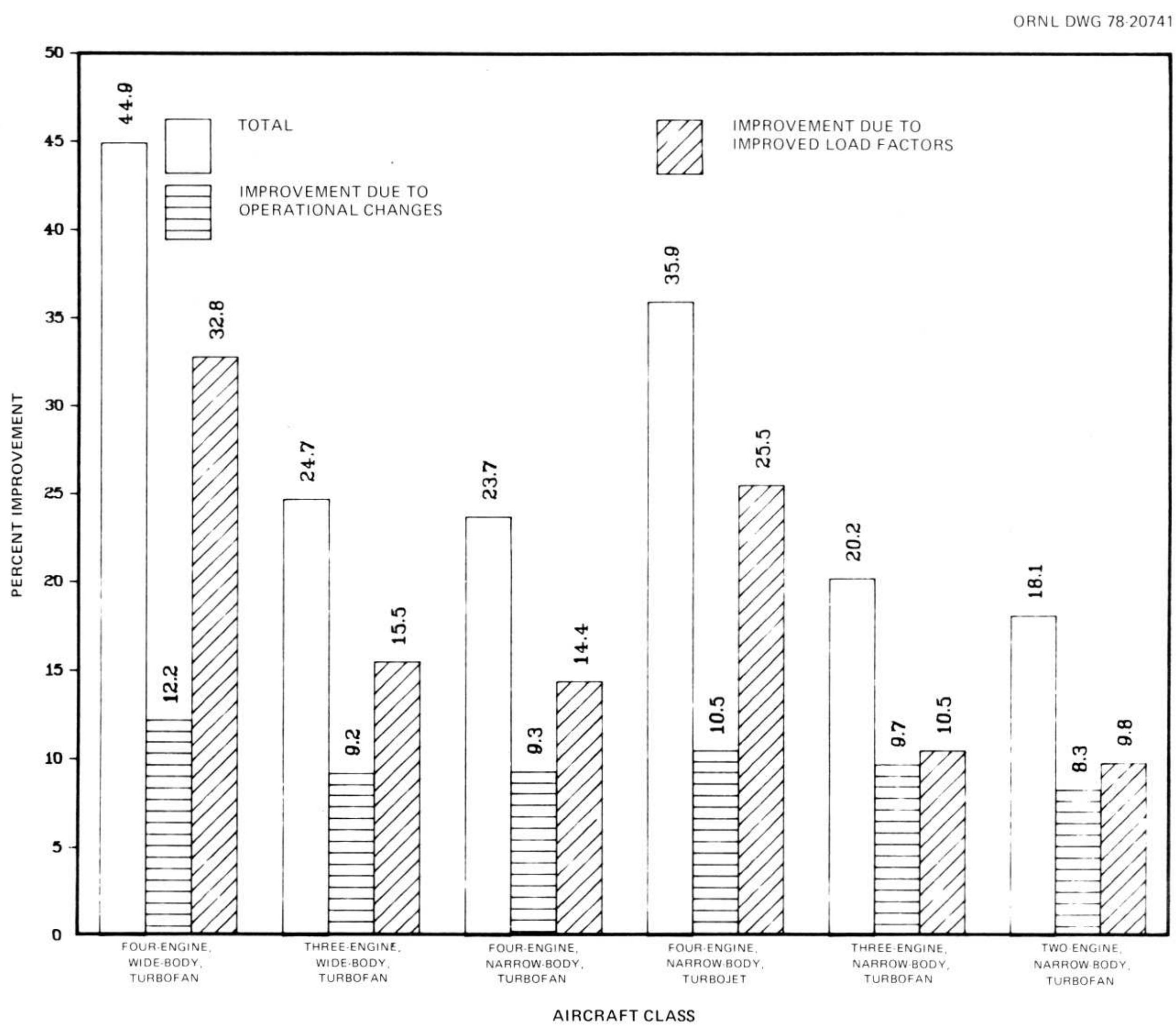


Fig. S.3. Summary Breakdown of Aircraft Efficiency Improvement, 1971-1976.

Automobile Transportation

When dealing with automobile energy intensities on the aggregate operational level, the user and analyst alike are confronted with a continuous series of data deficiencies and gaps. All the values shown in the graph below are subject to well-founded doubts. The FHWA

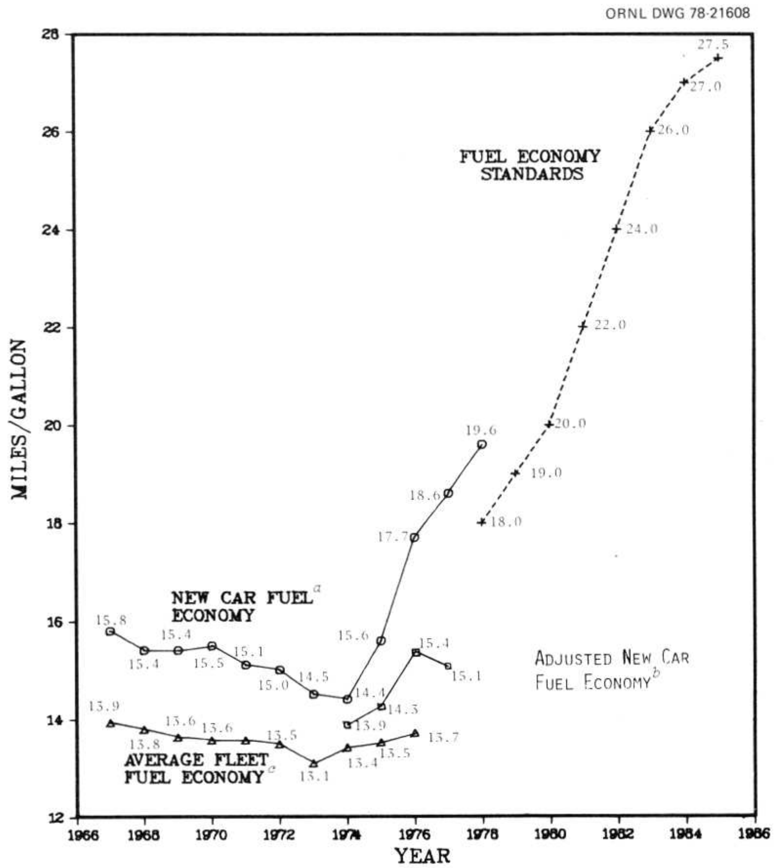


Fig. S.4. Automobile Fuel Economy and Standards, 1967 to 1985.

[a]Based on 1975 Federal Test Procedure (FTP) city/highway weighted. For the 1975-1978 model years the new car fuel economy is sales-weighted by manufacturers' sales forecast data. For earlier model years production data was utilized.

[b]The sales-weighted FTP value adjusted by the values given in Table to on-road fuel economy values.

[c]As calculated by the FHWA.

estimates are based on state estimates of vehicle miles traveled, which may contain substantial errors, while the EPA certification tests have been diverging more each year from the actual on-road fuel economies experienced.

Because of the increasing divergence of the EPA estimates, several studies have been undertaken to quantify these divergences and to determine their causes. One such study developed a series of regression equations which may be used to correct the EPA values to correspond more closely to actual on-road performance.

Table S.2. Regression Equations Relating EPA Certification (x) to Actual On-Road Fuel Economies (y)

Model year	Regression equation
1974	$y = 0.65x + 4.38$
1975	$y = 0.81x + 1.63$
1976	$y = 0.74x + 2.32$
1977	$y = 0.65x + 2.98$

Source: McNutt, B. D., et al., *A Comparison of Fuel Economy Results from EPA Tests and Actual In-Use Experience, 1974-1977 Model Year Cars*, U.S. Department of Energy, Washington, D.C., February 1978.

These regression equations yield correction factors of 0.5, 1.3, 2.3, and 3.5 mpg for model year 1974-77 cars, respectively, for the EPA sales-weighted fuel economy. This and other related data make it possible to estimate automobile energy intensities in both urban and intercity driving environments. The interested reader is referred to Section 4.3 of the report for the results.

In contrast to the lack of aggregate operational data, large quantities of information are available on the disaggregate influences

Table S.3. Energy Use Effects of Popular Options

Option	Approximate change in fuel economy
Air conditioning	-13%
Automatic transmission	-14 to 15.5%
Power steering	⩾1%
Radial tires	+2-2.5%
V-8 engine	-18.5%

of various operational and engineering parameters on automotive fuel economy. In addition to the effects of options the following are of general interest:

- A 10% change in gross vehicle weight will result in roughly a 4% change in fuel economy if all other factors remain unchanged.
- A 10% reduction in aerodynamic drag will yield a 2 to 3% improvement in fuel economy.
- Necessary engine maintenance will yield, on the average, close to a 5% improvement in fuel economy.
- Short trip lengths are associated with severe fuel economy penalties due to insufficient engine warm-up. At 70°F these may exceed 40% for trips under two miles.

Bus Transportation

Buses combine the flexibility of the automobile with the inherent efficiencies of operating larger capacity vehicles. Buses are also the most widely available public form of transportation, connecting virtually all major cities in regular scheduled service in addition to providing transit services in over 1000 cities.

Intercity buses are currently the most energy efficient mode of transportation available, operating at less than half the energy intensity of other intercity passenger modes.

The principal determinant of bus energy intensity is the number of passengers carried on board; because of their size buses are relatively insensitive to increases in weight through additional loading. At normal cruising speeds, aerodynamic drag dominates strongly, with rolling resistance and accessories using roughly equal amounts of energy. A recent study performed by the Department of Transportation has shown some rather counterintuitive results on the interactions of terrain and cruising speed. On flat terrain, an increase in cruising speed from 50 to 60 mph results in an increase in energy use. However, over rolling terrain, no fuel use penalty is associated with the same increase in speed, and over hilly terrain with no long grades, energy use actually decreases when the cruising speed is raised to 60 mph.

Rail Passenger Transportation

Rail systems, in theory at least, possess the lowest energy intensity of all transportation modes. In practice, however, they are operating at values close to an order of magnitude higher than this theoretically possible minimum because of a combination of several factors, the strongest being that:

- Transit rail systems are faced with a highly peaked demand curve, resulting in low overall load factors.
- Intercity rail consists (i.e., assembled trains) contain a significant number of low- or zero-density cars (sleepers, dining cars, etc.). These cars contribute substantially to the overall energy use yet carry few passengers.
- There is little demand for intercity rail service.
- Intercity rail circuities are very high when compared to those of other modes.

Table S.4. Summary of Bus Energy Intensities, 1970-1977

	Trolley coaches (Btu/VMT)	Transit buses (Btu/VMT)[a]	School buses (Btu/VMT)	Intercity buses	
				(Btu/VMT)[a]	(Btu/PM)[b]
1970	49,300	32,500	17,710	NA	NA
1971	52,100	30,420	17,710	NA	NA
1972	50,800	30,540	16,820	22,850	1,050
1973	41,200	30,800	16,820	22,840	1,020
1974	NA	31,520	16,850	22,300	960
1975	44,300	33,750	16,960	22,280	990
1976	NA	34,600	16,890	22,620	1,010
1977	NA	35,100		22,890	980

NA — no available.

[a]Large system-to-system variations exist within this category.

[b]These values are calculated on a route-mile basis. For purposes of intermodal comparisons they should be multiplied by a circuity factor of 1.114 to convert them to a great-circle-mile basis.

Sources: American Bus Association, *American's Number 1 Passenger Transportation Service*, Washington, D.C., 1977, supplemented with private communications with the American Bus Association; American Public Transit Association, *Transit Fact Book, '76-'77 ed.*, Washington, D.C., June 1977.

Table S.5. Summary of Rail Energy Intensities, 1972-1977

Year	Rail transit		Commuter rail (Btu/PM)[b]	Amtrak (Btu/PM)[c]
	(Btu/VM)	(Btu/PM)[a]		
1972	66,090	2,540	4,680	4,110
1973	60,460	2,480	4,710	3,590
1974	65,170	2,830	4,400	3,050
1975	67,100	2,960	3,900	3,410
1976	68,240	2,960	3,500	3,230
1977	68,350	2,700	3,790	3,410

[a]The values are estimated based on the assumption that the average trip length of 6.82 miles as estimated for 1975 holds for other years.

[b]Includes a small number of intercity operations.

[c]The values are based on route-passenger-miles. For intermodal comparisons they should be multiplied by the lower-bound passenger-mile weighted circuity ratio of 1.325 to yield great-circle-mile energy intensity values.

Source: American Public Transit Association, *Transit Fact Book, '77-'78 ed.*, Washington, D.C., 1978; Association of American Railroads, *Statistics of Railroads of Class I, Years 1967 to 1977*, Washington, D.C., September 1978; National Railroad Passenger Corporation, *Annual Report to the Interstate Commerce Commission*, Washington, D.C., 1972-1977; Stanford Research Institute, *Energy Study of Rail Passenger Transportation, Volume 2: Description of Operating System*, Menlo Park, Calif., August 1977.

1. INTRODUCTION

It is often stated and generally accepted that the United States is currently in an undesirable situation caused by the dilemma of increasing energy demand and dwindling energy supplies. The gravity of the situation is further compounded by the fact that in 1976 the U.S. produced only 80.7% of its energy needs and only 49.2% of its petroleum-derived energy, thus making the country susceptible to undesirable foreign political and economic pressures.

The importance of the transportation sector and its subsectors with their near 100% reliance on petroleum as an energy source is illustrated in Fig. 1.1. Clearly, any reduction in energy consumption which can be realized in the transportation sector will contribute substantially toward the alleviation of the U.S. energy problem. Developing a comprehensive and effective strategy for realizing the energy-conservation potential of the transportation sector requires a great deal of base data and a thorough understanding of the determinants of energy use. The author hopes that the data and analyses presented in this publication will contribute to the further understanding of transportation energy use. Any questions and comments should be addressed to:

Axel Rose
Data Management and Analysis Group
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830

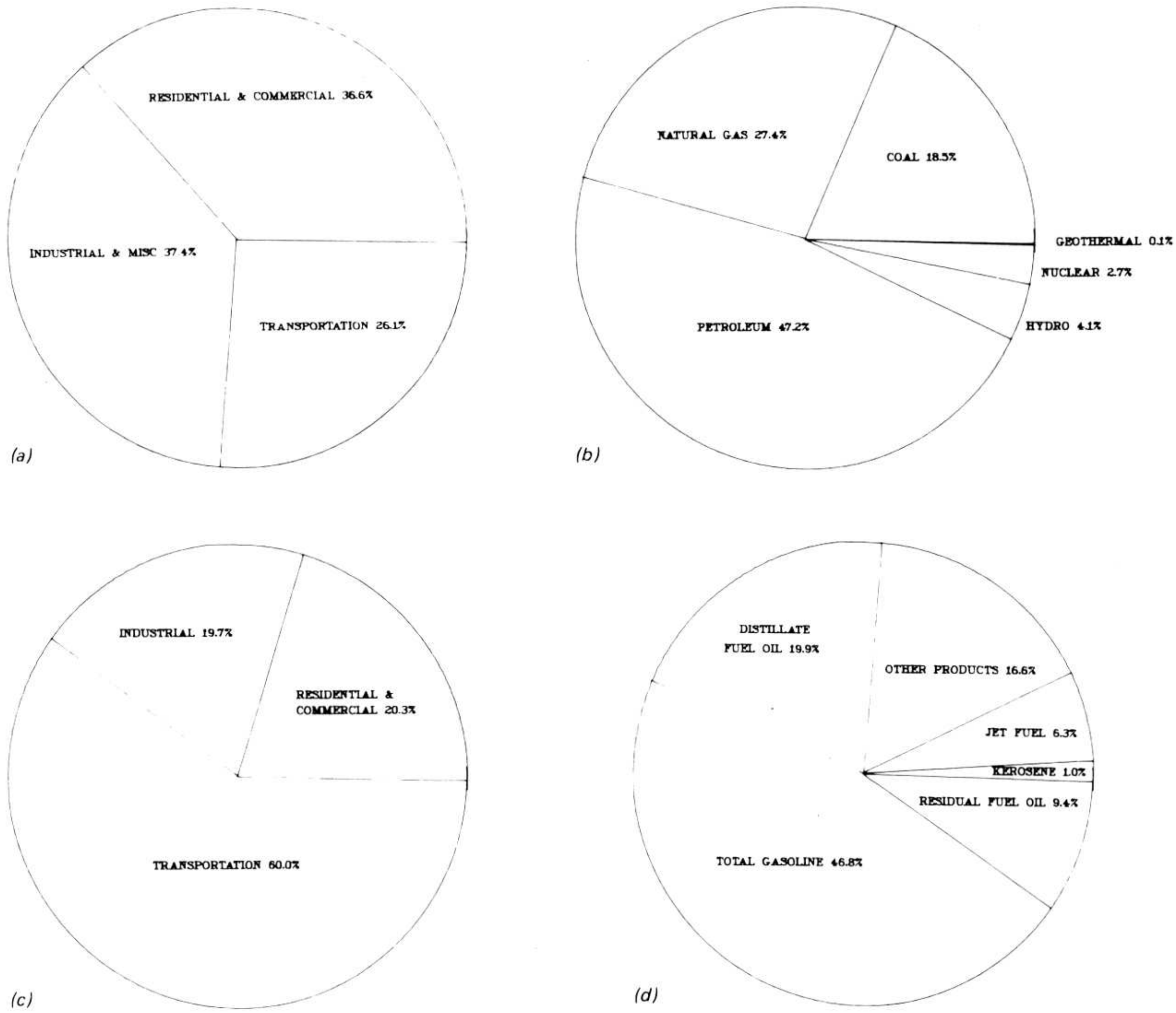


Fig. 1.1. U.S. Energy Consumption and Production, 1976: (a) consumption by end-use sector; (b) consumption by source; (c) petroleum consumption by end-use sector; (d) refined petroleum products output. Source: D. B. Shonka et al., *Transportation Energy Conservation Data Book: Edition 2*, ORNL-5320, Oak Ridge National Laboratory, Oak Ridge, TN, 1977.

2. THE CONCEPT OF ENERGY INTENSITY

In theory at least, the concept of energy intensity is readily defined as the energy use per unit productive output.

$$\text{EI} = \text{Energy Intensity} = \frac{\Sigma \text{ Energy Use}}{\Sigma \text{ Productive Output}} ,$$

and

$$\text{Energy Efficiency} = \frac{1}{\text{Energy Intensity}} .$$

However, no matter how simple the concept may seem initially, it has given rise to a plethora of widely divergent estimates of the respective values for the various transportation modes. The values shown in Tables 2.1 and 2.2 by no means encompass the universe of published estimates but rather a small subset of all values readily assembled to illustrate the variety of estimates. In view of the wide divergence of the values and the large possible errors which can be incurred by the use of inapplicable values, some of the major causes of this divergence deserve examination:

1. Energy intensity values are time-variant and implicitly contain certain modal operating characteristics such as the amount of empty backhaul or the fleet vehicle mix, etc. An EI value based on 1972 operational data may be widely different from a value calculated from 1976 data by the same procedures if any one of a number of modal operating characteristics changed.

2. The energy-use term is actually a summation of energies used for cruising, acceleration, idling, consist formation, heating, lighting, construction, etc. Many investigators have included different subsets of these energies, giving rise to further variations in the resultant EI

Table 2.1. Variations of Energy Intensity Estimates for Urban Passenger Transportation Modes

Mode	Per passenger-mile		Per seat-mile	
	Range (Btu/PM)	Maximum error[a] (%)	Range (Btu/sM)	Maximum error[a] (%)
Auto				
Compact	3220–4748	47.5	1187–1660	39.8
Average	4791–9500	98.3	1447–2799	93.4
Bus				
Urban Transit	1533–3700	141.4	375–771	105.6
Van	2670–3593	34.6	1130–1600	41.6
School	758–1100	45.1	300–410	36.7
Rail				
Commuter	1130–4310	281.4	452–1320	192.0
Rapid Transit	2133–4666	118.8	770–1400	81.8
Trolley	2521–4080	61.8	866–1400	61.7

[a]The maximum error which could be incurred (expressed as percent of the true value) if any value within the range may be used and the true value also falls within the range. This worst case error given by $\frac{(h - l)}{l} \times 100$.

Table 2.2. Variations of Energy Intensity Estimates for Intercity Passenger Transportation Modes

Mode	Per passenger-mile		Per seat-mile	
	Range (Btu/PM)	Maximum error[a] (%)	Range (Btu/SM)	Maximum error[a] (%)
Auto				
Compact	1900–2738	44.1	958–1352	41.1
Average	2400–7600	216.7	1167–1976	69.3
Bus	1100–1778	61.6	308–645	109.4
Rail				
Cross Country	924–3852	316.9	352–1000	184.1
Metroliner	1800–3650	102.8	436–1850	324.3
Commuter	1387–3186	129.7	693–1308	88.7
Aircraft				
Wide body	4827–6136	27.1	1985–4090	106.0
Average	5625–9642	71.4	2596–6136	136.4

[a]The maximum error which could be incurred (expressed as percent of the true value) if any value within the range may be used and the true value also falls into the range. This worst case error is given by $\frac{(h - l)}{l} \times 100$.

values. Further complications arise from the fact that, in many estimates, it is not explicitly stated which energies are included and which are not.

3. Energy-use values are commonly reported in gallons of fuel or kWh of electricity. In transforming these units to Btu, varying assumptions concerning the heat values of fuels and the electrical generation and transmission efficiencies have been made. Again, these assumptions have not always been properly documented.

4. EI values are highly sensitive to any assumptions concerning load factors or available seat miles. Although relatively few hard data are available in this area, investigators have in the past been reluctant to place their estimates on a vehicle-mile basis (for which data are generally available). Thus, a large portion of the divergence of estimates may be attributed to differing assumptions concerning the output of the transportation modes.*

5. EI estimates have been made for a large number of different levels of aggregation ranging from individual vehicles to systems to gross modal values. Large variations in energy intensity will exist in any given mode, yet the aggregation or coverage level has not always been specified.

These pitfalls facing investigators and users of energy intensity values should be kept in mind during the following discussion of results. The differentiation of intermodal and intramodal energy intensity values

---

*No mention of the difference between route and great-circle miles has been made, as great-circle miles have been used in only a small number of studies. See pages 2-6 and B-1 for a further description of this output measure.

is readily made on the basis of their intended use. Each of these types is briefly discussed in following sections in relation to how the data in this publication are intended to be used.

2.1. Intramodal Energy Intensity Values

These values may be characterized operationally as energy intensity values which are *never* to be used for intermodal comparisons. They are not normalized to account for intermodal differences and are generally calculated as the simple ratio of modal energy use to modal services produced. Their primary uses lie in the study of the energy-related behavior of a transportation mode and in the forecasting of modal energy use, given a specific level of demand. The main requirements of intramodal EI values are that:

1. A consistent time series of data should be available, generally for several levels of aggregation inside a given mode.

2. The aggregate EI value should cover the activities of the mode as fully as possible. EI estimates based, for example, on a 30% sample of the modal activity are of relatively little value and should be avoided wherever possible.*

3. A breakdown of the components in the EI value is desirable to provide insight into the modal determinants of energy use. This breakdown becomes particularly important when evaluating the conservation potential of various strategies.

---

*Obviously, a scientifically designed and statistically sound sample of this size will yield excellent results. However, very few such surveys are available.

A particular word of caution aimed at the user of EI values in forecasts is warranted if they are to yield realistic estimates of future modal energy demands. A change in the total travel demand for a given transportation mode will generally have differing effects on demands within the various subsectors of the mode. When such changes occur, the EI value of the base year is no longer applicable and must be recalculated on the basis of the new mix of activities inside the mode and any changes in efficiency that might have occurred.

Keeping these factors in mind, the data in this publication were organized and calculated in the following manner:

1. All EI values were calculated from operational data for the given years, and it is explicitly stated whenever the values presented are estimates based on less than full coverage of the modal activities.

2. The complete time series of data from 1970 to 1977 is given wherever possible.

3. All values presented are based on the energies directly associated with and necessary for vehicle movement. In particular, this includes energy used in vehicle propulsion, idling, environmental control inside the vehicle, empty vehicle shuttling, and, in the case of railroads, energy used in assembling the train consists.

4. The fuel-heat values and conversion factors given in Appendix D were used throughout.

5. Estimates of the reliability of the source data are given wherever possible.

6. Only the line-haul portions of modal energy use are covered. Any energies used in access and egress by the traveler, which may be substantial portions of the total for the shorter trip lengths, are not included.

2.2. Intermodal Energy Intensity Values

In general, these are energy intensity values used for evaluating the desirability and consequences of potential modal shifts of passenger travel. In the ideal case, before any fair intermodal comparisons may be made, the data should be normalized for travel time, quality of service, and modal circuities. Even though it is not possible to normalize the data for the first two factors quantitatively, the user should be very aware that there are considerable differences in travel time and the comfort levels between a sleeper compartment on a train and the economy class cabin of an intercontinental jet. The differences have significant impacts on the energies used and are implicitly contained in all EI values.

It is possible to normalize for the different route lengths by various modes through the use of a circuity factor which is defined as the ratio of the route distance to the great-circle distance between two points (or series of points). These circuity ratios are based on the concept that the net useful output of an intercity transportation mode is the movement of passengers from point A to point B, irrespective of the distances that the various modes had to cover in moving the passengers from A to B.

In view of these complicating factors, it is desirable to set down some basic guidelines which should be followed in making all intermodal energy intensity comparisons.

1. All comparisons should be made on the basis of great-circle miles covered.

2. As not all aspects of any two modes compete with each other, no comparisons should be made at the aggregate modal level. Only the EI values for the competitive segments and trip lengths should be compared.

3. The user should be aware that the resulting comparisons are still "unfair" in the sense that quality, speed, and cost of service have not been accounted for.

2.3. Indirect Energy Consumption

One final factor not treated in the body of the report should be mentioned. The energy used by the supporting infrastructures and operational facilities of the transportation modes consume considerable amounts of energy, both in absolute and relative measures. Examples of these indirect energy uses are energies expended in the manufacture of the vehicles, the construction of the necessary facilities (highway, airports, etc), and the maintenance and upgrading of the systems. At present, no precise definitions or quantifications of these energies are available. However, because of their importance, estimates of these energies, as derived by the TECNET modeling system, are given in Table 2.3.

Table 2.3. Indirect Energy Use as Percent of Direct Energy Use by Mode, 1977

Mode	Indirect Energy Use
Air	63.2
Automobile	37.9
Bus	100.0
Marine	85.7
Pipeline	7.1
Rail	116.7
Truck	42.9
Total	42.0

Source: R. M. Doggett et al., *Further Development and Use of the Transportation Energy Conservation Network (TECNET)*, Final Report, McLean, Va., 1978.

3. AIR PASSENGER TRANSPORTATION

The air transportation mode is in a unique position in relation to other intercity passenger transportation modes in that, at present, it represents the only viable alternative for the long distance traveler who places a high premium on time. In view of this advantage it is not surprising to find that in 1976 over 43% of air trips were for business reasons and that close to 60% of all air-carrier passenger-miles were generated on trips of over 1000 miles (Table 3.1). This advantage is also reflected in the strong showing of the Supplemental and Certified air carrier statistics in terms of all intercity passenger transportation. For the purposes of Table 3.1, intercity passenger transportation was defined as return trips to a place at least 100 miles away (including circuity).

Table 3.1. Air Carrier[a] Percent of All Intercity Passenger Transportation Statistics, 1976

	All intercity common carriers	All intercity passenger movements[b]
Great circle[c] vehicle miles	66	2
Great circle[c] passenger miles	89	39
Energy use	97	56

[a]Certification route and supplemental.

[b]General aviation statistics were left out because of lack of data.

[c]The great-circle distance is the shortest distance between two points.

Source: U.S. Travel Data Center, *1976 National Travel Survey, Full Year Report*, Washington, D.C., 1977. National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970-1977; American Bus Association, *America's Number 1 Passenger Transportation Service*, Washington, D.C., 1977; Association of American Railraods, *Statistics of Railroads of Class I; Years 1967 to 1977*, Washington, D.C., 1978; Civil Aeronautics Boards, *Handbook of Airline Statistics, Supplement*, Washington, D.C., December 1977.

3.1 Certificated Route Air Carriers

The air mode is utterly dominated by the activities of the certificated route air carriers, in terms of passenger transportation services rendered. In terms of the values given in Table 3.1 the certificated carriers accounted for 98, 97, and 98% of the vehicle miles, passenger miles, and energy use, respectively, for the air mode. As impressive as these statistics are in their own right, two additional factors lend them even greater importance.

- The air carrier market share has been experiencing a steady increase over the past years and virtually all projections predict even larger increases in the future.

- The air mode is beginning to penetrate significantly into the shorter-trip-length segment of the market while maintaining its traditional dominance over the longer distances.

Before delving into the available material on the air mode, the analyst should be aware that a substantial number of air trips are over rather short distances rather than the transcontinental movements generally associated with the air mode. In 1975 38.8% of all domestic air passengers boarded aircraft for trip lengths of less than 500 miles, even though only 23.0% of the city pairs served by certificated route air carriers fell into this distance interval. A possible explanation for this difference can be found in the relative proximity of many of the large population and commercial centers in the country.

The data given and Fig. 3.1 displays the counterintuitively low passenger trip length distribution for the 59,403 city-pairs which the certificated route air carriers served in 1975. Tables displaying the disaggregate data for the leading city-pairs and the source data for the figure are given in Appendix C.

ORNL DWG 78-20751

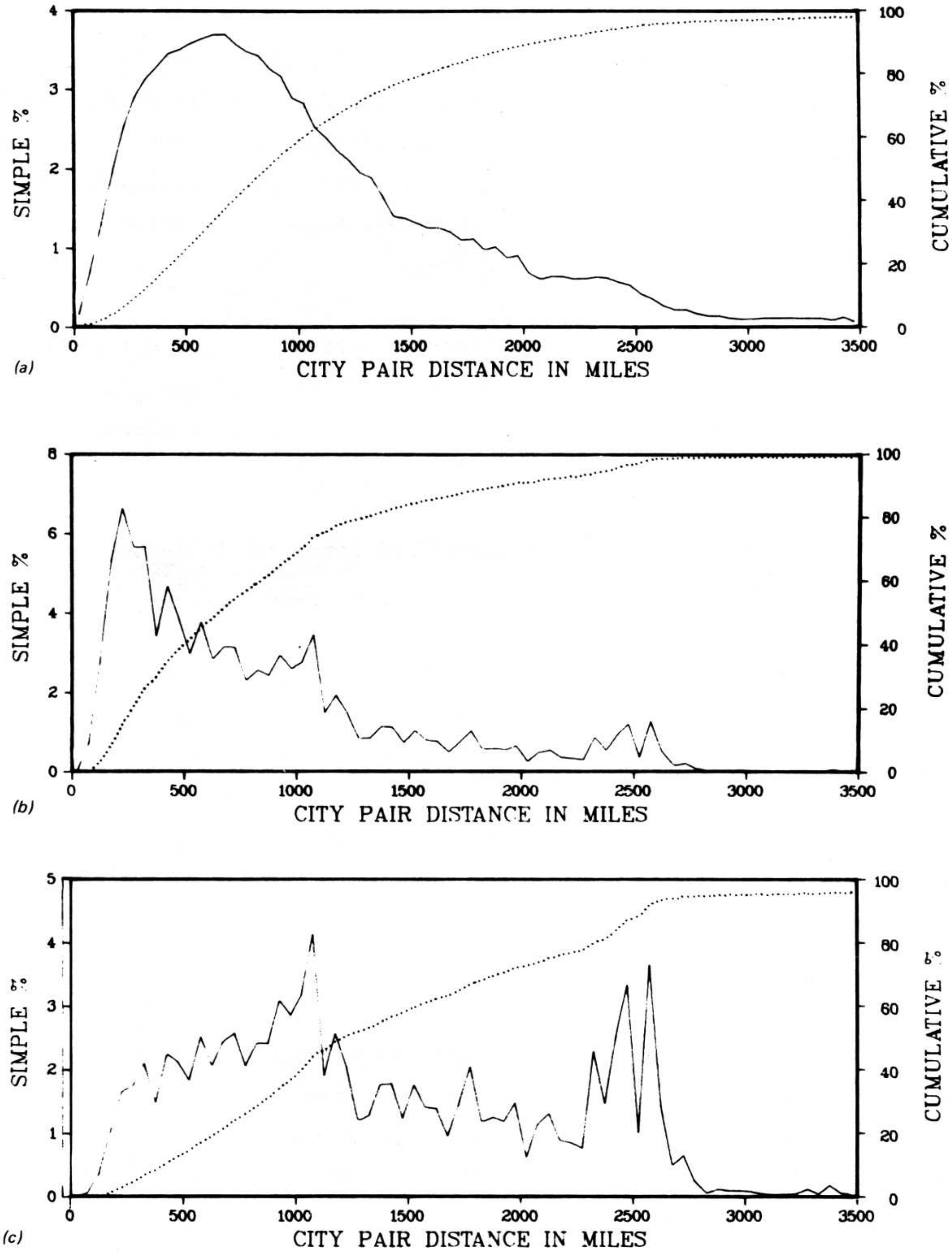


Fig. 3.1. Percent Distributions of U.S. Airline Operating Statistics by City-Pair Distance: (*a*) city-pair separation; (*b*) passengers carried; (*c*) passenger miles. Note: simple percentage plots are not to the same scale. Source: P. Gavel, Civil Aeronautics Board, *Supplement to the Handbook of Airline Statistics*, Washington, D.C., December 1977, pp. 103-104.

3.1.1 Determinants of Energy Use

Due to the wealth of data available on air carrier operations, virtually all analysis in the chapter is carried out in the section dealing with operational data, and this section is limited to a brief discussion of the effects on stage length. Decreasing flight stage lengths will have adverse affects on aircraft energy efficiency through the following interactions (Table 3.2, Figs. 3.2–3.4):

1. The overall efficiency of the aircraft decreases. The percentage of the fuel used for taxiing, idling, climb-out and approaches, which does not directly contribute to the movement of passengers, increases rapidly with decreasing stage lengths.

2. The large, more efficient, aircraft are not directly suitable for service over short stage lengths.

3. Load factors tend to decrease sharply with shorter stage lengths as the frequency of service increases in order to keep air travel competitive with other transporation modes.

A detailed analysis of the operational data aimed at segregating efficiency improvements resulting from increased load factors and more efficient aircraft operations by aircraft class is given on pages 3.8-3.18.

3.1.2 Operational data

In view of the importance of flight stage length and other service characteristics on energy intensity, it is desirable to split the data available on certificated route air carriers into several categories based on service characteristics. Data in this section are reported for the following carrier and service categories.

1. International/territorial operations. Those operations between the 50 states and foreign points and U.S. possessions or territories and operations between foreign points.

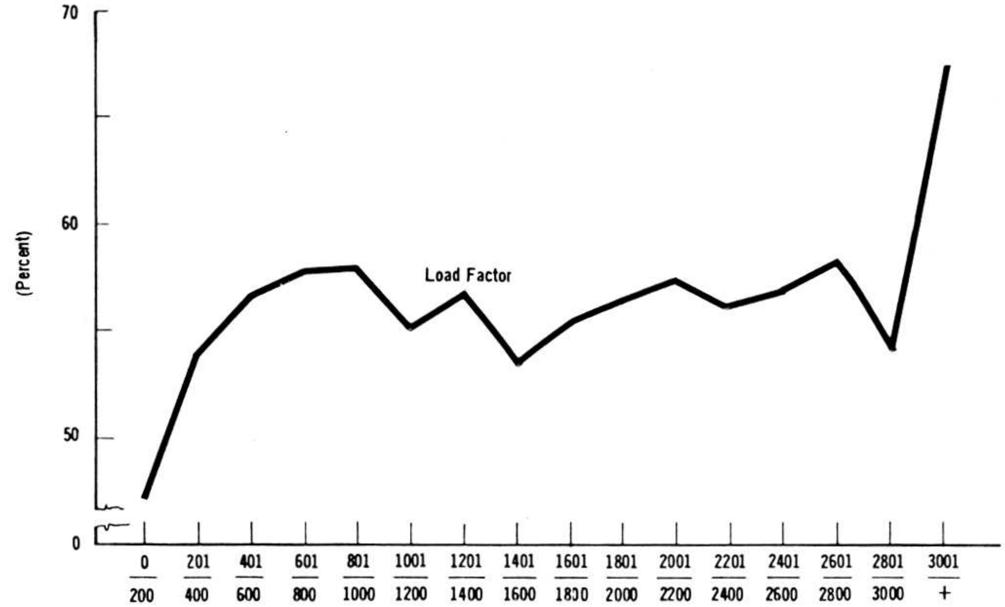


Fig. 3.2. Variation of Passenger Load Factors with Flight Stage Length, 1976. Source: Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement,* Washington, D.C., Dec. 1977.

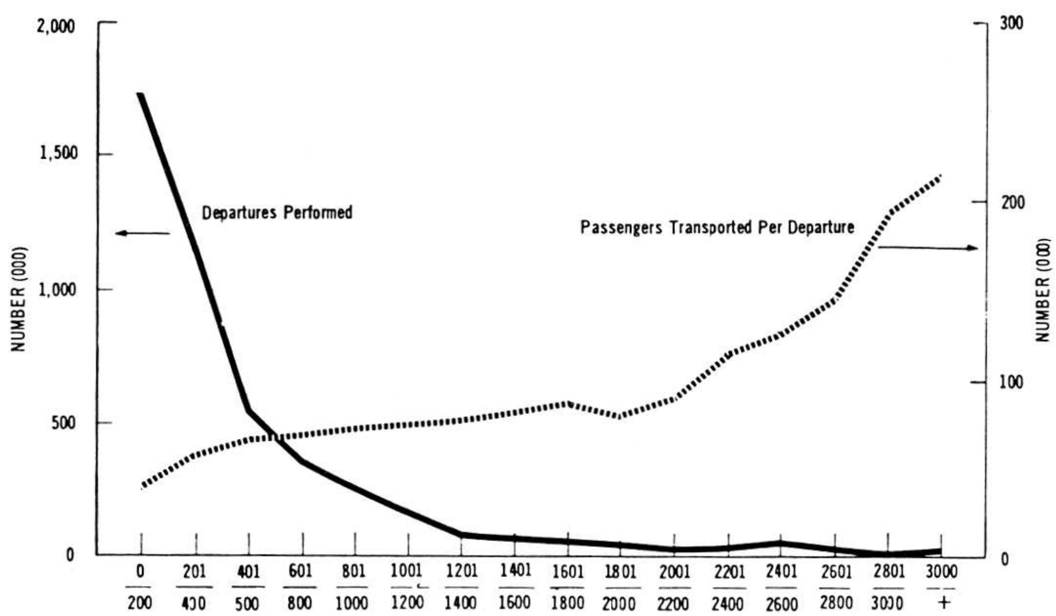


Fig. 3.3. Aircraft Departures and Passengers Per Departure vs Flight Stage Length, 1976. Source: Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement,* Washington, D.C., December 1977.

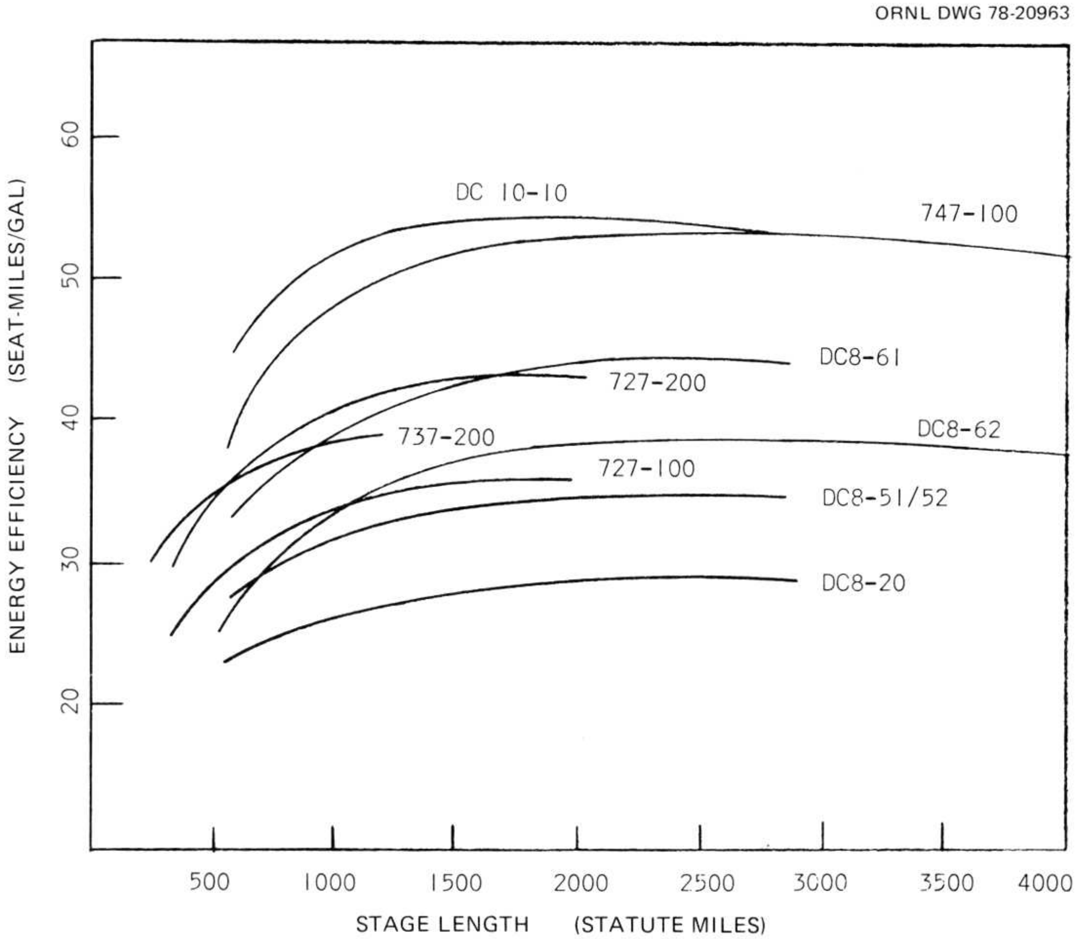


Fig. 3.4. Relationship between Energy Efficiency and Stage Length for Various Aircraft. Note: 10 seat-miles/gal = 13,500 Btu/seat-mile. Source: L. J. Williams, NASA Ames Research Center, *Air Transportation Energy Efficiency*, presented at the Fourth National Conference on the "Effects of Energy Constraints on Transportation Systems," Union College, Aug. 1-5, 1977, Fig. 13.

Table 3.2. Distribution of Air Carrier Service vs Flight Stage Length, 1976

Mileage blocks	Passengers transported (10^6)	Passengers transported (%)	Revenue passenger miles (10^9)	Revenue passenger miles (%)	Available seat miles (10^9)	Available seat miles (%)	Aircraft revenue departures (10^3)	Aircraft revenue departures (%)	Passenger load factor (%)	Average passengers transported per departure
0-200	66.8	26.6	8.2	5.7	17.4	6.7	1,744.0	38.6	47.2	38.3
201-400	66.5	26.5	18.9	13.0	35.0	13.4	1,169.2	25.9	53.9	56.9
401-600	36.1	14.4	17.6	12.1	31.1	11.9	550.1	12.2	56.6	65.5
601-800	22.7	9.0	15.7	10.8	27.1	10.4	331.0	7.3	57.8	68.5
801-1000	16.6	6.6	14.9	10.2	25.8	9.9	227.1	5.0	57.8	73.3
1001-1200	12.3	4.9	13.4	9.2	24.3	9.3	166.6	3.7	55.0	73.7
1201-1400	6.0	2.4	7.7	5.3	13.7	5.2	79.1	1.8	56.6	75.2
1401-1600	5.8	2.3	8.6	5.9	15.9	6.1	71.7	1.6	54.4	81.0
1601-1800	5.3	2.1	9.1	6.3	16.4	6.3	60.5	1.3	54.4	87.7
1801-2000	2.8	1.1	5.2	3.6	9.2	3.5	33.8	0.7	56.3	81.7
2001-2200	1.4	0.6	3.0	2.1	5.2	2.0	15.4	0.3	57.2	91.1
2201-2400	2.2	0.9	5.1	3.5	9.1	3.5	17.4	0.4	55.9	124.3
2401-2600	5.0	2.0	12.6	8.7	22.2	8.5	44.4	1.0	56.9	113.0
2601-2800	1.1	0.4	2.8	1.9	4.8	1.8	7.2	0.2	58.1	145.6
2801-3000	0.1	0.1	0.4	0.3	0.8	0.3	0.7	*a*	54.0	196.5
3001 plus	0.5	0.2	2.1	1.4	3.1	1.2	2.3	0.1	67.4	215.9

[a] Less than 0.05 percent.

Source: Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement*, Washington, D.C., December 1977.

2. Domestic trunk operations. Trunk air carriers are the large airlines serving primarily the large communities. Their operations cover virtually the entire spectrum of equipment and service characteristics.

3. Local service carriers. Those air carriers operating routes of lesser density between smaller traffic centers and between those and principal centers. These carriers operate 2-engine turbofan jets or smaller aircraft over shorter stage lengths.

4. Other carriers. Included in this category are intra-Alaskan and Hawaiian carriers and miscellaneous other carriers serving specialized routes. A large portion of these operations are carried out utilizing smaller aircraft.

The source of prime data on certificated route air carriers is the Civil Aeronautics Board, which, in conjunction with the performance of its regulatory functions, collects a great deal of high quality data covering all facets of the carriers operations. All data presented in this section are derived directly from the CAB data tapes distributed by the National Archives and Records Service. The fuel used in carrying belly freight on passenger flights was subtracted out by approximating the incremental fuel used per ton-mile for the aircraft types. Included in the statistics are the passengers carried by carriers in their scheduled and nonscheduled operations. Table 3.3 summaries the time series of data presented in Tables 3.4–3.15 and Figs. 3.5–3.10.

The time series of energy intensity data presented in Table 3.3 makes it evident that air passenger transportation has experienced significant increases in fuel efficiency on a passenger-mile basis. The CAB disaggregate data sets by aircraft type and class make differentiation possible between fuel efficiency improvements resulting from increased load factors and improvements resulting from more fuel-efficient operations

Table 3.3. Summary of Certificated Air Carrier Energy Intensity 1971–1976

	Domestic	International	Composite
		1971	
Btu/pm	8920	6540	8290
Btu/sm	4330	3700	4180
% load factor	48.6	56.6	50.5
		1972	
Btu/pm	8130	6080	7590
Btu/sm	4280	3670	4130
% load factor	52.6	60.3	54.5
		1973	
Btu/pm	8200	6020	7650
Btu/sm	4280	3520	4100
% load factor	52.2	58.4	53.6
		1974	
Btu/pm	7240	5630	6870
Btu/sm	4050	3200	3860
% load factor	55.9	56.8	56.1
		1975	
Btu/pm	7180	5730	6870
Btu/sm	3950	3120	3770
% load factor	55.0	54.4	54.9
		1976	
Btu/pm	6760	5230	6440
Btu/sm	3800	3060	3650
% load factor	56.2	58.6	56.7
		1977[a]	
Btu/pm	6580	5070	6260
Btu/sm	3720	3040	3590
% load factor	58.6	59.9	57.2

[a]Data for first 3 quarters only.

Source: National ARchives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970-1977.

Table 3.4. Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1971

	Aircraft-miles (10^6)	Jet fuel consumed (10^6 gal)	Passenger-miles (10^9)	Passenger load factor (%)	Mean stage length (miles)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
Domestic carriers	1,934	7,315	110.10	48.6		8,920	1.7
Domestic trunks	1,672	6,626	101.03	48.8		8,800	1.6
Big four	1,073	4,204	64.45	49.7		8,750	1.4
Others	600	2,422	36.58	47.3		8,880	1.9
Local carriers	246	621	8.09	45.6		10,310	1.8
Other domestic carriers	25	67	0.94	50.7		9,440	5.3
International carriers	379	1,940	39.64	56.6		6,540	2.8
Passenger carriers, total	2,322	9,256	149.70	50.5		8,290	1.9

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970 to 1977.

Table 3.5. Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1971

	Percent of all certificated air carriers[a]			Passenger load factor (%)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
	Aircraft-miles	Fuel consumed	Passenger-miles			
Long-haul aircraft	45.9	55.8	58.7	49.6	7,920	2.0
Four-engine narrow-body jet	39.2	43.1	44.0	52.8	8,170	2.1
Turbofan	30.4	32.1	35.8	53.6	7,470	2.2
Turbojet	8.8	11.0	8.2	49.4	11,200	1.7
Wide-body jet	6.6	12.7	14.7	42.0	7,160	1.7
Three-engine	0.08	.4	0.2	50.8	6,440	10.1
Four-engine	6.6	12.5	14.5	41.9	7,170	1.6
Three-engine narrow-body	29.5	26.9	25.9	52.0	8,700	1.5
Short-haul aircraft	24.4	17.0	15.2	51.6	8,970	1.9
Propellor	5.2	2.2	1.7	46.0	10,560	2.7
Piston	0.4	.1	0.001	44.7	10,430	5.7
Turboprop	4.8	2.1	1.6	46.1	10,560	2.5
Two-engine narrow-body jet	19.1	14.8	13.5	52.4	8,770	1.7
Helicopters	0.06	0.02	0.006	36.8	26,690	3.8

[a]Values will not sum to 100% exactly because only passenger cabin configurations were considered.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

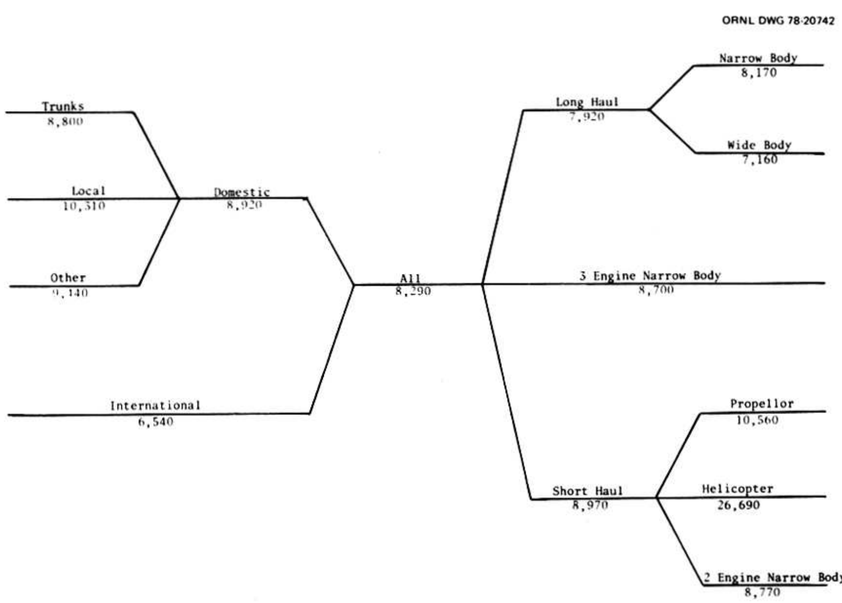


Fig. 3.5. Summary of Certificated Route Air Carrier Energy Intensity, 1971.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

Table 3.6. Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1972

	Aircraft-miles (10^6)	Jet fuel consumed (10^6 gal)	Passenger-miles (10^9)	Passenger load factor (%)	Mean stage length (miles)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
Domestic carriers	1,954	7,386	121.82	52.6		8,130	1.6
Domestic trunks	1,674	6,663	111.63	52.9		8,000	1.6
Big four	1,065	4,281	71.75	54.4		8,000	1.5
Others	609	2,383	39.88	50.4		7,990	1.7
Local carriers	254	651	9.11	49.4		9,580	1.9
Other domestic carriers	25.7	71	1.08	52.4		8,750	4.6
International carriers	378	1,977	43.42	60.3		6,080	2.5
Passenger carriers, total	2,332	9,366	165.24	54.5		7,590	1.8

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970 to 1977.

Table 3.7. Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1972

	Percent of all certificated air carriers[a]			Passenger load factor (%)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
	Aircraft-miles	Fuel consumed	Passenger-miles			
Long-haul aircraft	44.9	55.6	59.3	53.9	7,130	1.9
Four-engine narrow-body jet	34.9	38.0	38.0	56.9	7,620	2.1
Turbofan	27.8	29.3	31.7	57.8	7,050	2.1
Turbojet	7.1	8.7	6.3	53.1	10,440	1.8
Wide-body jet	10.1	17.6	21.3	49.2	6,260	1.6
Three-engine	2.3	3.0	3.4	46.6	6,680	2.2
Four-engine	7.8	14.7	17.9	49.7	6,180	1.3
Three-engine narrow-body	30.3	27.7	25.5	55.7	8,250	1.5
Short-haul aircraft	24.7	16.4	15.2	54.8	8,260	1.9
Propellor	5.0	2.1	1.6	48.9	9,960	2.6
Piston	0.5	0.1	0.1	46.2	10,290	4.9
Turboprop	4.5	2.0	1.5	49.1	9,940	2.4
Two-engine narrow-body jet	19.7	14.5	13.6	55.6	8,060	1.7
Helicopters	0.06	0.02	0.006	43.9	23,370	2.8

[a]Values will not sum to 100% exactly because only passenger cabin configurations were considered.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

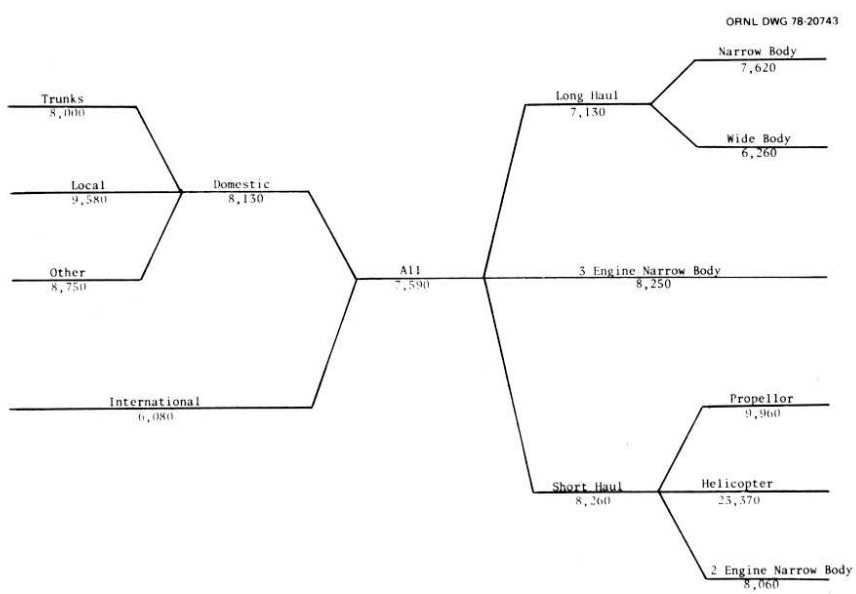


Fig. 3.6. Summary of Certificated Route Air Carrier Energy Intensity, 1972.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

Table 3.8. Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1973

	Aircraft-miles (10^6)	Jet fuel consumed (10^6 gal)	Passenger-miles (10^9)	Passenger load factor (%)	Mean stage length (miles)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
Domestic carriers	2,018	7,999	130.72	52.2	427	8,200	1.7
Domestic trunks	1,713	7,180	119.29	52.4	577	8,070	1.6
Big four	1,065	4,338	74.56	54.3	NA	7,810	1.5
Others	648	2,842	44.74	49.6	NA	8,510	1.9
Local carriers	275	728	10.07	48.9	177	9,690	1.8
Other domestic carriers	30	91	1.35	55.5	144	9,000	4.8
International carriers	379	1,980	43.90	58.4	1,243	6,020	2.8
Passenger carriers, total	2,397	9,980	174.63	53.6	477	7,650	1.9

NA — Not available.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970 to 1977.

Table 3.9. Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1973

	Percent of all certificated air carriers[a]			Passenger load factor (%)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
	Aircraft-miles	Fuel consumed	Passenger-miles			
Long-haul aircraft	43.5	54.6	59.0	52.9	7,070	2.1
Four-engine narrow-body jet	30.2	32.6	32.9	58.0	7,590	2.3
Turbofan	25.0	26.2	28.3	58.6	7,080	2.3
Turbojet	5.2	6.4	4.6	54.9	10,760	2.1
Wide-body jet	13.4	22.0	26.1	47.6	6,420	1.6
Three-engine	5.5	7.4	7.7	44.4	7,290	1.9
Four-engine	8.0	14.6	18.4	49.1	6,050	1.4
Three-engine narrow-body	32.0	28.8	26.2	55.0	8,450	1.6
Short-haul aircraft	24.5	16.5	14.8	54.2	8,570	1.9
Propellor	4.7	2.1	1.5	49.7	10,290	2.8
Piston	0.4	0.1	0.07	45.9	10,530	5.9
Turboprop	4.3	2.0	1.5	49.8	10,280	2.5
Two-engine narrow-body jet	19.8	14.5	13.2	54.8	8,370	1.6
Helicopters	0.06	0.02	0.006	43.6	23,840	3.0

[a]Values will not sum to 100% exactly because only passenger cabin configurations were considered.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

ORNL DWG 78-20744

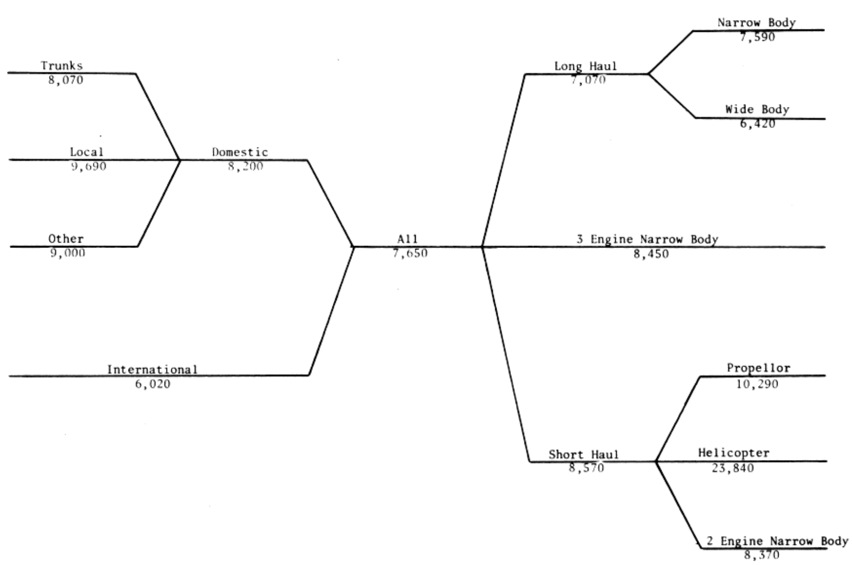


Fig. 3.7. Summary of Certificated Route Air Carrier Energy Intensity, 1973.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

Table 3.10. Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1974

	Aircraft-miles (10^6)	Jet fuel consumed (10^6 gal)	Passenger-miles (10^9)	Passenger load factor (%)	Mean stage length (miles)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
Domestic carriers	1,869	7,233	133.72	55.9	427	7,240	1.2
Domestic trunks	1,568	6,424	121.36	56.2	582	7,090	1.1
Big four	986	3,957	76.60	58.1	NA	6,930	1.1
Others	582	2,465	44.77	53.3	NA	7,360	1.2
Local carriers	269	720	11.03	52.8	183	8,760	1.3
Other domestic carriers	30	86	1.32	55.2	159	8,670	4.3
International carriers	339	1,712	40.46	56.8	1,293	5,630	2.3
Passenger carriers, total	2,208	8,945	174.19	56.1	478	6,870	1.4

NA — Not available.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970 to 1977.

Table 3.11. Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1974

	Percent of all certificated air carriers[a]			Passenger load factor (%)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
	Aircraft-miles	Fuel consumed	Passenger-miles			
Long-haul aircraft	40.8	51.9	56.5	54.5	6,290	1.6
Four-engine narrow-body jet	25.4	27.2	28.0	59.9	6,680	1.7
Turbofan	23.4	24.6	26.0	59.9	6,510	1.7
Turbojet	2.0	2.6	2.0	58.8	8,990	2.4
Wide-body jet	15.4	24.7	28.6	50.2	5,910	1.4
Three-engine	8.3	11.4	12.3	49.5	6,390	1.7
Four-engine	7.1	13.3	16.3	50.8	5,560	1.0
Three-engine narrow-body	35.1	31.5	28.9	58.4	7,520	1.1
Short-haul aircraft	23.9	16.5	14.5	58.1	7,820	1.5
Propellor	3.9	1.6	1.2	52.8	9,060	2.8
Piston	0.3	0.07	0.05	46.5	10,470	5.2
Turboprop	3.6	1.5	1.2	53.1	9,010	2.5
Two-engine narrow-body jet	20.0	14.9	13.3	58.6	7,710	1.2
Helicopters	0.06	0.02	0.006	42.6	27,770	2.5

[a]Values will not sum to 100% exactly because only passenger cabin configurations were considered.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

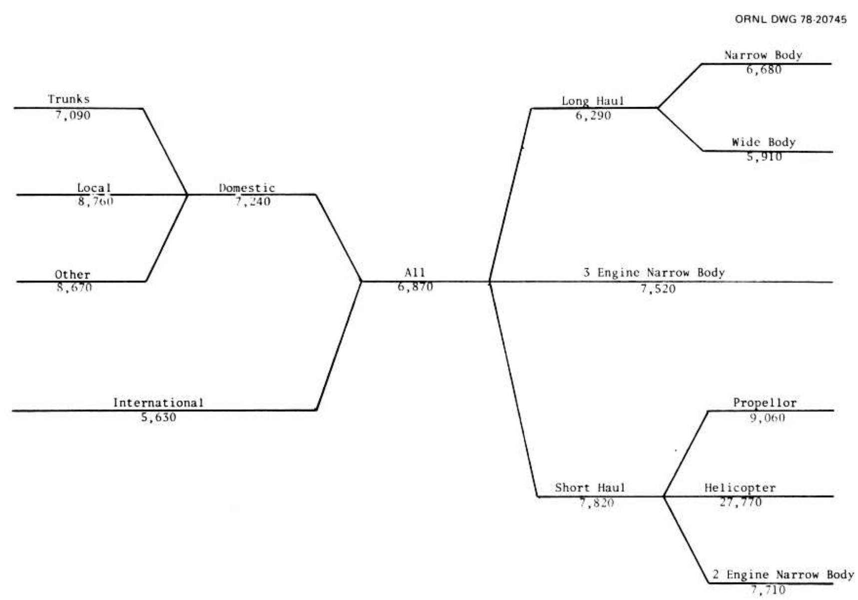


Fig. 3.8. Summary of Certificated Route Air Carrier Energy Intensity, 1974.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

Table 3.12. Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1975

	Aircraft-miles (10^6)	Jet fuel consumed (10^6 gal)	Passenger-miles (10^9)	Passenger load factor (%)	Mean stage length (miles)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
Domestic carriers	1,885	7,287	136.00	55.0	429	7,180	1.1
Domestic trunks	1,584	6,459	123.40	55.3	583	7,010	1.0
Big four	996	3,949	77.08	56.8	NA	6,870	1.0
Others	588	2,510	46.32	53.0	NA	7,240	1.0
Local carriers	264	726	10.97	51.8	188	8,890	1.1
Other domestic carriers	37	101	1.62	58.4	170	8,310	4.0
International carriers	310	1,606	37.32	54.4	1,332	5,730	2.7
Passenger operations, total	2,195	8,894	173.32	54.9	476	6,870	1.3

NA — Not available.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970 to 1977.

Table 3.13. Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1975

	Percent of all certificated air carriers[a]			Passenger load factor (%)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
	Aircraft-miles	Fuel consumed	Passenger-miles			
Long-haul aircraft	40.1	51.2	56.4	53.4	6,220	1.7
Four-engine narrow-body jet	22.8	24.2	24.8	58.4	6,690	2.0
Turbofan	20.8	21.8	22.9	58.4	6,520	2.0
Turbojet	1.9	2.4	1.9	59.1	8,680	1.8
Wide-body jet	17.3	27.0	31.5	50.0	5,860	1.3
Three-engine	10.4	14.2	15.8	50.2	6,150	1.3
Four-engine	6.8	12.8	15.7	49.8	5,560	1.4
Three-engine narrow-body	36.6	32.6	29.9	57.3	7,520	0.9
Short-haul aircraft	23.2	16.0	13.6	55.7	8,080	1.3
Propellor	3.4	1.4	1.0	49.8	9,490	2.7
Piston	0.3	0.5	0.04	46.8	9,480	5.5
Turboprop	3.2	1.3	0.9	49.9	9,490	2.5
Two-engine narrow-body jet	19.7	14.6	12.6	56.2	7,970	1.0
Helicopters	0.05	0.02	0.005	39.5	29,520	3.2

[a]Values will not sum to 100% exactly because only passenger cabin configurations were considered.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

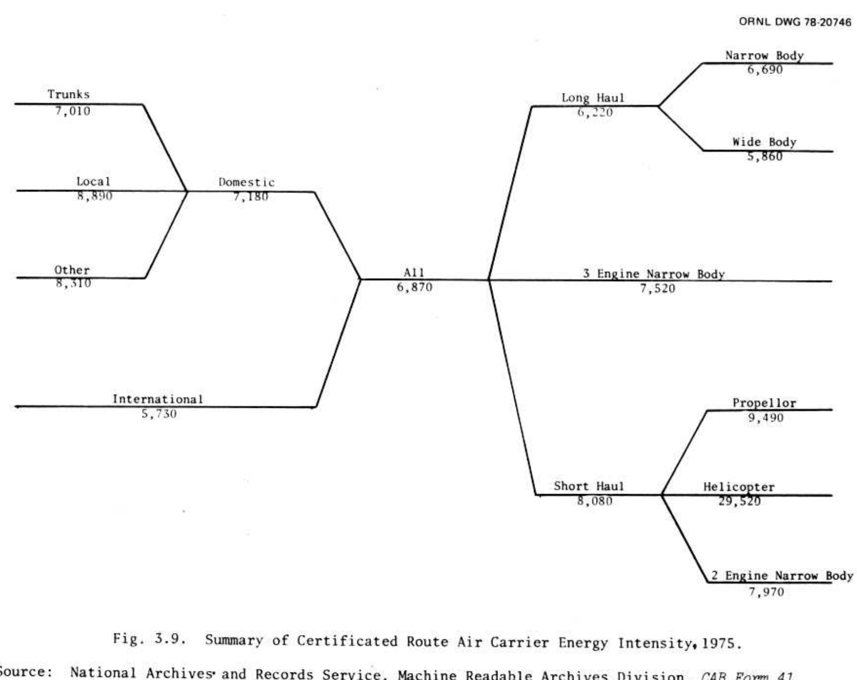


Fig. 3.9. Summary of Certificated Route Air Carrier Energy Intensity, 1975.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

Table 3.14. Certificated Air Carrier Operating Statistics and Energy Intensities, by Carrier Type, 1976

	Aircraft-miles (10^6)	Jet fuel consumed (10^6 gal)	Passenger-miles (10^9)	Passenger load factor (%)	Mean stage length (miles)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
Domestic carriers	1,995	7,642	151.37	56.2	435	6,760	1.1
Domestic trunks	1,673	6,667	136.97	56.4	584	6,620	0.9
Big four	1,047	4,129	85.62	58.5	NA	6,470	0.9
Others	626	2,639	51.35	53.3	NA	6,870	0.8
Local carriers	284	786	12.67	53.4	195	8,320	1.2
Other domestic carriers	37	89	1.74	61.1	173	6,880	2.4
International carriers	305	1,588	404.6	58.6	1,359	5,230	2.0
Passenger carriers, total	2,295	9,230	191.70	56.7	480	6,440	1.1

NA — Not available.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970 to 1977.

Table 3.15. Certificated Air Carrier Operating Statistics and Energy Intensities, by Aircraft Category, 1976

	Percent of all certificated air carriers[a]			Passenger load factor (%)	Passenger energy intensity (Btu/PM)	Portion of EI due to nonrevenue operations (%)
	Aircraft-miles	Fuel consumed	Passenger-miles			
Long-haul aircraft	38.7	50.0	56.1	56.1	5,720	1.4
Four-engine narrow-body jet	20.2	21.4	22.3	61.4	6,210	1.7
Turbofan	18.4	19.1	20.5	61.3	6,030	1.7
Turbojet	1.8	2.3	1.8	62.0	8,190	1.9
Wide-body jet	18.5	28.5	33.8	53.1	5,400	1.0
Three-engine	11.5	15.6	17.2	51.2	5,830	1.0
Four-engine	7.0	12.9	16.6	55.2	4,950	1.0
Three-engine narrow-body	37.6	33.5	29.9	57.7	7,220	0.7
Short-haul aircraft	23.1	16.1	13.5	57.1	7,660	1.2
Propellor	3.0	1.2	0.9	51.4	9,140	2.5
Piston	0.2	0.03	0.02	43.5	10,360	3.5
Turboprop	2.8	1.2	.8	51.7	9,110	2.5
Two-engine narrow-body jet	20.1	14.8	12.7	57.6	7,550	1.0
Helicopters	0.03	0.02	0.003	40.2	27,390	3.7

[a]Values will not sum to 100% exactly because only passenger cabin configurations were considered.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

ORNL DWG 78 20747

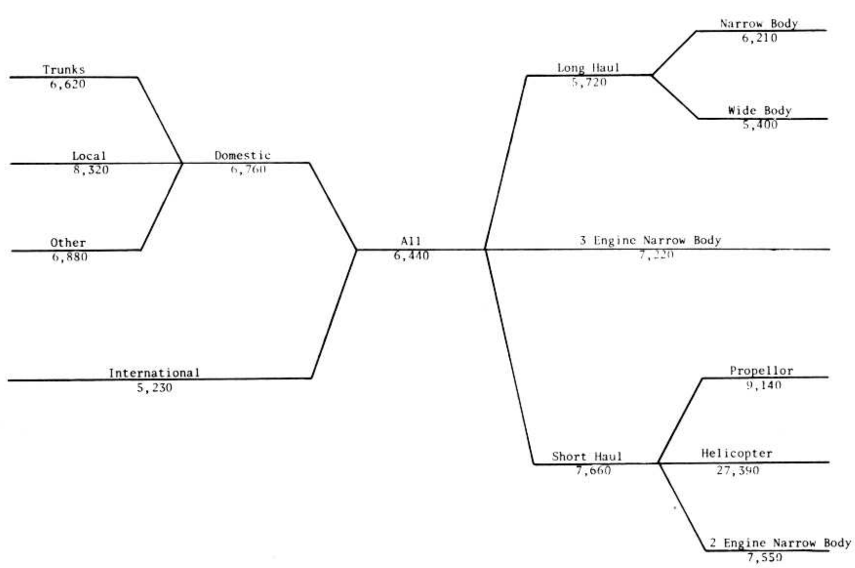


Fig. 3.10. Summary of Certificated Route Air Carrier Energy Intensity, 1976.

Source: National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970–1977.

and maintenance procedures. This distinction may be accomplished in the following manner:

Given that $\mu_{PM} = LF \cdot \mu_{SM}$

where

μ_{PM} = aircraft energy efficiency in passenger-miles per gallon,
μ_{SM} = aircraft energy efficiency in seat-miles per gallon,
LF = seat load factor,*
taking the total differential yields:

$$d(\mu_{PM}) = d(LF)\mu_{SM} + LFd(\mu_{SM}) \ .$$

The differential elements may then be approximated by the larger changes in the annual data giving:

$$\Delta\mu_{PM} = \Delta LF \cdot \mu_{SM} + LF \cdot \Delta\mu_{SM} \ ,$$

where the first term yields the efficiency improvement due to increased load factors and the second term yields the improvements due to operational measures.

In performing such an analysis, the user should be aware of several factors affecting the outcome:

1. The differential elements should be approximated by deltas only over shorter time intervals. As the time intervals increase in length, the resultant values may begin to differ significantly from actual observed values.

---

*These values may be derived from the tabular data in the following manner: μ_{PM} is 135,000 times the reciprocal of the value for energy intensity in Btu per passenger mile; μ_{SM} is μ_{PM} divided by the load factor.

2. If the analysis is to yield purely the impact of operational factors, including improved aircraft maintenance, reduced taxiing, and the like, it must be carried out at the aircraft-class, or lower, level.

   At higher levels of aggregation, the effects of changing aircraft fleet mixes and the shifting of passenger-miles values from one aircraft type to another will be included in the operational term of the equation.

The results presented in Table 3.16 and Fig. 3.11 were derived from an analysis carried out at the aircraft class level.

Table 3.16. Fuel Efficiency Improvements Due to Increased Load Factors and Operational Improvements, by Aircraft Class, 1971–1976

Improvement type	Calculated efficiency improvement[a] (passenger-miles/gallon)						Actual observed efficiency improvement
	1971–72	1972–73	1973–74	1974–75	1975–76	1971–76	
Four-engine wide-body							
Operational	-0.41	0.75	1.15	0.44	0.37	2.30	
Load factor	3.51	-0.26	0.77	-0.48	2.63	6.17	
Total[b]	3.09	0.48	1.93	-0.04	3.00	8.46	8.44
Three-engine wide-body[c]							
Operational			0.43	0.52	0.75	1.70	
Load factor			2.13	0.30	0.44	2.87	
Total[b]			2.56	0.82	1.19	4.57	4.64
Four-engine turbo-fan							
Operational	-0.31	-0.35	1.22	0.50	0.62	1.68	
Load factor	1.38	0.30	0.46	-0.59	1.06	2.61	
Total[b]	1.07	-0.05	1.67	-0.08	1.68	4.29	4.32
Four-engine turbo-jet							
Operational	-0.02	-0.80	1.46	0.48	0.14	1.26	
Load factor	0.90	0.44	0.89	0.08	0.76	3.07	
Total[b]	0.88	-0.36	2.35	0.55	0.90	4.32	4.41
Three-engine narrow-body							
Operational	-0.22	-0.18	0.93	0.28	0.59	1.50	
Load factor	1.10	-0.21	0.99	-0.28	0.03	1.63	
Total[b]	0.88	-0.39	1.92	0.00	0.72	3.13	3.17
Two-engine narrow-body							
Operational	0.40	-0.38	0.24	0.15	0.50	0.91	
Load factor	0.95	-0.25	1.12	-0.72	0.42	1.52	
Total[b]	1.35	-0.63	1.36	-0.57	0.92	2.43	2.48

[a] Values derived from $\Delta\mu = \Delta LF \cdot \mu_{SM} + LF \cdot \Delta\mu_{SM}$.

[b] Values may not add due to independent rounding.

[c] Prior to 1973 an insufficient number of aircraft were operating for a meaningful analysis.

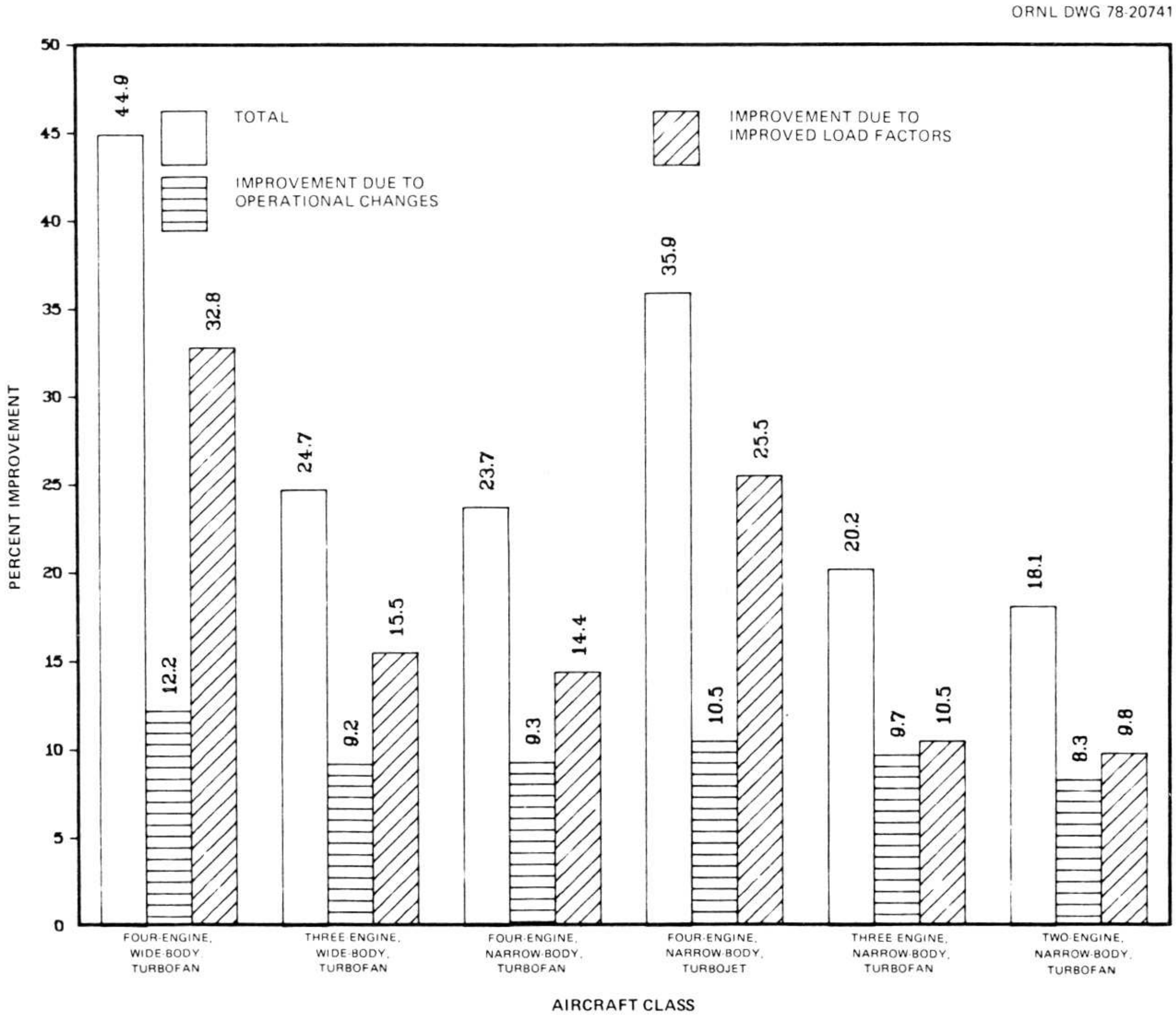


Fig. 3.11. Summary Breakdown of Aircraft Efficiency Improvement, 1970-76.

3.2 Supplemental Air Carriers

Supplemental air carriers are carriers authorized to perform chartered services supplementing the scheduled services of the certificated route air carriers. Because these carriers do not fall under the same stringent reporting requirements as the Certificated Route Air Carriers, little other than systems-aggregate level data are available for analysis. This lack of detailed data presents a problem in that a substantial portion of the aircraft miles are flown for military purposes, yet only the systems-aggregate fuel consumption is known. The fuel use and energy intensity values given in Table 3.17 were derived by allocating the

Table 3.17. Supplemental Air Carrier Operating Statistics,[a] 1975–1976

	1975			1976		
	Domestic	International	Total	Domestic	International	Total
Revenue aircraft miles (10^6)	8.18	29.33	37.41	7.51	30.67	38.18
Revenue passenger miles (10^9)	0.88	6.00	6.88	0.91	5.74	6.65
Load factor (%)	89.9	88.1	88.3	89.5	87.6	87.8
Fuel use (10^6 gal)	NA	NA	164	NA	NA	177
Energy intensity (Btu/PM)	NA	NA	3200	NA	NA	3600

[a]Data pertain to civilian operations only.

NA — Not available.

Source: Civil Aeronautics Board, *Handbook of Airline Statistics Supplement*, Washington, D.C., Dec. 1977.

fuel used for civilian and military purposes on a per-aircraft-mile basis. Although the resultant values are entirely reasonable, the user should be aware that they are based on a crude approximation technique necessitated by data gaps and, therefore, may contain significant errors.

3.3 General Aviation Operations

All readily available source data on general aviation activity are derived from Part 2 of AC Form 8050-73 which general aviation aircraft owners fill out on a voluntary basis. The Federal Aviation Administration tabulates these data and accounts for nonrespondents on the assumption that they use their aircraft in exactly the same pattern as owners who do respond. Clearly, this is a somewhat tenuous assumption, and the FAA states:

> It must be emphasized that these measures of general aviation aircraft activity are estimates.

Nevertheless, when these data are utilized in conjunction with fuel-use data from the Bureau of Mines, they yield relatively consistent results for the later years which are presented in Table 3.18.

Table 3.18. Estimates of General Aviation Activity and Energy Intensity, 1970–1976

	Active aircraft	Aircraft-miles flown (10^9)	Fuel Consumption			Total Btu (10^{14})	Btu per aircraft-mile
			AVGAS (10^6 gal)	Jet Fuel			
				Naphta (10^6 gal)	Kerosine (10^6 gal)		
1970	131,743	3.207	362.25	414.58[a]		1.009	31,460
1971	131,148	3.207	396.82	347.68[a]		0.919	29,230
1972[b]	145,010	3.317	404.46	37.34	535.92	1.273	38,370
1973	153,540	3.729	410.00	16.97	358.76	1.014	27,200
1974	161,502	4.043	403.2	15.04	468.17	1.151	28,470
1975	168,475	4.238	397.11	31.92	477.67	1.178	27,800
1976	180,854	4.476	432.68	25.49	562.67	1.329	29,680

[a] Combined Naphta and Kerosine type fuels.

[b] The data for this year, and possibly other years, are likely to be erroneous.

Source: U.S. Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation, Calendar Year 1976*, Washington, D.C., 1976; U.S. Department of the Interior, Bureau of Mines, *Petroleum Statement Annual*, Washington, D.C., 1970–1976.

3.4 Summary Graphs

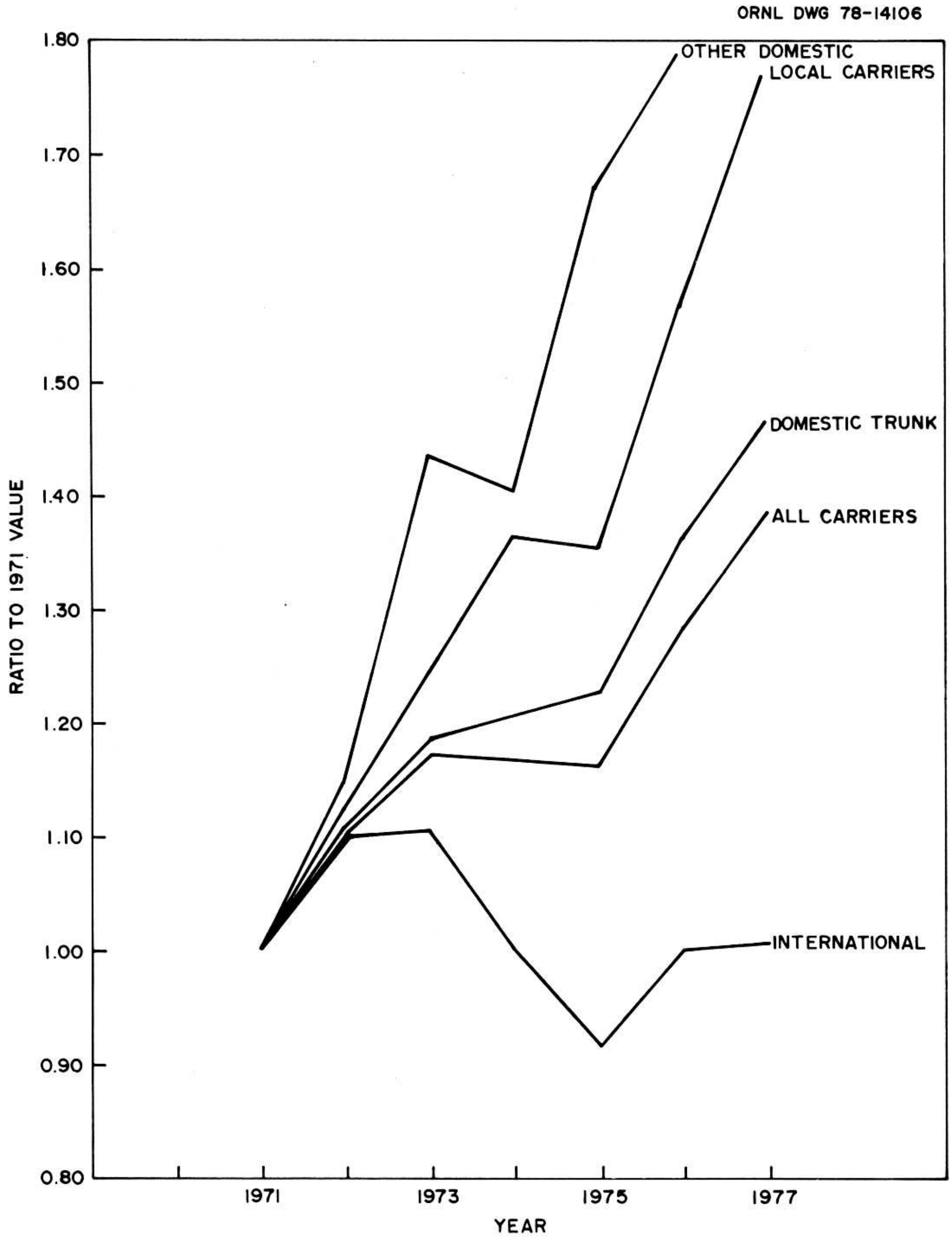


Fig. 3.12. Certificated Route Air Carrier Passenger-Miles, 1971–77, Normalized to 1971 Values.

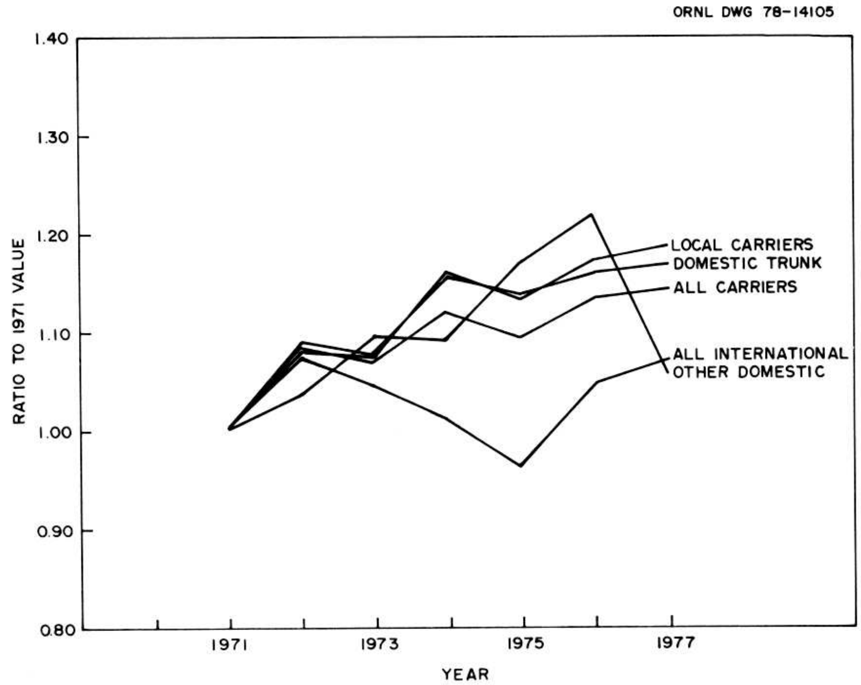


Fig. 3.13. Certificated Route Air Carrier Passenger Load Factors, 1971–77, Normalized to 1971 Values.

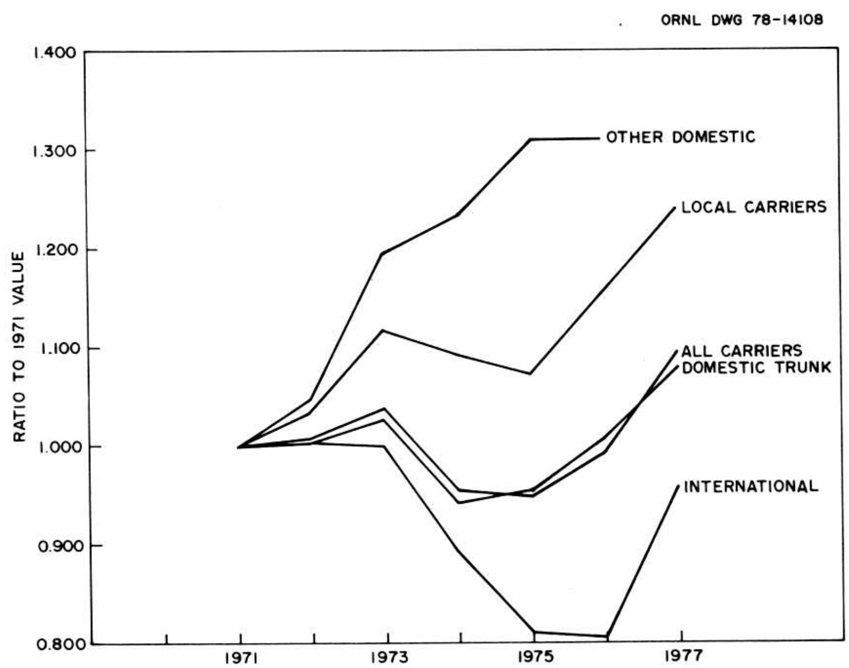


Fig. 3.14. Certificated Route Air Carrier Aircraft-Miles, 1971–77, Normalized to 1971 Values.

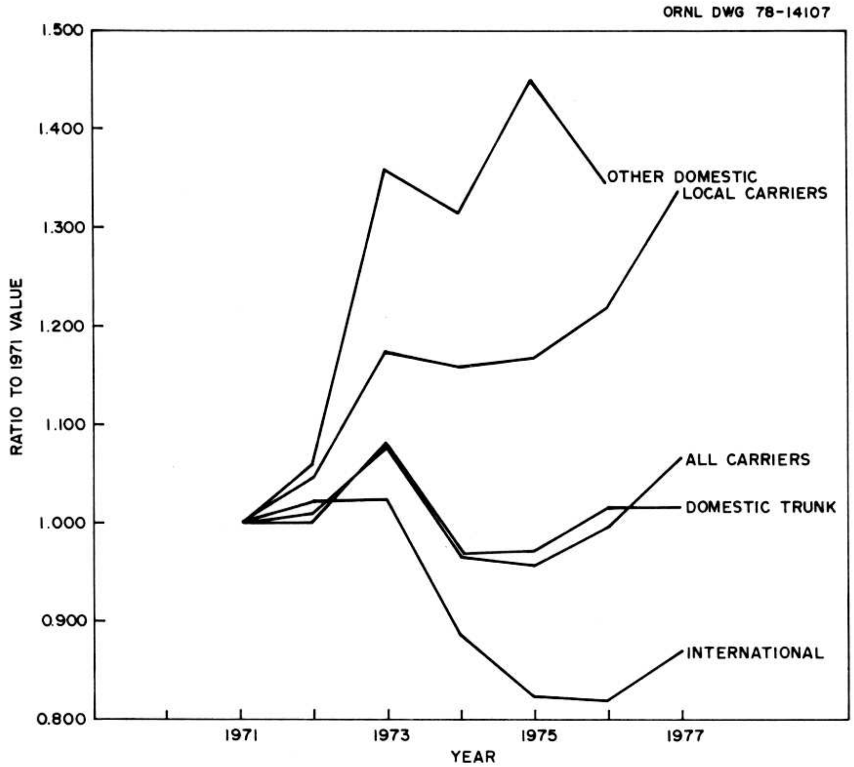


Fig. 3.15. Certificated Route Air Carrier Fuel Consumption, 1971–1977, Normalized to 1971 Values.

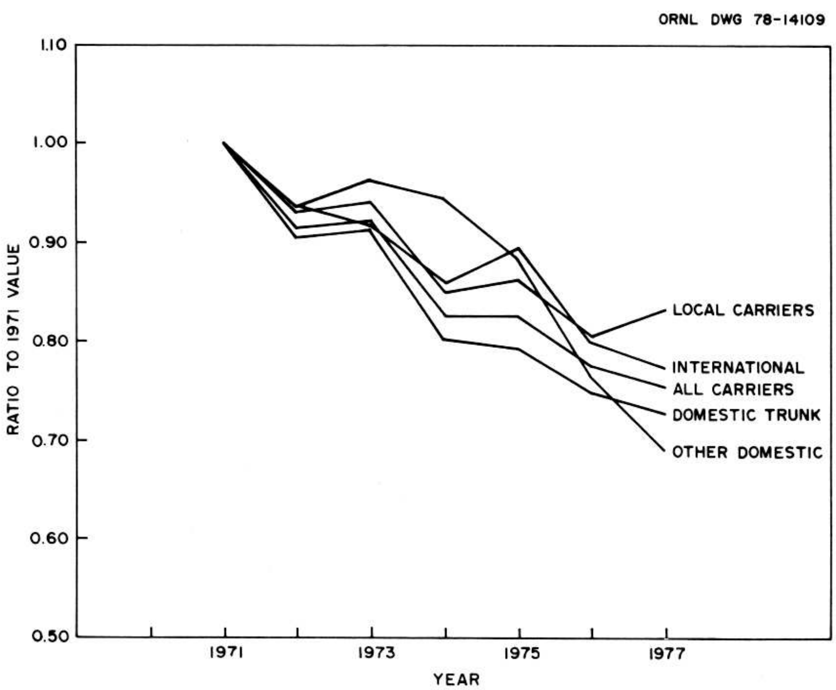


Fig. 3.16. Certificated Route Air Carrier Energy Intensity in Btu per Passenger-Mile, 1971–1977, Normalized to 1971 Values.

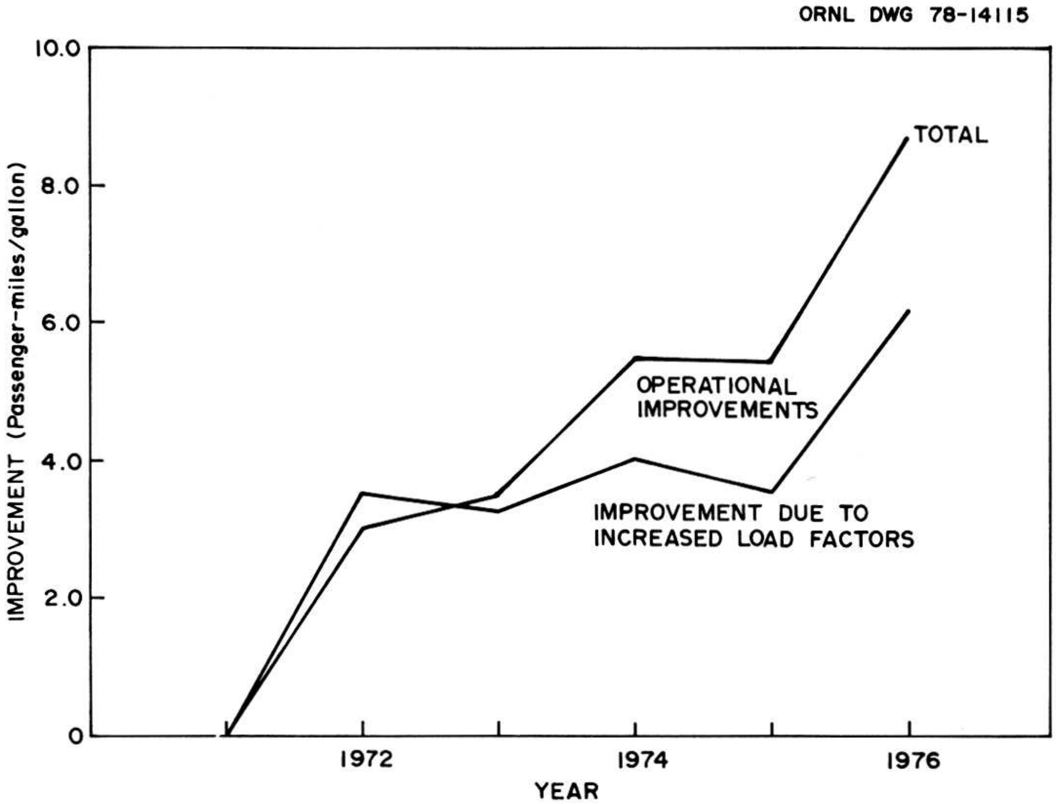


Fig. 3.17. Breakdown of Cumulative Fuel Economy Improvements for Four-Engine, Wide-Body Aircraft, 1971–76.

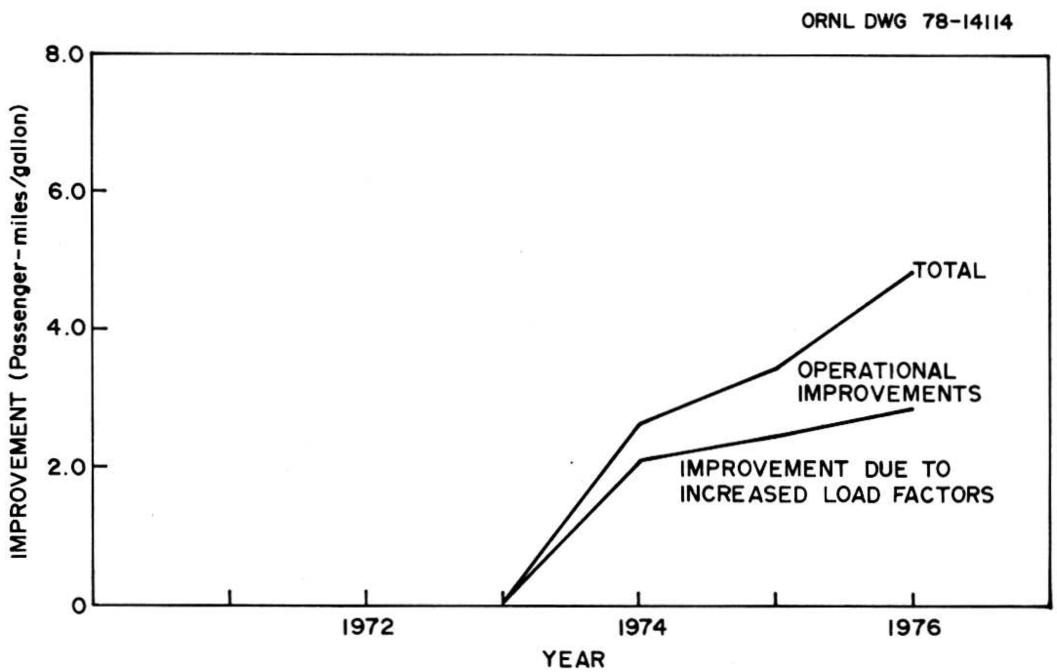


Fig. 3.18. Breakdown of Cumulative Fuel Economy Improvements for Three-Engine, Wide-Body Aircraft, 1973–76.

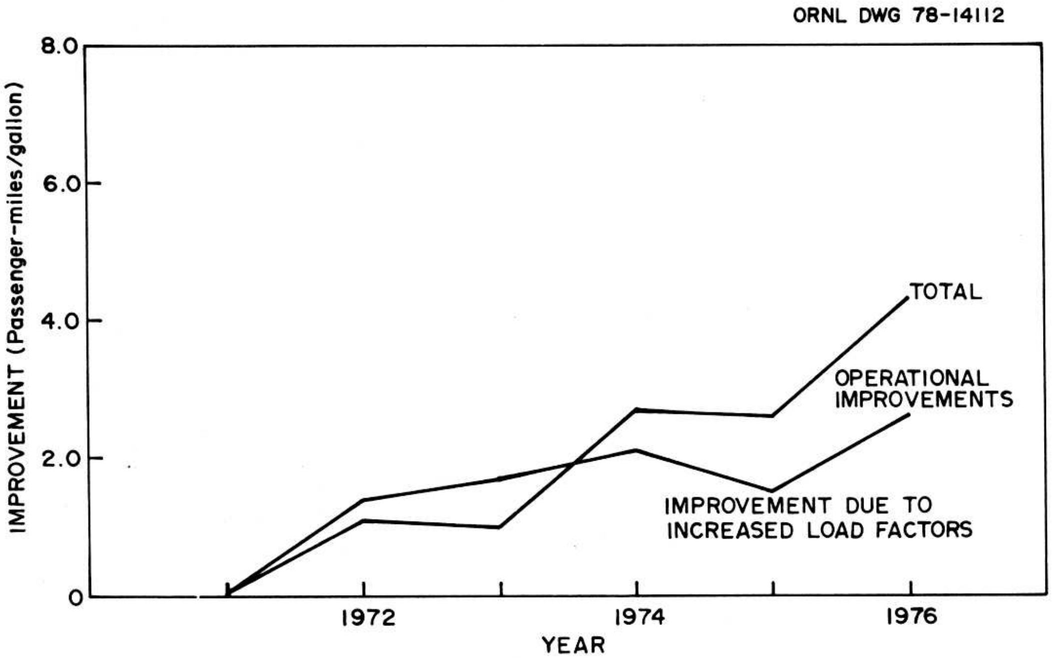


Fig. 3.19. Breakdown of Cumulative Fuel Economy Improvements for Four-Engine, Narrow-Body Turbofan Aircraft, 1971–76.

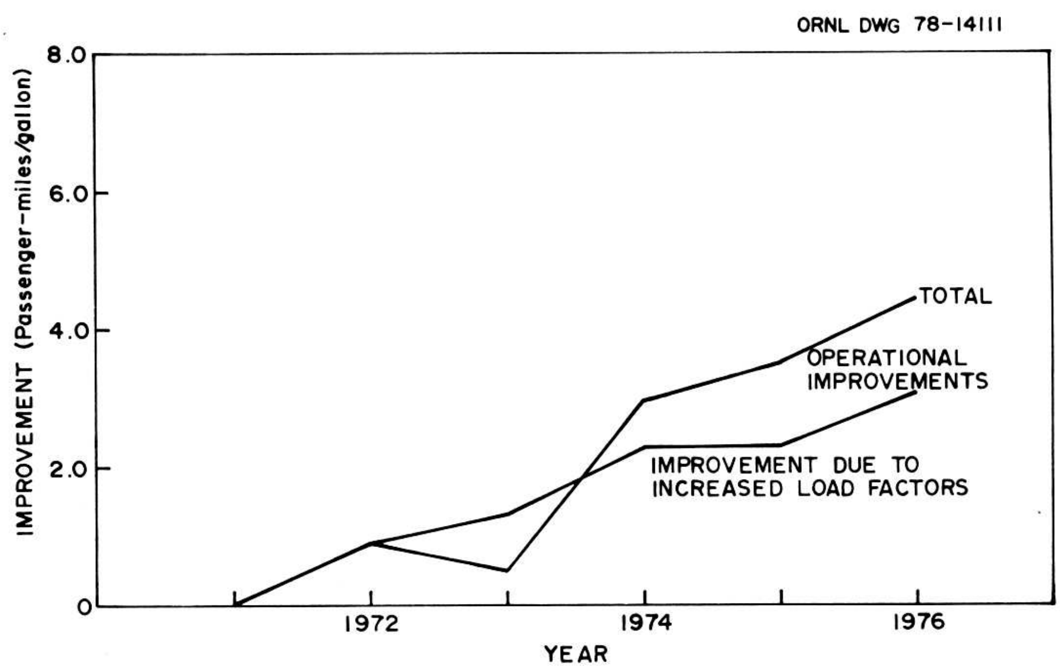


Fig. 3.20. Breakdown of Cumulative Fuel Economy Improvements for Four-Engine, Narrow-Body Turbojet Aircraft, 1971–76.

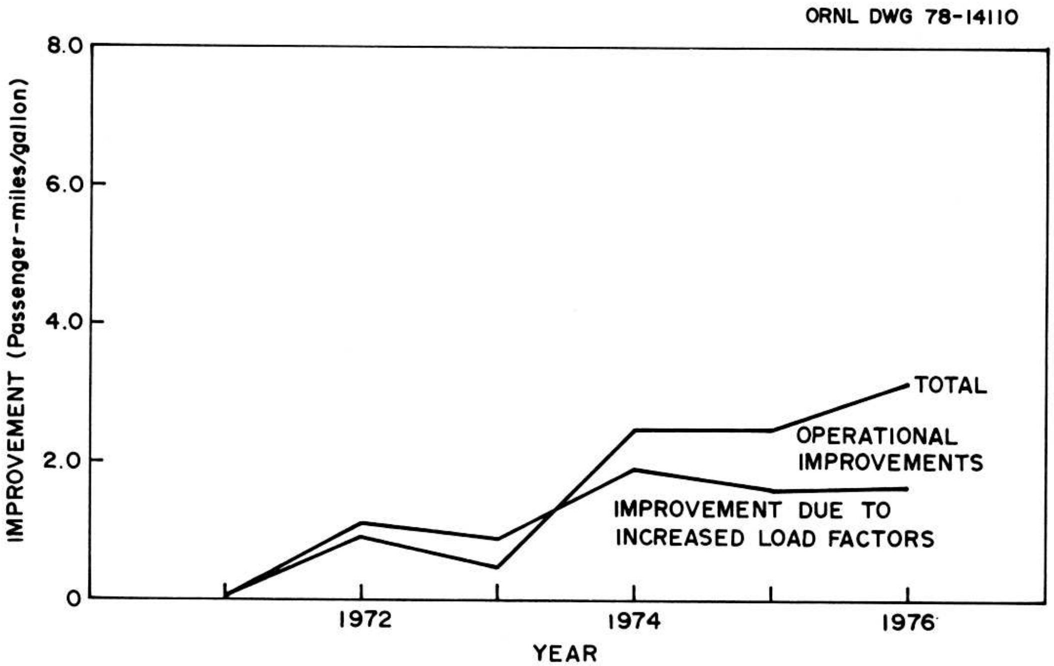


Fig. 3.21. Breakdown of Cumulative Fuel Economy Improvements for Three-Engine, Narrow-Body Aircraft, 1971–76.

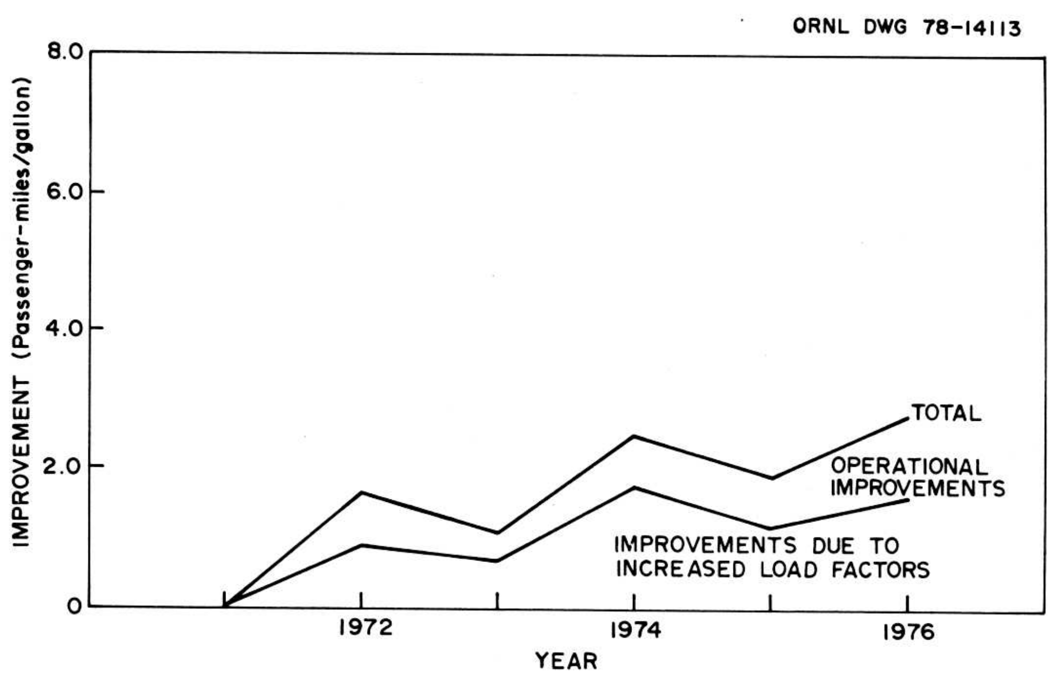


Fig. 3.22. Breakdown of Cumulative Fuel Economy Improvements for Two-Engine, Narrow-Body Aircraft, 1971–76.

4. PASSENGER AUTOMOBILE TRANSPORTATION

The automobile is, and will continue to be for the foreseeable future, the most widely accepted form of personal transportation in the United States. It is the most flexible and responsive transportation mode and is used for 90% of all personal travel. Furthermore, expenditures for operation of automobiles comprise a significant proportion of the average family income (10-13%), and account for over 85% of total expenditure on passenger transportation in the United States. At the same time, about 5 million Americans are employed in occupations involving the automobile and its operation.

The automobile, therefore, can be seen to play an important role in our national mobility and economy. In fact, the mobility provided by the automobile has become an integral part of the American lifestyle.

Our dependence on the automobile in our economy and lifestyle is now being questioned as a result of the critical situation we are facing in regard to petroleum supplies. In 1976, the automobile consumed 58% of the total energy used by the transportation sector. This is equivalent to 35% of total petroleum consumption in the United States. Clearly any attempt at reducing petroleum consumption in the United States must involve the automobile.

In stark contrast to the importance of the automobile is the lack of reliable data on its aggregate operations. For this reason the emphasis of this chapter has been shifted somewhat. While most of the other chapters center around the presentation and analysis of available operational data, this chapter is aimed at defining and circumventing data shortcomings or gaps. Consequently the section on the determinants of energy use has been strengthened and a section on estimation procedures has been added.

4.1 Determinants of Energy Use

Because of the high state of the art and the importance of the automobile to passenger transportation, a large amount of data is available on the many, often interdependent, determinants of automotive fuel consumption. In the interest of brevity, only summary data on several of the most important operational determinants are presented in this section, and the reader desiring further information is referred to the technical literature on the subject.

Figures 4.1 and 4.2 present the general breakdown of how energy is utilized in automobiles. Fig. 4.1 displays the heat balance of a typical engine, and Fig. 4.2 describes how the resultant brake horsepower output from the engine is utilized during steady-state cruising conditions. By necessity these curves are general: the exact breakdown will vary from vehicle to vehicle, as will the detailed effects of the parameters discussed in the following subsections.

4.1.1 Vehicle weight

The tractive force needed to move an automobile in a straight line may be approximated by:

$$T = C_R W + GW + \frac{W}{g} a + 0.0026 C_D A v^2 ,$$

where

T = tractive force,
C_R = coefficient of rolling resistance,
G = gradient,
W = gross vehicle weight,
g = gravitational constant,
a = vehicle acceleration,
C_D = coefficient of aerodynamic drag,
A = vehicle frontal area,
v = vehicle velocity.

As examination of the equation shows that all terms except the aerodynamic drag are linearly related to vehicle weight, it is not surprising to find that, for a given velocity profile, it is possible to quantify in a general form the effect of weight on fuel consumption. Regressions run on the EPA combined urban/highway fuel economy suggested

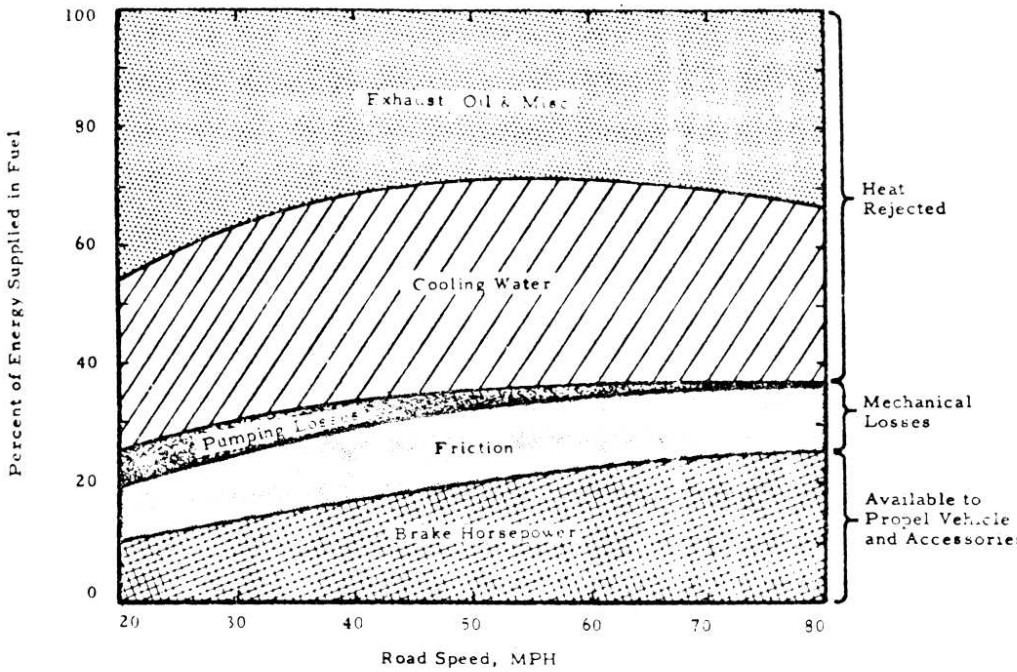


Fig. 4.1. Automobile Engine Heat Balance During Cruising. Source: T. Iura, W. U. Roessler, and H. M. White, *Research Plan for Achieving Reduced Automotive Energy Consumption*, Aerospace Report No. ATR-76(7467)-1, National Science Foundation, Washington, D.C., 1975, Fig. 2-2.

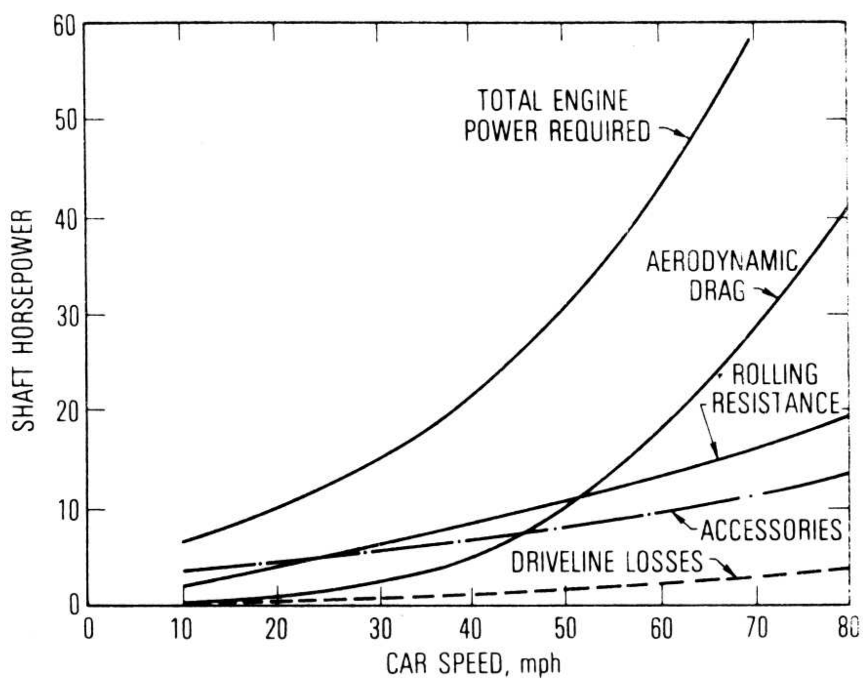


Fig. 4.2. Component Breakdown of Engine Load for a Standard-Size Automobile. Source: T. Iura, W. U. Roessler, and H. M. White, *Research Plan for Achieving Reduced Automotive Energy Consumption*, Aerospace Report No. ATR-76(7467)-1, National Science Foundation, Washington, D.C., 1975, Fig. 2-3.

that a 10% change in vehicle weight will result in approximately a 4% change in fuel economy.* An additional benefit of a weight reduction is that the power requirement for a given level of performance is lowered. If, concurrently with the weight change, adjustments are made to maintain the same level of performance, the same 10% change in gross vehicle weight will yield an 8% change in fuel economy (LaPoint, 1977).

4.1.2 Vehicle Aerodynamics

A series of operational tests and simulations have shown that, for a 10% reduction in vehicle aerodynamic drag, a 2-3% increase in fuel economy may be expected (Sturm, [1977]; LaPoint, 1977). As is evident from the equation given in the preceding section, the two parameters may influence drag. Of these the vehicle frontal area is constrained by the desired interior volume and by conventional design procedures, but substantial leeway exists in influencing the aerodynamic drag coefficient. The lowest drag coefficient of any domestic automobile currently manufactured is claimed to be 0.46, which corresponds to the average value for European automobiles (Janssen, 1978; Sturm,[1977]; Blackmore, 1977). Research in Europe has shown that drag coefficients of 0.42 are possible through optimization techniques, without influencing styling, and that coefficients of 0.37 are possible when the styling is influenced by aerodynamics and is subsequently optimized. If the design procedure is substantially influenced by aerodynamics, drag coefficients from 0.28 to 0.32 seem technically feasible (Janssen, 1978).

4.1.3 Trip length

Trip length is an important determinant of fuel consumption, not only because the total distance traveled partially determines the amount of fuel used, but also because it determines the engine operating tem-

* These regressions will not hold beginning with model year 1977, as a portion of the test procedures were changed. However, large changes in these values are not expected, and, pending furhter analysis, the 10%:4% ratio can still be used.

perature and the degree of warm-up. The severe degradation of fuel economy for short trips depicted in Fig. 4.3 is caused by a combination of the reduced efficiency of lubricants at lower temperatures (resulting in higher frictional losses) and the heat absorbed by the engine in rising to its normal operating temperature. These effects continue for approximately the first 10 miles of any trip, until the engine has reached its steady-state operating point. The fuel economy of trips over 10 miles

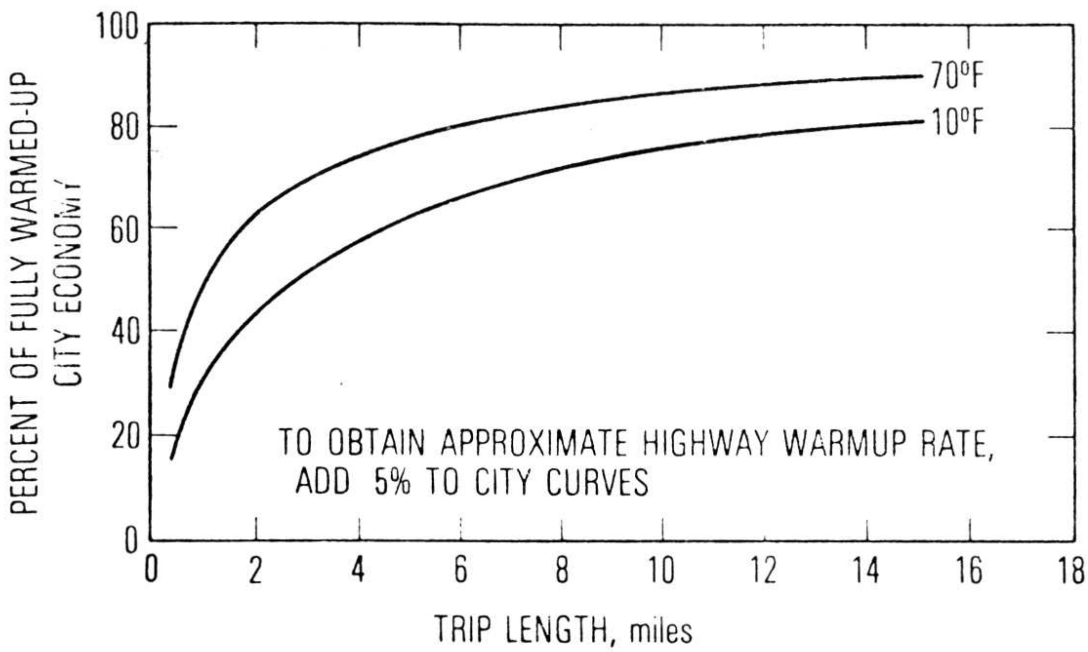


Fig. 4.3. Variation of Fuel Economy with Trip Length. Source: T. Iura, W. U. Roessler, and H. M. White, *Research Plan for Achieving Reduced Automotive Energy Consumption*, Aerospace Report No. ATR-76 (7467)-1, National Science Foundation, Washington, D.C., 1975, Fig. 2-4.

may be thought of as the harmonic mean of the reduced fuel economy during the first 10 miles and the fuel economy of the fully warmed-up engine after 10 miles.

The importance of these characteristics is best shown by example. Assuming that 100 miles of city driving are to be accomplished at 70°F ambient conditions, roughly 1.4 times the fuel will be consumed if 50 2-mile trips are made rather than 10 10-mile trips.

4.1.4 Installed options

As can be seen from Fig. 4.4, a very large percentage of all new cars are factory equipped with a series of options. Because these options tend to compound — air conditioners, for example, due to their power demands, tend to be installed in conjunction with larger engine options — it is not possible to isolate the effects of any single option completely. However, because options are important determinants of fuel consumption, the approximate values for energy consumption in Table 4.1 are provided.

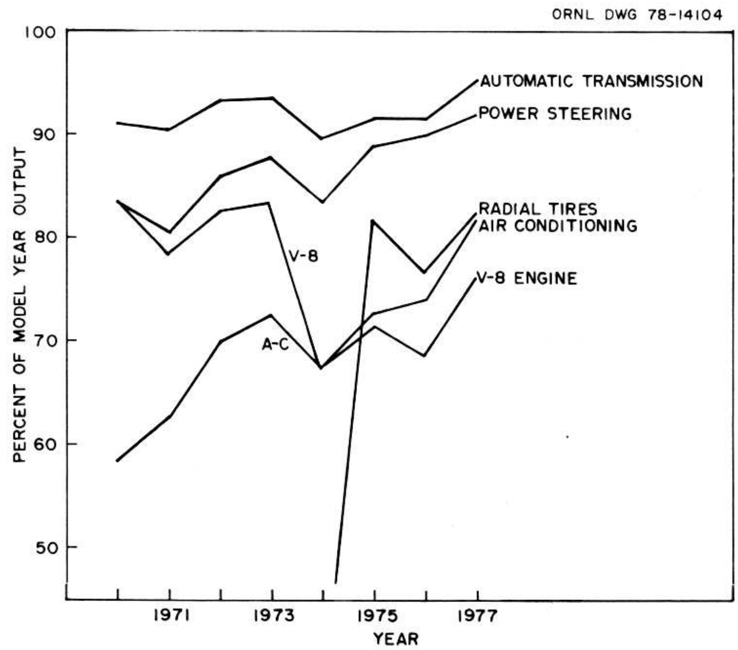


Fig. 4.4. Factory Installations of Popular Options in New Automobiles by Model Year.

The energy use penalty for V-8 engines given in Table 4.1 differs from most values published in the literature. It was calculated by comparing the harmonic mean city-highway fuel economies of 6-cylinder cars with those of 8-cylinder cars for all cars available in both configurations in model year 1976.

Table 4.1. Energy Use Effects of Popular Options

Option	Approximate change in fuel economy
Air conditioning	-13%
Automatic transmission	-14 to 15.5%
Power steering	≥-1%
Radial tires	+2 to 2.5%
V-8 engine	-18.5%

Sources: Society of Automotive Engineers, *Automotive Fuel Economy*, Report PT-15, Warrendale, PA, 1976; T. C. Austin, K. H. Hellman, *Passenger Car Fuel Economy Trends and Influencing Factors*, SAE Paper 730790, 1973, D. R. Blackmore and A. Thomas, eds., *Fuel Economy of the Gasoline Engine*, New York, 1977; U.S. Environmental Protection Agency, *1976 Gas Mileage Guide for New Car Buyers*, Washington, D.C., 1976.

4.1.5 Vehicle maintenance

The National Highway Traffic and Safety Administration conducted a careful study during the calendar years 1975 and 1976, aimed at quantifying the effects of engine maintenance on fuel economy and exhaust emissions. Of interest to this section are the full data sets collected on 322 1968 to 1973-model year cars which underwent engine maintenance. Analysis of the data yielded an average improvement of 4.7% in the on-road fuel economy, with an average maintenance cost of $25.79. Equally interesting is the data presented in Table 4.2, showing the fuel economy improvement broken down by the repair cost. No data on the nature of the performed maintenance are available.

An additional study was performed by the Champion Spark Plug Company beginning in May of 1975. Five thousand six hundred sixty-six cars were run through diagnostic checks, and, of these, 216 were selected for further testing on a dynamometer. The results of these tests are given in Table 4.3.

Table 4.2. Fuel Economy Improvement vs Cost of Maintenance Action[a]

Maintenance cost ($)	Average cost ($)	Fuel consumption (mpg)		Improvement (%)
		Before	After	
0–10	6.84	12.36	13.28	7.5
10–20	14.80	13.02	13.94	6.7
20–40	28.09	12.64	13.39	5.9
>40	47.06	12.41	12.77	2.9

[a]Cars undergoing major engine repairs were excluded from the data.

Source: T. Bayler, L. Eder, *Impact of Diagnostic Inspection on Automotive Fuel Economy and Emissions*, SAE Paper 780028, 1978.

Table 4.3. Percent Fuel Economy Improvement after Maintenance Action

Test condition	Maintenance	
	New plugs only	Tune-up
35 mph cruise	4.92	14.45
55 mph cruise	2.61	9.27
65 mph cruise	3.56	8.86
Cyclic	3.44	11.36

Source: D. L. Walker, J. O. Boord, J. S. Pigitt, E. R. Sutton, *How Passenger Car Maintenance Affects Fuel Economy and Emissions, A Nationwide Survey*, SAE Paper 780032, 1978.

4.2 Development of Circuities

Given the automobile travel data from Appendix A and the circuity data from Appendix B, it is a straightforward task to calculate the passenger-mile–weighted circuity ratio for intercity automobile travel (Tables 4.4 and 4.5). The odd distance categories arise when one converts the round-trip mileage intervals from the NTS to one-way trip lengths and removes the erroneous circuity of 1.56.

Table 4.4. Intercity Automobile Circuities, 1972

One-way trip length (great-circle miles)	Great-circle-passenger-miles (10^6)	Circuity ratio	Route-passenger-miles (10^6)
63.9-127.9	34,520	1.161	40,077
127.9-191.9	26,442	1.218	32,205
191.9-255.9	17,585	1.204	21,173
255.9-319.9	11,580	1.313	15,206
319.9-639.9	30,246	1.231	37,233
Over 639.9	43,815	1.213	53,148
All	164,188	1.212[a]	199,042

[a]Passenger-mile–weighted circuity ratio.

Source: U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Vol. 1: National Travel Survey*, Washington, D.C., Feb. 1974.

Table 4.5. Intercity Automobile Circuities, 1976

One-way trip length (great-circle miles)	Great-circle-passenger-miles (10^6)	Circuity ratio	Route-passenger-miles (10^6)
63.9-95.9	21,170	1.226	25,954
95.9-127.9	27,531	1.111	30,587
127.9-191.9	39,231	1.218	47,783
191.9-319.9	47,111	1.264	59,548
319.9-639.9	52,079	1.231	64,110
Over 639.9	89,194	1.213	108,192
All	276,316	1.217[a]	336,174

[a]Passenger-mile–weighted circuity ratio.

Source: U.S. Travel Data Center, *1976 National Travel Survey*, Full Year Report, Washington, D.C., 1977.

4.3 Operational Data

Because of the large number of vehicles in use and the difficulties inherent in estimating the vehicle-miles traveled, there are at present no fully reliable data available on the overall efficiency of the automobile fleet. The two currently available sources of time series data on automotive fuel economy will be discussed;

- FHWA estimates
- EPA certification tests.

4.3.1 FHWA estimates

The Federal Highway Administration (FHWA) calculates on an annual basis the fleet-average fuel efficiency, using the following equation:

$$\text{Fleet mpg} = \frac{\text{vehicle miles traveled}}{\text{fuel consumption}} .$$

Although the fuel consumption may be ascertained relatively accurately from gasoline tax receipts, the accuracy of the VMT estimates are subject to debate. The FHWA relies entirely on the individual states' estimates of the vehicle miles traveled, which are generated in one of two ways (or a combination thereof) (TERA, 1978):

1. Traffic count: The highway system is monitored with a series of traffic counters yielding traffic-flow values which may then be integrated over time to yield vehicle-miles traveled. Typically states rely on a mixture of continuous monitoring of a few primary routes, statistical sampling, and slowly rotating coverage of all road sections with a cycle time of up to a decade.

2. Fuel consumption: An average mile-per-gallon value is multiplied by the state's fuel sales to yield the state estimate of vehicle miles traveled. The fuel consumption value is generally derived from tax receipts, and the vehicle efficiency is either the value suggested by FHWA,

adjusted by the states according to their judgment, or is generated from state studies.

At present 23 states utilize the traffic-count method, 11 states the fuel consumption method, and 16 states a combination thereof (TERA, 1978).

In view of the potential for error inherent in the methods of calculation and the variety of methods used, the precision of the resulting estimates is questionable. Therefore, the FHWA national figures shown in Table 4.6 should be viewed more as indicators of the midpoints of bands of possible values rather than as precise point values.

Table 4.6. FHWA Estimates of Automotive Fleet Fuel Efficiency, 1970–1976

Year	Passenger car VMT (10^6)	Fuel consumption (10^6 gal)	Fuel efficiency (mpg)	Energy intensity (Btu/VMT)
1970	890.8	65.65	13.57	9140
1971	939.1	69.21	13.57	9140
1972	986.4	73.12	13.49	9270
1973	1016.9	77.62	13.10	9470
1974	990.7	73.77	13.43	9310
1975	1028.1	76.01	13.53	9240
1976	1074.0	78.29	13.72	9110

Source: U.S. Department of Transportation, Federal Highway Administration, *Table VM-1*, 1970–1976.

4.3.2 EPA certification tests

The Environmental Protection Agency (EPA) has performed new-car certification tests on all cars beginning with the 1973 model year. Although the tests were originally designed to measure the emissions of the automobiles, they have yielded a considerable data base on model-specific fuel economy. All EPA fuel efficiency data are derived from three basic driving cycles carried out on a chassis dynamometer with fuel consumption calculated by the carbon-balance method from the emissions collected in bags.

1. 1972 EPA Urban Driving Cycle: The vehicle is run through the 23-min. driving cycle depicted in Fig. 4.5 from a cold start. Emissions are collected in a single bag. Vehicles in the 1972–74 model years were tested under this cycle.

2. 1975 EPA Urban Driving Cycle: The same cycle as in 1972 is used except that the emissions are collected in three bags: (1) the first 8.5 min. of the cycle from a cold start, (2) the remaining 14.5 min. of the cycle, and (3) the first 8.5 min. of the cycle rerun after a 10 min. shutdown. Finally the bags are weighted at 0.43, 1.0, and 0.57, respectively, to yield the fuel economy (Fels, 1977). Typically this test yields an economy 4.5% higher than the 1972 test (Murrel, 1976).

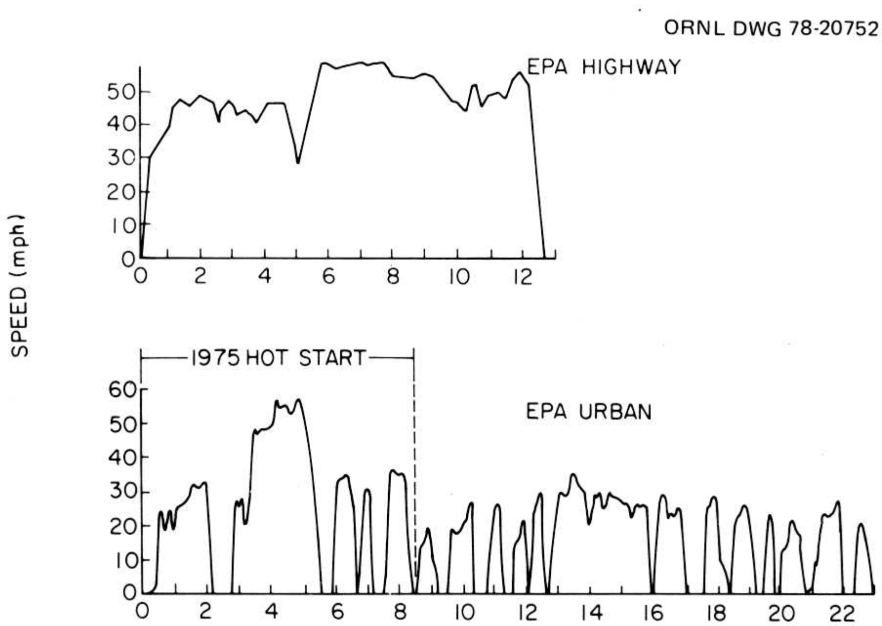


Fig. 4.5. EPA Urban and Highway Driving Cycles. Source: D. B. Shonka et al., *Transportation Energy Conservation Data Book, Edition 2*, Report ORNL 5320, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1977.

3. <u>EPA Highway Driving Cycle</u>: The vehicle is driven over the cycle shown in Fig. 4.5 after having been warmed up over a preconditioning cycle.

Finally, in addition the highway and urban fuel economy results, a composite is calculated from:

$$MPG_{u-h} = \frac{1}{\frac{0.55}{MPG_u} + \frac{0.45}{MPG_h}} \quad .$$

Repeatability of the results from these tests has been estimated to be within 2–9% of the mean. The carbon balance method of calculating fuel economy yield results within 2 to 3% of values obtained by fuel metering (Fels, 1977).

Given the availability of the EPA test results, manufacturers' annual shipments, and motor vehicle registration data, the approach of calculating a fleet fuel economy by combining the sources suggests itself. In practice several difficulties arise which would reduce the results to mere approximations of the true fleet fuel economy in addition to making the calculations involved extremely cumbersome.

A general formulation of the weighted harmonic mean fuel economy for any model year may be written as:

$$\mu_f = \frac{\sum_{i=1}^{n} n_i m_i}{\sum_{i=1}^{n} \frac{n_i m_i r_i}{\mu_{hi}} + \frac{n_i m_i (1 - r_i)}{\mu_{ui}}} ,$$

where

μ_f = new car fleet fuel economy,

μ_h = EPA highway fuel economy in mpg,

μ_u = EPA urban fuel economy in mpg,

h = number of automobiles manufactured as registered,

m = average number of miles driven,

r = fraction of miles driven under rural or highway conditions.

i = index for auto model or auto size/weight class in a less disaggregate approach.

Closer examination of current practices and available data yields the following results for the variables needed in the calculation:

μ_h, μ_u: known but subject to corrections explained on pages to

n_i: available but not used in calculations to avoid time lag. Manufacturers' estimated sales or forecasts are used.

m_i: not known by vehicle type.

r_i: not known by vehicle type.

The methodology on which current available data (see Tables 4.7–4.10) are based may then be summarized as

$$\text{mpg}_f = \frac{\sum_{i=1}^{n} N_i}{\sum_{i=1}^{n} \frac{N_i}{\mu_{u-h}}}$$

where

i = index by model,

mpg_f = annual new car fleet fuel economy,

N_i = manufacturers' sales estimates,

μ_{u-h} = EPA urban-highway combined fuel economy.

Implicit in this equation are several somewhat tenous assumptions which have to be made because of data gaps:

1. All cars, regardless of size and other factors, are driven the same number of miles.
2. The urban-to-highway mileage split of 55-45 applies for all vehicles.
3. The 1969 data on which the 55-45 urban-highway mileage split is based also holds for other years.

Table 4.7. Sales Fractions[a] vs Inertia Weight, 1970–1978

Model year	Inertia weight class									
	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
1970	.0128	.0737	.0344	.0502	.0600	.1261	.2387	.2918	.0915	.0209
1971	.0111	.0882	.0736	.0237	.0548	.1183	.1984	.2657	.1299	.0363
1972	.0116	.0463	.0656	.0680	.0477	.1248	.2033	.2467	.1241	.0617
1973	.0157	.0438	.0572	.0945	.0577	.1181	.1221	.2545	.1682	.0681
1974	.0076	.0493	.0442	.0752	.1279	.0997	.1062	.2314	.1619	.0866
1975	.0095	.0448	.0423	.0180	.1009	.1273	.1566	.1938	.1921	.1146
1976	.0103	.0692	.0383	.0217	.1339	.1368	.1417	.2323	.1404	.0753
1977	.0119	.0761	.0313	.0366	.0776	.0854	.2933	.2837	.0847	.0193
1978	.0234	.0705	.0550	.0326	.0746	.2826	.2119	.1941	.0438	.0115

[a]1970–1973 data are from registration summations. 1974 data are based on production figures. 1975–1978 data are based on manufacturers' sales forecasts.

Source: J. D. Murrell, *Light Duty Automotive Fuel Economy — Trends Through 1978*, SAE Paper 780036.

Table 4.8. City-Highway Sales-Weighted Passenger Car Fuel Economy by Inertia Weight Class, 1970–1978[a]

Model year	Inertia weight class (lb)										Sales-weighted average
	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500	
1970	27.9	27.1	23.3	22.6	19.5	16.2	14.6	13.6	12.8	10.2	15.5
1971	26.4	26.7	25.5	21.6	18.7	15.5	14.5	13.1	11.6	12.5	15.1
1972	26.6	25.7	23.2	23.8	18.8	15.7	14.3	13.1	12.5	11.3	15.0
1973	26.9	26.6	23.0	21.5	17.5	15.0	13.9	13.2	11.6	10.8	14.5
1974	27.7	26.3	23.5	20.8	18.6	16.4	13.4	12.4	11.8	11.1	14.4
1975	31.4	27.9	24.3	22.2	21.4	17.5	15.6	14.6	13.0	12.0	15.6
1976	32.1	28.7	26.0	24.4	23.4	19.1	17.3	15.5	14.6	13.3	17.7
1977	36.1	31.6	28.8	25.2	23.9	20.2	18.0	16.6	14.2	12.7	18.6
1978	35.4	32.4	28.0	24.5	22.4	20.1	18.0	16.3	14.6	12.4	19.6

[a]1970–1973 data are from registration summations, 1974 data are based on production figures, and 1975–78 data are based on manufacturers' sales forecasts.

Source: J. D. Murrel, *Light Duty Automotive Fuel Economy — Trends Through 1978*, SAE Paper 780036.

Table 4.9. Weight Class Distribution for Light-Duty Trucks, 1975–1978

Weight class (lb)	Model Year			
	1975	1976	1977	1978
2750	.1284	.2349	.1554	.1321
3000	.0739	.1319	.1044	.1293
3500	.0274	.0663	.0404	.0599
4000	.2684	.3057	.3247	.3528
4500	.4466	.2332	.3587	.3093
5000	.0552	.0279	.0165	.0166

[a]Data based on manufacturers' sales estimates.

Source: J. D. Murrell, *Light Duty Automotive Fuel Economy — Trends Through 1978*, SAE Paper 780036.

Table 4.10. Sales-Weighted[a] Fuel Economy[b] for Light-Duty Trucks, 1975–1978

Inertia weight (lb)	Fuel economy (mpg)			
	1975	1976	1977	1978
2750	22.3	24.3	25.6	25.9
3000	18.8	20.2	25.5	25.0
3500	20.6	17.7	18.2	18.3
4000	15.6	17.3	19.0	18.3
4500	14.1	14.8	16.7	15.8
5000	11.5	13.1	12.5	18.2
All	15.4	18.0	19.1	18.7

[a]Data based on manufacturers' sales estimates.

[b]EPA urban/highway mpg.

Source: J. D. Murrell, *Light Duty Automotive Fuel Economy — Trends Through 1978*, SAE Paper 780036.

In addition to the aforementioned difficulties in aggregating the EPA data, problems arise out of the EPA estimates themselves. In recent years it has become evident not only that there are serious discrepancies between the EPA certification fuel economies and actual on-the-road fuel economies, but also that the gap between the two was consistently widening. Out of growing concern over these discrepancies, the Department of Energy initiated a study as part of which actual in-use fuel economies were collected for a large number of vehicles and regressed against the EPA values. The results of these regressions are presented in Fig. 4.6 and Table 4.11.

4.4 Estimates of Automobile Operational Energy Intensity

As the preceding section documents in detail, no data are available which would allow accurate computation of the energy intensity of automobiles from operational data. This is particularly true when a segregation by types of automobile use is desired. This section presents automobile energy intensities at the aggregate level derived through a series of approximation techniques.

4.4.1 Intercity automobile travel

Given the operational data presented in the preceding section and the values from Appendices A and B, it is possible to calculate the intercity automobile energy intensity as given in Tables 4.12 and 4.13. However, because of the questionable accuracy of some of the source data, the user should be cautioned that the values in the tables are approximations which may differ substantially from the actual values.

The values presented in Tables 4.10 and 4.11 were calculated based on the sales-weighted EPA urban/highway fuel economy for the given model year. In order to approximate the actual operating conditions more closely, the EPA values were modified as follows:

- The 1976 EPA value was derated by the 2.3 mpg factor given in Table 4.11 for EPA to on-road fuel economy. As no correction factors for 1972 exist that value was left as it was.

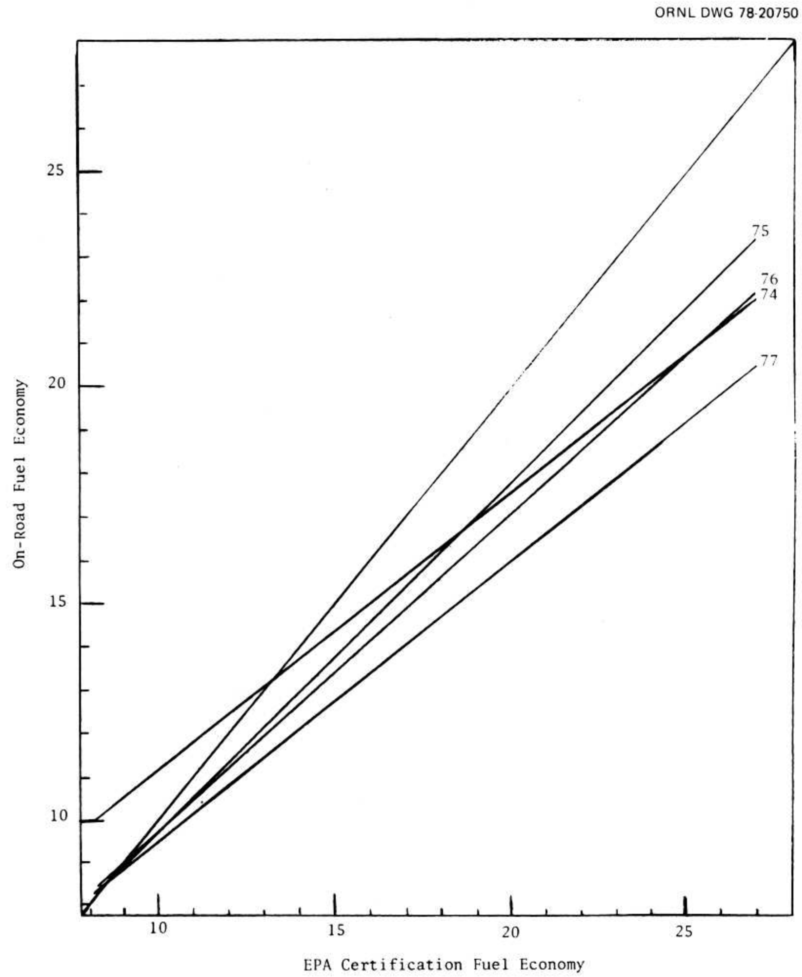


Fig. 4.6. Regression Lines of EPA Certification Fuel Economy vs On-Road Fuel Economy.

Table 4.11. EPA Certification vs Actual On-Road Fuel Economy, Model Years 1974–1977

	1974	1975	1976	1977
Regression equation,				
On-Road mpg (y) to EPA mpg (x)	$y = 0.65x + 4.38$	$y = 0.81x + 1.63$	$y = 0.74x + 2.32$	$y = 0.65x + 2.98$
Mean certification mpg	14.0	15.5	18.6	19.5
Mean on-road mpg	13.4	14.1	16.0	15.7
Difference (x-y) for car with 20-mpg on-road economy	4.0	2.7	3.9	6.2
Difference for car with EPA sales-weighted mpg	0.5	1.3	2.3	3.5

Source: B. D. McNutt, D. Pirkey, R. Dulla, C. Miller, *A Comparison of Fuel Economy Results from EPA Tests and Actual In-Use Experience, 1974–1977 Model Year Cars*, U.S. Department of Energy, Washington, D.C., Feb. 1978.

Table 4.12. Intercity Automobile Energy Intensity for 1972 Model Year Automobiles and Travel Characteristics

One-way trip length[a] (great-circle miles)	Average vehicle[b] occupancy	Energy intensity (Btu/route PM)	Circuity[c] ratio	Great-circle-mile-based energy intensity	
				(Btu/VMT)	(Btu/PM)
63.9-127.9	2.06	3180	1.161	7600	3690
127.9-191.9	2.09	3130	1.218	7970	3810
191.9-255.9	2.09	3130	1.204	7880	3770
255.9-319.9	2.17	3020	1.313	8600	3960
319.9-639.9	2.25	2910	1.231	8070	3590
Over 639.9	2.34	2800	1.213	7960	3400
All	2.19[d]	2990	1.212[e]	7940	3630

[a]These odd categories arise when the round-trip categories from the NTS are converted to one-way mileages and the erroneous circuity of 1.56 is removed.

[b]Occupancy — Person-trips divided by the number of trips, from the NTS data. The resulting occupancy should be considered a lower bound value because the NTS only shows the number of household members in the travel party.

[c]Derived from disaggregate data in Appendix B (see Section 4.2).

[d]This is the passenger-mile—weighted mean occupancy rather than the unweighted value from the NTS.

[e]The passenger-mile—weighted circuity ratio calculated in Section 4.2.

Table 4.13. Intercity Automobile Energy Intensity, 1976

One-way trip length[a] (great-circle miles)	Average vehicle[b] occupancy	Energy intensity (Btu/route PM)	Circuity[c] ratio	Great-circle-mile-based energy intensity	
				(Btu/VMT)	(Btu/PM)
63.9-95.9	2.17	2940	1.226	7820	3610
95.9-127.9	2.08	3070	1.111	7080	3410
127.9-191.9	2.15	2970	1.218	7770	3610
191.9-319.9	2.18	2930	1.264	8070	3700
319.9-639.9	2.32	2750	1.231	7870	3390
Over 639.9	2.43	2630	1.213	7760	3190
All	2.27[d]	2810	1.217[e]	7770	3420

[a]These odd categories arise when the round-trip categories from the NTS are converted to one-way mileages and the erroneous circuity of 1.56 is removed.

[b]Occupancy — Person-trips divided by the number of trips, from the NTS data. The resulting occupancy should be considered a lower bound value because the NTS only shows the number of household members in the travel party.

[c]Derived from disaggregate data in Appendix B (see Section 4.2).

[d]This is the passenger-mile-weighted mean occupancy rather than the unweighted value from the NTS.

[e]The passenger-mile-weighted circuity ratio calculated in Section 4.2.

- The resultant value was multiplied by 1.3 to account for the increased fuel efficicney on longer trips.*
- A 4% fuel economy penalty for each 10% weight increase was assessed to account for the increased vehicle loading by passengers. A weight of 200 lb was assumed for each passenger and luggage. The sales-weighted mean test weight for both years was 3942 lb (Murrel, 1978).

Once these adjustments were made the resultant values were merged with the data from Appendix A and B and the remainder of the values in the tables calculated.

4.4.2 Urban automobile travel

In spite of the multitude of factors influencing automotive fuel consumption in urban traffic, it is possible to model the urban fuel economy on the basis of only a few parameters because of the high degree of correlation among the principle determinants of energy use. Researchers at the General Motors Research Laboratories have shown through simulations and operational tests that the urban automobile energy intensity may be approximated by:

$$EI = k_1 + k_2\bar{t} \quad (1)$$

or

$$EI = C_1W + C_2I\,\bar{t}\ , \quad (2)$$

where

EI = energy intensity in gallons per vehicle-mile,

$\bar{t}$ = average trip time per mile in hours per mile,

W = vehicle weight in pounds,

I = idle fuel flow rate in gallons per hour,

k_1, k_2, C_1, C_2 are operationally determined constants of proportionality.

---

*This corresponds to a ratio of ≈1.5 for intercity to urban fuel efficiency, which is consistent with the literature.

Since, in many cases, values for the constants in the equation are not readily available, it is useful to rewrite the equation in a form which allows calculation of energy intensities for alternative average trip times as a ratio once an initial energy intensity is given.

$$E_b = E_a \frac{v_b(v_a + u)}{v_a(v_b + u)} \quad , \tag{3}$$

where

E_a and E_b are the fuel economies in miles per gallon for two driving cycles,

v_a and v_b are the average speeds over the driving cycles,

u is the ratio of k_1 over k_2 for which an average value of 21.2 mph may be assumed.

Equation 3 may be expected to yield results with rootmean-square errors of less than 10%. However, the user should be aware that the procedure is applicable only for urban driving conditions, and average route speeds of over roughly 35 mph will yield erroneous results (Evans 1976, 1977, 1978). Table 4.14 shows energy intensities calculated by this method using the 1976 EPA sales-weighted urban fuel economy of 15.4 mpg as the base value; Table 4.14 gives the average speeds for various test procedures and city centers.

Table 4.14. Estimated Urban Automobile Energy Intensity

Average speed (mph)	Energy efficiency (mpg)	Energy Intensity (BTU/VMT)
10	10.3	12,150
12	11.6	10,770
14	12.8	9,790
16	13.8	9,050
18	14.7	8,480
20	15.6	8,020
22	16.4	7,650
24	17.0	7,330
26	17.7	7,070
28	18.3	6,840
30	18.8	6,650

Table 4.15 Average Route Speeds for Central Business Districts and Test Procedures

Route	Average speed (mph)
Los Angeles CBD	19.1
Detroit CBD	17.8
Chicago CBD	13.4
New York/Newark CBD	10.2
SAE Urban Cycle	15.6
EPA Urban Cycle	19.5
GM City/Surburban Cycle	23.9

Source: Evans, L., Herman, R., *Automobile Fuel Economy on Fixed Urban Driving Schedules*, Transportation Science, Vol. 12 No. 2, May 1978.

5. BUS PASSENGER TRANSPORTATION

Buses combine the flexibility of the automobile with the efficiencies inherrent in operating larger capacity vehicles. In addition to including the cities despicted in Fig. 5.1 on a regular basis, buses provided intracity and urban transportation services to 4.24 billion passengers in the over 1000 cities having bus transit systems.

Fig. 5.1. Principal Communities in the United States Served by Intercity Buses. Source: American Bus Association, *America's Number 1 Passenger Transportation Service,* Washington, D.C., 1977.

The many different types of buses in service, ranging from vans seating less than 12 to large intercity coaches, and the variety of services provided make analysis at the type, systems level impossible within the scope of this publication. This chapter presents data and analyses on the generic categories of intercity buses, transit buses, and school buses. Together, these three categories accounted for 97% of all bus vehicle-miles traveled in the United States in 1976.

5.1 Intercity Bus

In 1976 over 15,000 (see Fig. 5.1) communities were served by intercity buses, which represent by far the widest coverage for any public intercity transportation mode. Concurrent with this wide availability, intercity buses were by far the most energy efficient mode of intercity passenger transportation. In dealing with intercity bus transportation, analysts and forecasters should bear two factors in mind which have a strong influence on the modal operations.

1. As displayed in Table 5.1, intercity buses predominantly serve a distinct subset of the traveling population.
2. The intercity bus industry itself does not forecast any increases in its activity for the future. Industry spokesmen state that this is due to the "unfair" competitive advantage given to the Amtrak rail network.

Table 5.1. Selected Characteristics of Intercity Travelers by Mode, 1972

	Percent of modal passenger trips falling in category			
	Air	Auto	Bus	Rail
Passengers on personal trips	50	84	88	70
Passenger's income under $10,000	22	41	60	38
Passengers over 55 or under 18	28	43	61	44
Female passengers	36	46	61	47

Source: Department of Commerce, Bureau of the Census, *1972 Census of Transportation*, Vol. I, National Transportation Survey, Washington, D.C., 1974.

5.1.1 Determinants of energy use

A standard technique for gaining insight into the determinants of energy use involves the simulation of vehicle movement through a resistance equation coupled with the specific fuel consumption curve of the engine. The vehicle drag of an intercity bus on a level road can be approximated by (Arrowsmith Corp., 1977):

$$D = W[a + \frac{b}{p} + \frac{cV^2}{p}] + CV^2 \ ,$$

where

D = total vehicle in lb-force

W = weight of vehicle in short tons = 16.5 for a 50% occupied MCI bus

a = rolling coefficient = 10 $\text{lb}\cdot\text{ton}^{-1}$

b = rolling coefficient = 300 $\text{lb}\cdot\text{psi}\cdot\text{ton}^{-1}$

c = rolling coefficient = 0.07 $\text{lb}\cdot\text{psi}\cdot\text{ton}^{-1}\cdot\text{mph}^{-2}$

p = tire pressure = 96 psi

C = aerodynamic drag coefficient = 0.139 $\text{lb}\cdot\text{mph}^{-2}$ corresponding to a frontal area of 73.6 ft^2 with $C_D = 0.7$

V = vehicle velocity in mph

Additional loads are placed on the engine by grades, curves, vehicle auxiliaries and drivetrain friction. For the purpose of this analysis, a level tangent surface, a constant auxiliary load of 7 hp (U.S. Department of Transportation, 1977), and a constant overall efficiency of 85% were assumed. This, when coupled with the fuel consumption data for the Detroit Diesel 8V-71 engine commonly used in intercity buses (Mittal, 1977), yielded the results depicted in Figs. 5.2 and 5.3 for steady cruising conditions.

Parametric variation of the vehicle-weight yields results indicating that a 10% change in vehicle weight will result in a corresponding change in energy use of 2–3% throughout the range of normal operating speeds. This relatively low sensitivity to vehicle weight is readily explained because at normal operating speeds the aerodynamic drag and accessory components of energy use (see Fig. 5.2) are highly dominant. Placed in the context of analyzing and utilizing operational data, this indicates that once the operational energy intensity is known on a vehicle-mile basis, any changes in bus load factors may be ignored with

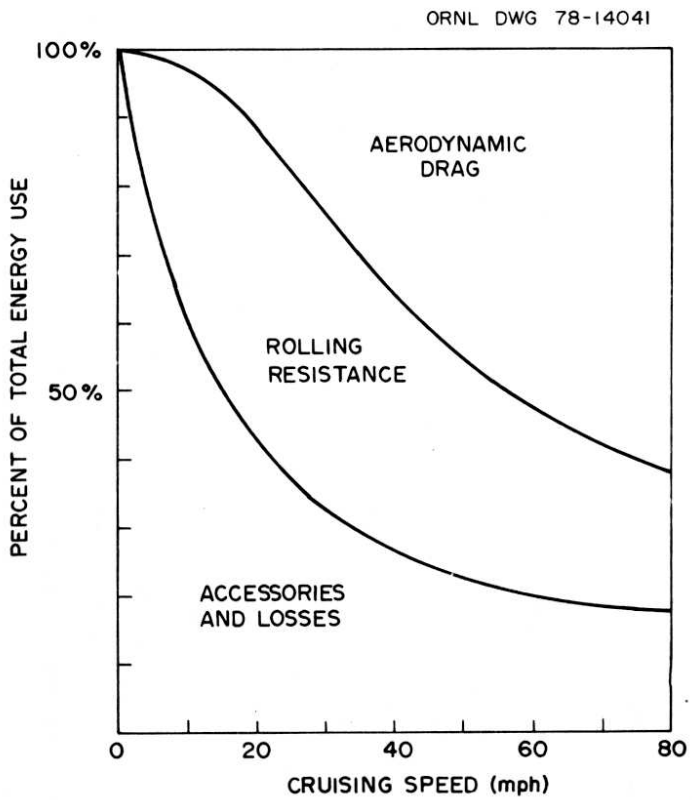


Fig. 5.2. Componential Breakdown of Energy Use for Steady-State Cruise Conditions.

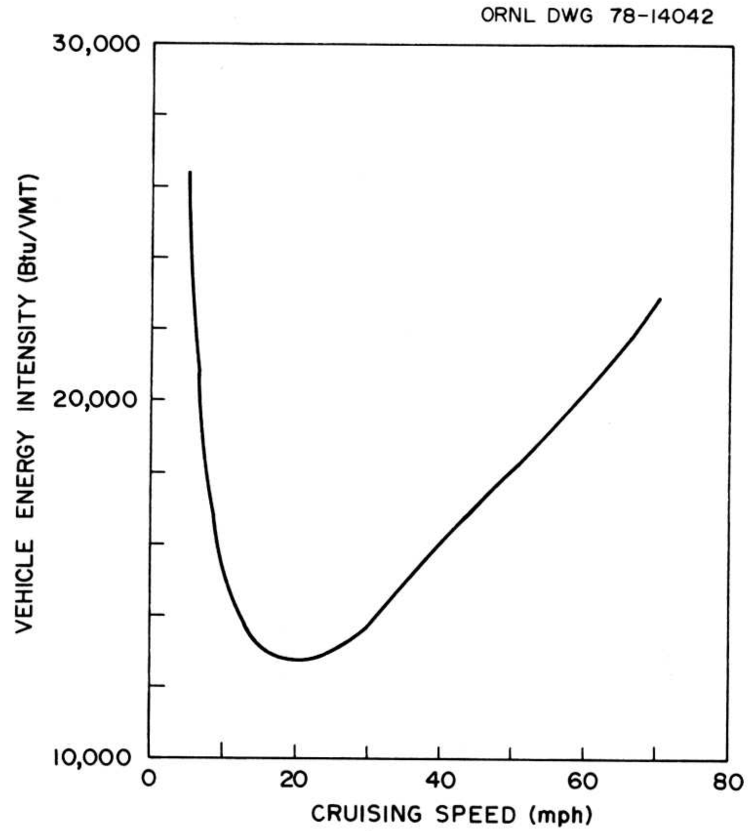


Fig. 5.3. Variation of Energy Intensity with Cruising Speed.

respect to changes in energy use caused by weight increases or decreases. These changes would almost certainly be smaller than the unavoidable reporting errors in the operational data.

In 1973, the U.S. Department of Transportation performed a series of over-the-road tests on buses furnished by intercity operators to determine the effects of operating speeds and terrain on fuel consumption. The highlights of the test results are:

- Over flat terrain, a speed increase from 50 to 60 mph will result in an increase in fuel consumption of ∿9%.
- Over hilly terrain including long hills, there is no significant difference in fuel consumption for route speeds of 50 and 60 mph.
- Over hilly terrain without long hills, there is a decrease in fuel consumption when the route speed is increased from 50 to 60 mph.

A summary of the test results is given in Fig. 5.4.

5.1.2 Development of circuities

A prerequisite for any intermodal comparisons is normalization of the mileage-related data of the various transportation modes on a common basis. This is readily accomplished through the use of circuity ratios which convert the reported route-mile data to great-circle mileages.

For intercity buses the circuity ratios by distance category and finally the passenger-mile–weighted circuity ratios may be calculated through the combination of several data sources. The data presented in Table 5.2 were calculated in the following manner.

One-way trip length — the rather odd great-circle distance categories arise when the round trip distance categories from the *National Travel Survey* (NTS) (see Appendix A) are converted to one-way trip lengths and the undocumented and erroneous circuity ratio of 1.25 is removed.

Number of trips — the total number of trips is available from the American Bus Association, and the values for trip lengths over 80 great-circle miles are given in the NTS.

ORNL DWG 78-14037

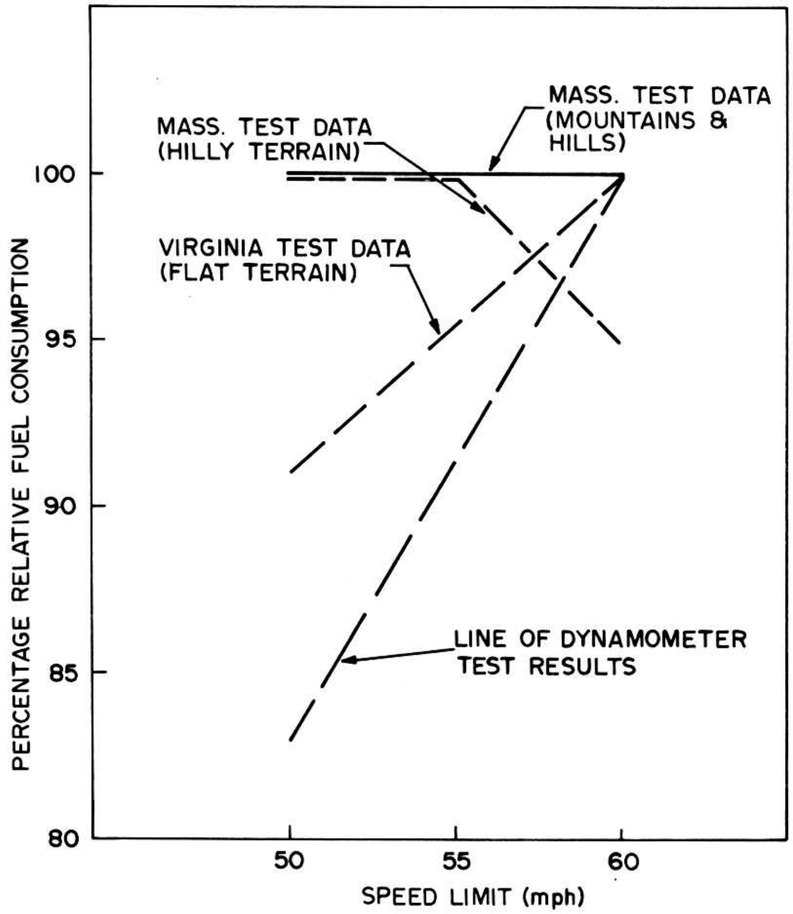


Fig. 5.4. Summary of Over-the-Road Test Results on the Effects of Speed on Intercity Bus Fuel Consumption.

Source: U.S. Department of Transportation, *Effect of Variation of Speed Limits on Intercity Bus Fuel Consumption, Coach and Driver Utilization, and Corporate Profitability*, Boston, November 1975, p. 19.

Great-circle–passenger-miles — for trip lengths over 80 miles are derived from the NTS by removing the circuity ratios of 1.25.

Circuity ratio — the values for the individual distance categories are aggregated from the city-pair values given in Appendix B.

Route-passenger-miles — the total is available from the American Bus Association. Data for the categories over 80 miles are the product of the NTS great-circle miles and the circuity ratios for the categories.

Table 5.2. Average Trip Lengths and Circuities for All Intercity Buses, 1972

One-way trip length (great-circle miles)	Number of trips (10^3)	Great-circle PM (10^6)	Circuity ratio	Route PM (10^6)
0–79	377,020	18,284	1.096	20,039
80–159	7,050	887	1.151	1,021
160–239	3,708	776	1.147	890
240–319	1,492	444	1.199	532
320–399	876	336	1.215	408
400–799	2,078	1,226	1.211	1,485
Over 800	776	1,020	1.201	1,225
Total	393,000	22,973	1.114	25,600

Source: American Bus Association, *America's Number 1 Passenger Transportation Service*, Washington, D.C., 1977; U.S. Department of Commerce, Bureau of the Census, *1977 Census of Transportation, Vol I: National Transportation Survey*, Washington, D.C., 1974.

Given these data, the remaining entries in the table are calculated as follows.

$$[\text{Route PM}]_{0-79} = [\text{Route PM}]_{\text{total}} - [\text{Route PM}]_{280}$$

$$[\text{Great-circle PM}]_{0-79} = [\text{Route PM}]_{0-79}/[\text{Circuity}]_{0-79}$$

$$[\text{Great-circle PM}]_{\text{total}} = \sum_{i=0}^{\infty} [\text{Great-circle PM}]_i$$

$$[\text{Circuity}]_{\text{total}} = [\text{Route PM}]_{\text{total}}/[\text{Great-circle PM}]_{\text{total}}$$

The average bus passenger's trip length increased steadily from 63.1 route-miles in 1970 to 73.8 in 1976. As no other data are available and the 1972 value of 65.1 route-miles lies within this range, the passenger-mile–weighted circuity ratio of 1.114 will be used over the entire time series of data. The reader is cautioned that this value is probably slightly high for 1970 and 1971 and slightly low for years after 1972. However, it is felt that the errors introduced by this are small.

5.1.3 Operational data

Intercity bus operators are categorized by the Interstate Commerce Commission as Class, I, II, or III carriers. Class I carriers are the large carriers such as Greyhound and Trailways with annual operating revenues of $1 million or more;* the other classes are made up of the smaller, more localized companies (Table 5.3). All Class I carriers are covered by extensive reporting requirements by the ICC and these quarterly and annual reports represent the best available source of prime data. Reporting requirements for the smaller carriers are not as extensive, but some data are available from the reports, with additional estimates provided by the American Bus Association. The data gaps for the smaller carriers are not as critical as it may seem initially because Class I carriers tend to dominate the intercity bus transportation market as shown in Table 5.3. Table 5.4 presents the operating statistics and energy intensities for intercity buses, 1970-76.

Table 5.3. Percent of All Intercity Bus Operations Performed by Class I Carriers, 1970–76

	Number of companies	Buses owned	Bus-miles	Revenue passengers	Revenue passenger-miles
1970	7.1	46.2	72.0	43.4	69.5
1971	7.1	45.2	71.2	42.3	69.4
1972	7.4	45.4	71.6	41.7	68.3
1973	7.5	44.7	72.2	40.7	67.8
1974	8.5	47.1	74.1	43.7	68.5
1975	8.5	48.9	75.4	43.4	69.8
1976	8.1	49.8	75.0	42.9	68.8

Source: American Bus Association, *America's Number 1 Passenger Transportation Service*, Washington, D.C., 1977.

*As of Jan 1, 1977, the revenue criterion for Class I carriers was changed to $3 million.

Table 5.4. Operating Statistics and Energy Intensities of Intercity Buses,[a] 1970 through 1976

	Passengers (10^6)	Passenger-miles (10^6)	Vehicle-miles (10^6)	Fuel used[b] (10^6 gal)	Route-miles–based energy intensities		Great-circle miles–based[c] energy intensities	
					Btu/VMT	Btu/PM	Btu/VMT	Btu/PM
1970								
Regular route intercity	309	20,405	1,030					
Other operations	92	4,895	179					
Total	401	25,300	1,209					
1971								
Regular route intercity	305	20,315	1,020					
Other operations	90	5,185	182					
Total	395	25,500	1,202					
1972								
Regular route intercity	304	19,887	988	162.7		1,140		1,260
Other operations	89	5,713	194	32.0		700		870
Total	393	25,600	1,182	194.7	22,850	1,050	25,450	1,180
1973								
Regular route intercity	293	20,523	975	160.6		1,090		1,210
Other operations	88	5,877	203	33.4		790		880
Total	381	26,400	1,178	194.0	22,840	1,020	25,450	1,140
1974								
Regular route intercity	289	21,431	978	157.2		1,020		1,130
Other operations	97	6,269	217	34.9		770		860
Total	386	27,700	1,195	192.1	22,300	960	24,840	1,070
1975								
Regular route intercity	271	18,946	914	146.8		1,070		1,200
Other operations	80	6,454	212	34.1		730		820
Total	351	25,400	1,126	180.9	22,280	990	24,820	1,100
1976								
Regular route intercity	261	18,244	897	146.3		1,110		1,240
Other operations	79	6,856	221	36.0		720		800
Total	340	25,100	1,118	182.3	22,620	1,010	24,190	1,120
1977								
Total	NA	25,700	1,102	181.9	22,890	980	25,500	1,090

NA – Not available.

[a]Includes statistics of Class I, II, III carriers reporting to the ICC and Intrastate Carriers.

[b]All intercity buses are assumed to use diesel fuel. Prior to 1974, fuel consumption was not reported to the ICC and the fuel consumption data for those years are based on estimates from the American Bus Association.

[c]All great-circle-based energy intensity values are derived utilizing the passenger-mile-weighted systems circuity of 1.114 (see page).

Source: American Bus Association, *America's Number 1 Passenger Transportation Service*, Washington, D.C., 1977; supplemented by private communications with the American Bus Association.

5.2 Transit Buses

Transit buses are generally classified into the generic categories of trolley coaches and conventional buses. Trolley coaches are similar to their conventional counterparts except that they are powered by electric motors which draw their power from electric cables suspended overhead and thus offer the advantage of not being directly dependent on petroleum as an energy source. Although many different kinds of conventional buses are in service, the diesel-engine-powered bus seating over 40 passengers is strongly dominant. The importance of bus systems becomes evident when viewed in relation to all mass transit operations (see Table 5.5).

Unfortunately no consistent energy-use information for trolley-coaches is available after 1972. However, because of the relatively small market share of trolley coaches (see Table 5.5), the energy intensity of bus transit systems may be approximated by the value for conventional buses. The error introduced by this approximation is consistently less than 2% for 1970-72 and should decline in proportion to the trolley-coach market share for later years.

The American Public Transit Association (APTA) is the prime source of statistical data for bus systems and annually publishes aggregate data in the *Transit Fact Book* and data on individual systems in the *Transit Operating Report*. In scope, these data are meant to cover all U.S. transit systems, both public and private. Excluded from the statistics are school buses, jitneys, sightseeing buses, and intercity buses.

All APTA data are derived from an annual survey of its members. The individual responses are published in the *Transit Operating Report*. The aggregate estimates are based on the responses of roughly 125 systems, which represent approximately 75% of all mass-transit VMT. Values for the missing systems are estimated on the basis of the number of buses owned and are adjusted for the service area population (Chomitz, 1978). Other, perhaps more important, shortcomings exist in the data. An Urban Mass Transit Administration (UMTA) study reports:

Table 5.5. Bus Transit Statistics Expressed as Percent of All Mass Transit, 1976

	Trolley coach	Conventional bus	Total[a]
Total vehicles	1.1	82.1	83.1
Total VMT	0.8	78.0	78.8
Revenue passenger rides	1.0	73.5	74.4
All passenger rides	1.1	74.1	75.2
Energy use	NA	65.1	NA

NA — Not available.

[a]Values do not add because of independent rounding.

Source: American Public Transit Association, *Transit Fact Book*, 1976–1977 Edition, Washington, D.C., June 1977.

> ...the data's main limitations lie in the basic structure of the reporting elements, a lack of conformity by data suppliers to the (APTA reporting) system with regard to data submissions. In other words, the APTA system does not provide the scope, uniformity, consistency, and accuracy that would be desirable for current and future requirements.*

Project FARE, developed by UMTA in association with APTA, aims at providing a consistent base of information pertaining to mass transit operations. Until this project is fully implemented, the APTA data are the best available (Chomitz, 1978).

On the basis of the available APTA data, one can readily calculate the fuel consumption (mpg) and energy intensity (Btu/VMT) of transit buses (Tables 5.6-5.9).

---

*U.S. Urban Mass Transportation Administration (1977), *Urban Mass Transportation Industry Uniform System of Accounts and Records and Reporting System, Volume I: General Description*, Report No. UMTA-IT-06-0094-77-1.

Table 5.6. Stock of Transit Buses Owned and Leased, 1970–77

Year	Trolley coaches	Conventional buses	Total
1970	1,050	49,700	50,750
1971	1,037	49,150	50,187
1972	1,030	49,075	50,105
1973	794	48,286	49,080
1974	718	48,700	49,418
1975	703	50,811	51,514
1976	685	52,382	53,067
1977	645	51,968	63,287

Source: American Public Transit Association, *Transit Fact Book*, 1977-1978 Edition, Washington, D.C., May 1978.

Table 5.7. VMT, Energy Use, and Energy Intensity of Trolley Coaches, 1970–77

	Vehicle-miles (10^6)	Energy use[a] (10^6 kWhr)	Energy intensity	
			(kWhr/VMT)[a]	(Btu/VMT)[b]
1970	33.0	143	4.33	49,300
1971	30.8	141	4.58	52,100
1972	29.8	133	4.46	50,800
1973	25.7	93	3.62	41,200
1974	17.6	NA	NA	NA
1975	15.3	NA	3.90[c]	44,300[c]
1976	15.3	NA	NA	NA
1977	14.8	NA	NA	NA

NA — Not available.

[a]Does not include generation losses.

[b]Calculated assuming 30% efficiency for electrical generation and distribution.

[c]Calculation based on individual systems data accounting for 17.9% of VMT.

Source: American Public Transit Association, *Transit Fact Book*, 1978 Edition, Washington, D.C., May 1978, American Public Transit Association, *Transit Operating Report for Calendar/Fiscal Year 1975*, Washington, D.C., March 1977.

Table 5.8. VMT, Energy Use, and Energy Intensity of Conventional Transit Buses, 1970–77

	Vehicle-miles (10^6)	Fuel consumption (10^6 gal)			Energy use (10^{12} Btu)	Energy intensity
		Gasoline	Diesel	Propane		(Btu/VMT)
1970	1,409.3	37.2	270.6	31.0	45.17	32,050
1971	1,375.5	29.4	256.8	26.5	41.85	30,420
1972	1,308.0	19.65	253.3	24.4	39.94	30,540
1973	1,370.4	12.33	282.6	15.2	42.21	30,800
1974	1,431.0	7.46	316.4	3.1	45.11	31,520
1975	1,526.0	5.02	365.1	2.6	51.51	33,750
1976[a]	1,581.4	5.20	389.2	1.0	54.72	34,600
1977	1,623.3	8.07	402.8	1.1	56.98	35,100

[a]Preliminary data.

Source: American Public Transit Association, *Transit Fact Book*, 1977–1978 Edition, Washington, D.C., May 1978.

Table 5.9. VMT, Energy Use, and Energy Intensity for All Transit Bus Operations, 1970–76

	Vehicle-miles (10^6)	Energy use (10^{12} Btu)	Energy intensity (Btu/VMT)
1970	1442.3	46.80	32,450
1971	1406.3	43.45	30,900
1972	1337.8	41.45	31,000
1973	1396.1	43.27	31,000
1974	1448.6	*a*	*a*
1975	1542.3	52.19[b]	33,800[b]
1976	1596.7	*a*	*a*
1977[c]	1638.1	*a*	*a*

[a]No energy use data available for trolley-bus operations.

[b]Trolley-bus energy use estimated from data accounting for 17.9% of trolley-bus VMT.

[c]Preliminary data.

Source: American Public Transit Association, *Transit Operating Report for Calendar/Fiscal Year 1976*, *Transit Fact Book*, Washington, D.C., May 1978.

The user should be aware that the values presented in the tables are gross aggregate figures masking all variations from system to system. As summarized in Table 5.10, tremendous variations exist because of varying bus sizes, operating, and environmental conditions. The higher mpg value for gasoline buses in Table 5.10, although perhaps unexpected, is readily explained in that virtually all large buses are diesel powered and gasoline engines are generally installed only in smaller buses.

Table 5.10. Variations in Energy Intensity Among Systems, 1970, 1973, and 1975

	Diesel buses	Gasoline buses	Propane buses
1970			
Systems in sample	60	14	6
High mpg	7.5	8.2	10.6
Low mpg	3.2	2.4	1.3
Mean mpg	4.7	5.4	3.7
1973			
Systems in sample	31	4	3
High mpg	5.5	6.0	3.15
Low mpg	3.1	2.9	2.0
Mean mpg	4.2	4.0	2.4
1975			
Systems in sample	79	18	NA
High mpg	7.5	7.4	NA
Low mpg	2.7	2.3	NA
Mean mpg	4.0	5.5	NA

NA — Not available.

Source: Ram K. Mittal, *Energy Intensity of Various Transportation Modes*, Draft September 1977; American Public Transit Association, *Transit Operating Report for Calendar/Fiscal Year 1975*, Washington, D.C., March 1977.

As no bus transit systems regularly report data related to passenger-miles or load factors, it is virtually impossible to derive accurate values for energy consumption per passenger-mile for the period. A single estimate of total passenger-miles for 1971 is available from the 1974 National Transportation Report (U.S. Department of the Interior, 1970; U.S. Department of Transportation, 1976). As the VMT and passenger-trip data from this study are in close agreement with APTA data, it is reasonable to combine the $16,858 \times 10^6$ passenger-mile total with the APTA energy use value, yielding

Bus transit EI for 1971 = 2570 Btu/PM* .

An alternative approach yielding a reasonable range of Btu/PM estimates can be constructed through the use of the passenger-trip data reported by APTA (Table 5.11). A parametric analysis of Btu/PM versus average trip length per passenger-trip yields the series of curves in Fig. 5.5. These curves may then be entered in the vicinity of the 1971 value of 4.38 (U.S. Department of Transportation, 1976) average miles per revenue trip to yield reasonable estimates for other years.

In the interest of clarity, not all possible curves for the time series of data are presented. However, the interested reader may easily generate the missing curves from the data in this section through the following approximation technique:

$$EI = \frac{E}{PASS \cdot TL} ,$$

where

EI = energy intensity in Btu per passenger-mile,
E = total energy use for the year from Tables 5.6–5.9,
PASS = number of passenger-trips for the year from Table 5.11,
TL = the assumed trip length in miles.

*Due to the dominance of conventional buses, the value for trolley-coaches may differ significantly from this average.

Table 5.11. Passenger-Trips on Bus Transit Systems, 1970–1976

Year	Revenue passenger-trips (10^6)			Revenue as percent of total trips		
	Trolley coach	Conventional bus	Total	Trolley coach	Conventional bus	Total
1970	127.5	4058.3	4185.8	70.1	80.6	80.2
1971	113.1	3734.8	3847.9	76.4	81.9	79.4
1972	99.5	3560.8	3634.4	76.5	79.2	78.6
1973	73.6	3652.8	3726.4	75.9	78.7	78.6
1974	59.5	3997.6	4057.1	71.7	80.3	80.2
1975	56.0	4094.9	4150.9	71.8	80.5	80.4
1976	53.9	4168.0	4221.9	71.9	79.4	79.3
1977[a]	51.3	4246.5	5722.7	NA	NA	NA

NA — Not available.

[a]Preliminary.

Source: American Public Transit Association, *Transit Fact Book*, 1976–1977 Edition, Washington, D.C., June 1977.

ORNL DWG 78-14040

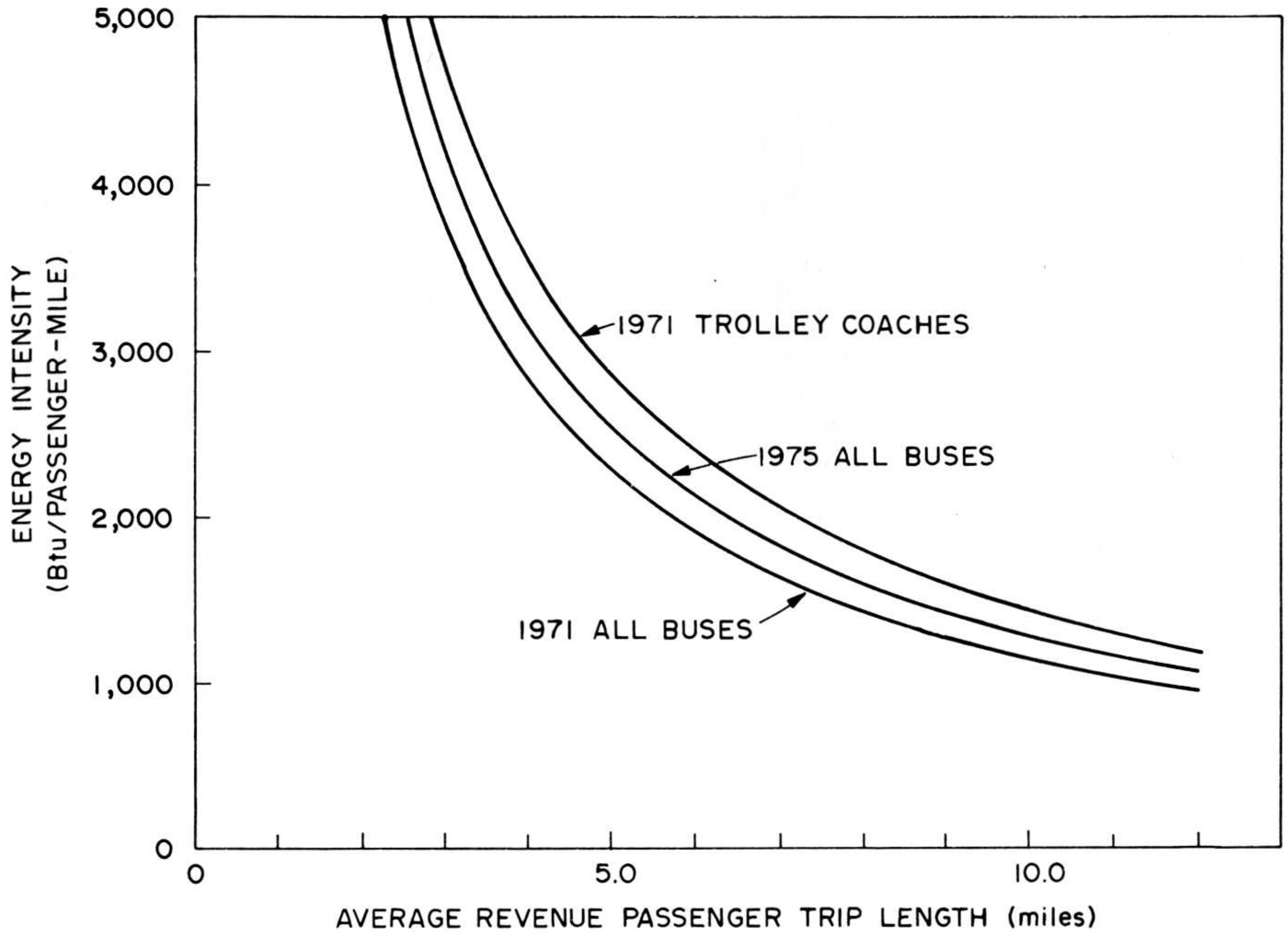


Fig. 5.5. Variation of Bus Transit Energy Intensity with Passenger Trip Length.

Table 5.12. School Bus Operational Data, 1970 through 1976

	1970	1971	1972	1973	1974	1975	1976[a]
Registered buses, 10^3	288.7	307.3	318.2	336.0	356.9	368.3	381.5
Vehicle-miles traveled on, 10^6							
Urban streets	414	429	475	497	520	550	874
Main rural roads	784	825	880	920	920	930	1,349
Local rural roads	902	958	1,004	995	1,010	1,020	639
Total	2,100	2,212	2,359	2,412	2,450	2,500	2,862
Fuel consumed, 10^6 gal	300	316	320	327	333	342	389.9
Average mpg	7.00	7.00	7.37	7.37	7.36	7.31	7.34
Average Btu/VMT	17,710	17,710	16,820	16,820	16,850	16,960	16,890

[a] Highway categories are based on functional classification in accordance with 23 U.S.G. 103 (B) (2), (C) (2), (d) (2) established for 1976 and differ from earlier years. Compared to the earlier procedure, main rural travel is 8% higher, local rural travel is 36% lower, and urban travel is 1% higher.

Source: U.S. Department of Transportation, Federal Highway Administration, *Table VM-1*, 1970 and 1976.

5.4. Summary Graphs and Charts

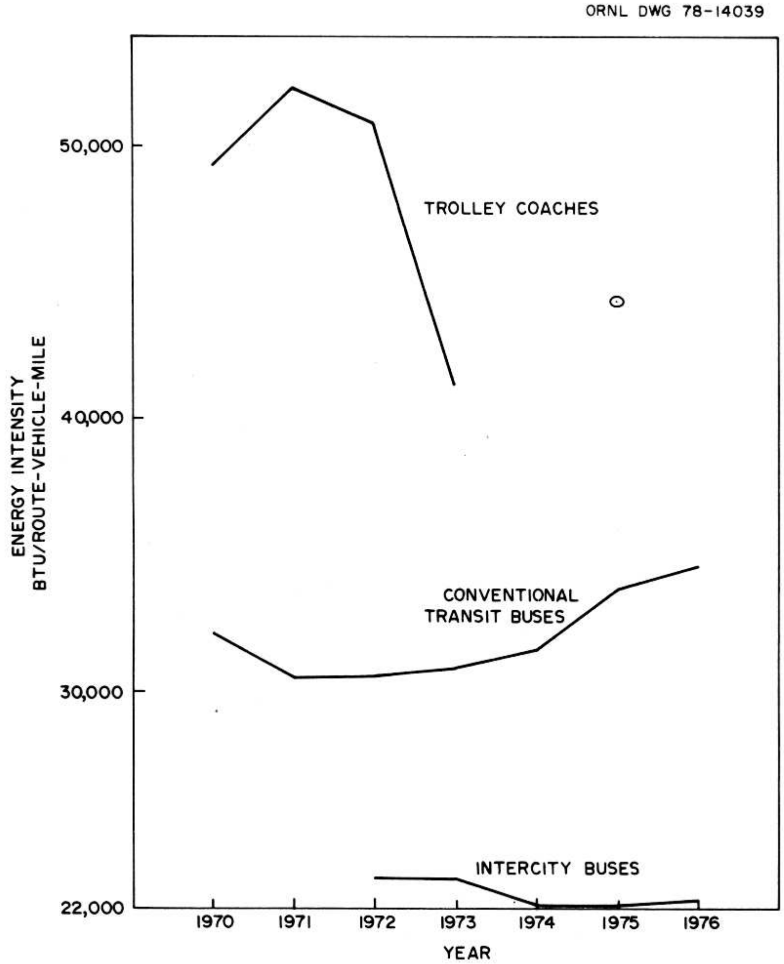


Fig. 5.6. Variation of Bus Energy Intensity 1970–76 in Btu per Vehicle-Mile.

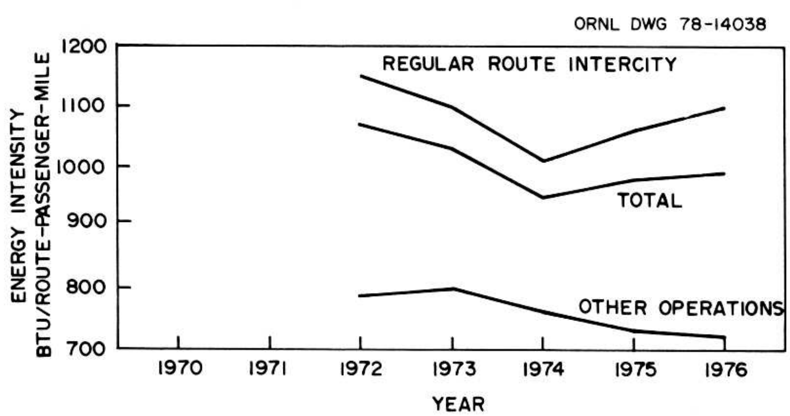


Fig. 5.7. Variation of Intercity Bus Energy Intensity 1970–1976 in Btu per Passenger-Mile.

ORNL DWG 78-20754

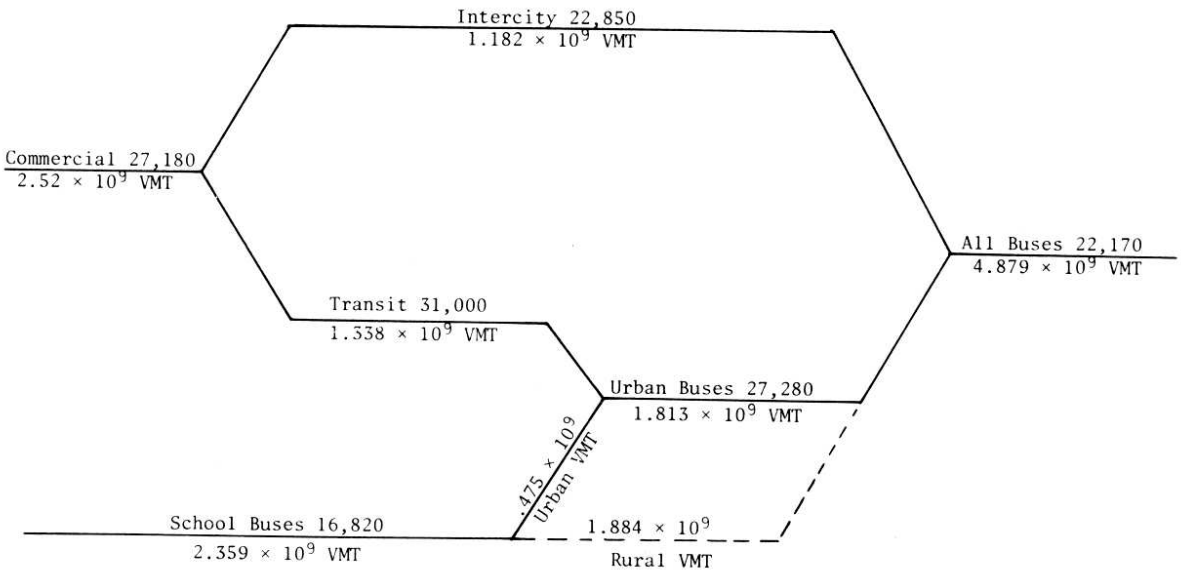


Fig. 5.8. Bus Energy Intensity and VMT Summary, 1972
(Btu per route vehicle-mile)

ORNL DWG 78-20755

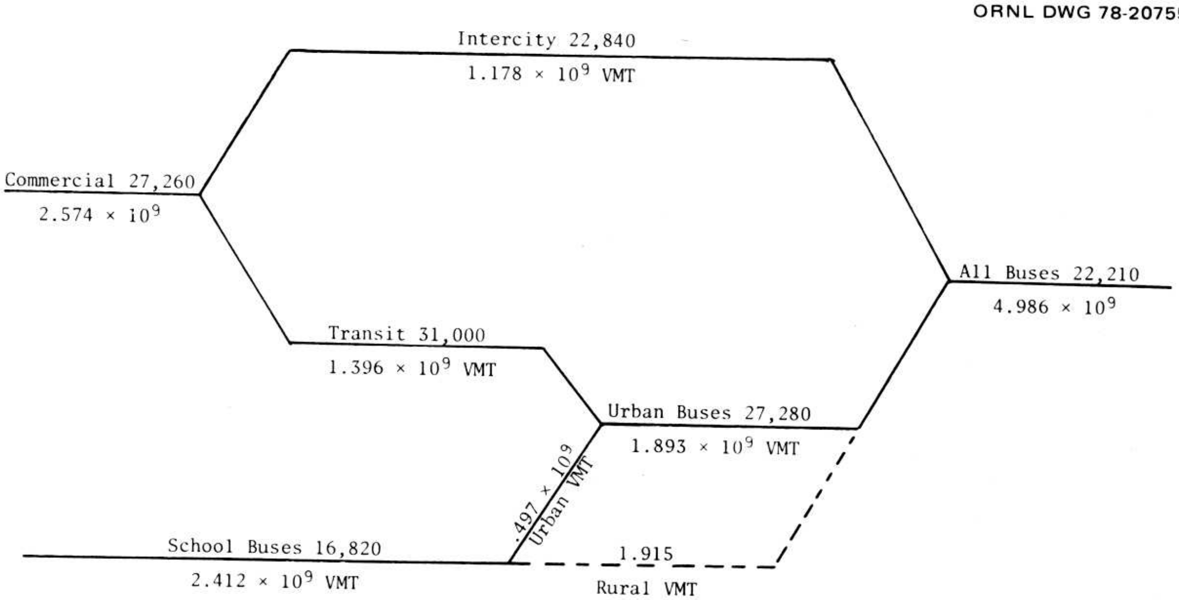


Fig. 5.9. Bus Energy Intensity and VMT Summary, 1973
(Btu per route vehicle-mile)

ORNL DWG 78-21609

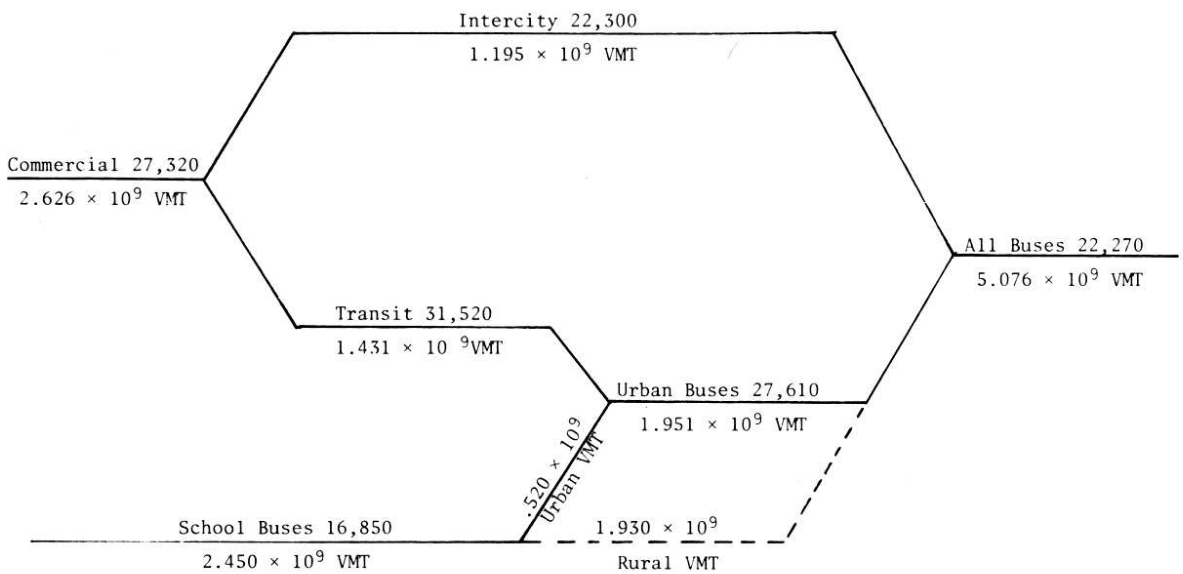


Fig. 5.10. Bus Energy Intensity and VMT Summary, 1974
(Btu per route vehicle-mile)

ORNL DWG 78-21610

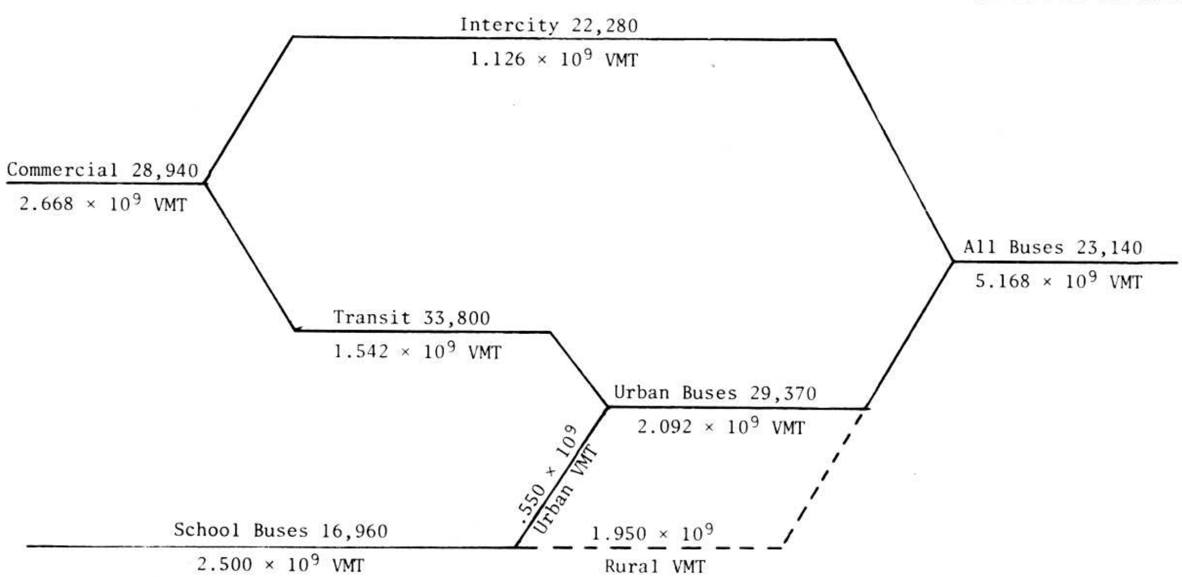


Fig. 5.11. Bus Energy Intensity and VMT Summary, 1975
(Btu per route vehicle-mile)

ORNL DWG 78-20753

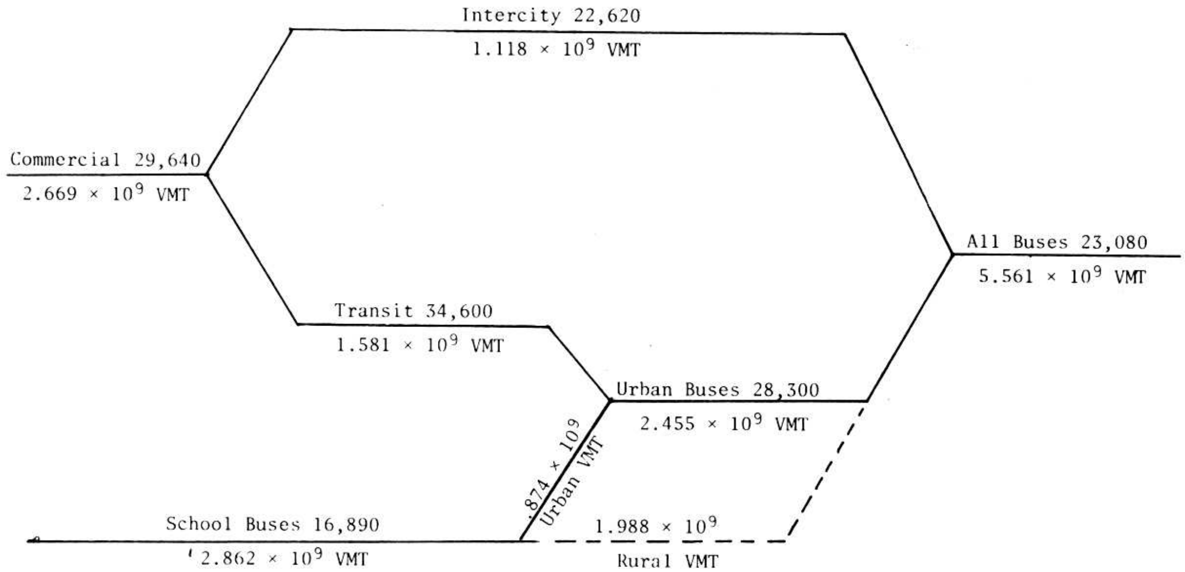


Fig. 5.12. Bus Energy Intensity and VMT Summary, 1976
(Btu per route vehicle-mile)

6. RAIL PASSENGER TRANSPORTATION

Rail systems enjoy several advantages in relation to other passenger transportation modes. The most notable of these are:

1. The rolling resistance per unit weight carried is considerably lower for steel wheels on steel than for the corresponding materials in alternative modes.
2. The large diesel engines and electrical propulsion systems used for rail are more efficient than the prime movers used in other modes.
3. The exclusive right-of-way utilized by most rail systems makes possible assembly of very large consists and further exploitation of available economics of scale.

These advantages enable one to formulate readily possible rail consists which are more efficient from a line-haul, energy use per seat-mile standpoint than any other means of transportation. However, the actual operational values for the years under analysis are close to an order of magnitude higher than the theoretically attainable values because of a combination of the following factors.

1. Current intercity rail consists contain a substantial portion of low-density cars (parlor, observation, etc.) which are not included in the theoretical high-efficiency consists.
2. The demand for intercity passenger rail transportation is sufficiently low that not even the low-density consists are operating at high load factors.
3. Poor track conditions necessitate slow orders in many instances, which in turn lead to highly energy-intensive acceleration periods when normal cruising speeds are resumed.
4. Urban rail systems are faced with a highly peaked and directional demand profile which causes low overall systems load factors.

This chapter presents data on intercity, commuter, and rail transit systems.

6.1 Intercity Rail

In most countries around the world, rail is, and will most likely remain, one of the mainstays of the intercity passenger transportation systems. Primarily because of the flexibility of the private automobile and its widespread use, the intercity rail system in the United States has experienced sharp declines in popularity over recent years (Table 6.1).

Table 6.1. Historical Trends of Intercity Rail Service, 1929-1977[a]

Year	Passengers-miles (10^6)
1929	24,180
1939	18,645
1944	90,231
1947	39,921
1955	23,747
1965	13,260
1970	6,179
1972	4,332
1974	5,799
1976	5,808
1977	5,710

[a]For the purpose of this table, intercity passenger-miles comprise all passenger-miles not on multiple-ride tickets. This definition is not consistent with the definition used in the remainder of the chapter. However, it is the only definition for which the historical time series is available.

Source: Association of American Railroads, *Yearbook of Railroad Facts, 1978 Edition*, Washington, D.C., 1978.

The declining demand for intercity passenger service has caused maintaining such service to become associated with ever-increasing losses for the railroads. Finally, in 1971 the National Railroad Passenger Corporation (Amtrak) was created by the government to maintain passenger rail service. Since then Amtrack has assumed virtually all intercity passenger service, while operating under heavy government subsidies.

6.1.1 Determinants of energy use

Through the use of sophisticated computer models commonly known as Train Performance Calculators, a great deal of insight may be gained into the determinants of energy use for passenger rail systems. These models simulate the movement of a train over the actual track conditions (grades, curvatures, and speed limits), taking into account a large number of the actual design characteristics of the train consist such as weight, aerodynamic drag coefficient, tractive effort available, transmission efficiency, and brake specific fuel consumption curves. Such a Train Performance Calculator, written by the author while working at Union College with R. K. Mittal, was exercised extensively to yield most of the results presented in this section.

The data presented in Table 6.2 were derived from a series of runs simulated from New York to Albany following the actual operating speed limits in 1977. Table 6.3 presents similar results derived from high-speed* runs from New York to Washington for several electric train consists.

One of the primary determinants of the possible energy efficiency that an intercity train can achieve is its consist, i.e., the numbers and types of cars in the train. It takes roughly the same amount of energy to pull a sleeper car carrying 20 passengers as it does to pull a high-density coach car carrying 84 passengers. Yet, on a per-passenger-mile basis, the coach car will be about 4 times as efficient. Many of the long-distance rail consists have low energy efficiencies because of the baggage, diner, lounge, etc., cars included in them, which in essence have a carrying capacity of close to 0 yet are essential if the quality of service needed to attract riders is to be maintained. Table 6.4

---

*Speed limits were set at 120 mph maximum. These conditions reflect the anticipated track conditions once the Northeast Corridor is repaired and may be considered characteristic of high-speed rail operations. (The data presented are for comparison purposes only, as pure diesel-electric equipment cannot run into Grand Central Station. Actual runs employ hybrid locomotives equipped for third-rail electric pickup below Harmon.)

Table 6.2. Percent Components of Energy Use for Several Train Consists, New York to Albany, 1977[a]

Source of loss	E8[b] locomotive-hauled consist	P30CH[c] locomotive-hauled consist	Rohr[d] Turboliner	LRC[e]
	Consist type			
Engine thermal losses	70.3	66.3	88.9	70.0
Auxiliaries (train heating etc.)	6.0	6.2	2.5	7.3
Transmission losses	4.5	4.5	1.6	4.2
Track resistance (grade curves)	1.9	2.2	0.7	1.9
Rolling resistance	6.5	7.2	2.3	6.6
Aerodynamic drag	5.5	6.3	1.8	3.6
Kinetic losses	6.1	7.3	2.2	6.4
Total	100.0	100.0	100.0	100.0

[a]These consists are for comparison purposes only; actual operation requires hybrid locomotives equipped for third-rail electric pickup.

[b]An E8 is a locomotive type characteristic of designs in the late 1950s.

[c]A new locomotive only recently coming into service.

[d]A gas-turbine-powered train of French design. The use of turbine power accounts for the high thermal loss percentage.

[e]Light, Rapid, Comfortable: a new, Canadian high-speed rail consist.

Source: R. K. Mittal, *Energy Intensity of Intercity Passenger Rail*, Washington, D.C., Dec. 1977, p. 7-3.

presents energy intensity values derived from the Train Performance Calculator for several hypothetical train consists on a single route. The additional data presented in Table 6.5, based on a less sophisticated modeling approach used by the Stanford Research Institute in a recent study, provides information on further rail consists.

6.1.2 Development of circuities

The values presented in Table 6.6 are the result of an iterative process, based on the combination of several data sources, aimed at deriving the passenger-mile–weighted system circuity of 1.256. The methodology is most easily explained in terms of the column headings and the available data.

Table 6.3. Percent Components of Energy Use for Several Electric Train Consists, New York to Washington, 1977

Source of loss	Consist type			
	Standard Metroliner	EGOCP[a] locomotive-drawn consist	CC15000[b] locomotive-drawn consist	RC4a[c] locomotive-drawn consist
Thermal losses[d]	63.5	64.3	64.3	64.3
Auxiliaries (heating, etc.)	4.1	3.3	3.5	4.0
Transmission losses[e]	4.8	6.4	4.8	4.8
Track resistance (grades curves)	0.8	0.9	0.9	0.8
Rolling resistance	6.1	4.7	4.7	4.9
Aerodynamic drag	7.4	6.4	6.5	7.2
Kinetic losses	13.2	14.0	15.3	14.1
Total	100.0	100.0	100.0	100.0

[a]A domestic electric locomotive of recent design.

[b]A French high-speed electric locomotive.

[c]A Swedish high-speed electric locomotive.

[d]Includes electric generation and transmission losses.

[e]For electric locomotives this may be considered 1 locomotive efficiency.

Source: R. K. Mittal, *Energy Intensity of Intercity Passenger Rail*, Washington, D.C., Dec. 1977, p. 7-4.

One-way trip length — the round trip length taken from the *National Travel Survey, 1972* divided by two, with the erroneous circuity of 1.25 removed. (See Appendix A for all NTS source data.)

Number of trips — the number of trips in the mileage categories above 80 great-circle miles (gcm) are directly available from the NTS. The total number of trips is available from the reports filed with the ICC.

Great-circle—passenger-miles — the values for trip lengths over 80 gcm are available from the NTS 72, when the circuity is removed.

Circuity ratio — the values for the individual mileage categories are aggregated from the data given in Appendix B.

Table 6.4. Variations in Energy Intensity for Various Train Consists, New York to Albany[a], 1977

Type of locomotive	EI values under		Average speed (mph)	Train configuration[a]	No. of passengers	Remarks
	50% load factor	100% load factor				
E8	1,627	820	49.66	1-3-1-0	121	Hauling refurbished cars
E8		820	49.34	1-3-1-0	242	
E8	1,430		49.33	2-8-2-1	306	
E8		723	49.27	2-8-2-1	612	
E8	1,555		49.96	3-8-2-1	306	
E8		786	49.93	3-8-2-1	612	
P30CH	1,151		50.49	1-3-1-0	156	Amfleet cars
P30CH		582	50.46	1-3-1-0	312	
SDP40F	1,100		50.90	1-3-1-0	156	Amfleet cars
SDP40F		555	50.50	1-3-1-0	312	
SDP40F	911		50.25	2-8-2-1	421	
SDP40F		462	48.92	2-8-2-1	842	Amfleet cars
SDP40F	1,035		50.44	3-8-2-1	421	
SDP40F		524	50.42	3-8-2-1	842	
LRC	1,041		50.48	1-3-1-0	152	LRC-car consists
LRC		528	50.43	1-3-1-0	304	

[a]These consists are for comparison purposes only; actual operation requires hybrid locomotives equipped for third-rail electric pickup.

[b]The figures indicate, in order, the numbers of locomotives, the number of coach cars, the number of snack cars, and the number of parlor cars in the consist.

Source: R. K. Mittal, *Energy Intensity of Intercity Passenger Rail*, Washington, D.C., Dec. 1977, pp. G-3, G-4.

Route–passenger-miles – for the mileage categories over 80 gcm are calculated as the product of the great-circle–passenger-miles and the circuity ratios for the distance category. The total intercity-route passenger-miles are available from the Associatio of American Railroads.

Given these data the remaining entries in the table are calculated as follows:

$$[\text{Route PM}]_{0\text{-}79} = [\text{Route PM}]_{\text{total}} - [\text{Route PM}]_{>80}$$

$$[\text{Great-Circle PM}]_{0\text{-}79} = [\text{Route PM}]_{0\text{-}79}/[\text{Circuity}]_{0\text{-}79}$$

Table 6.5. Variations in Energy Intensity for Additional Amtrak Consists

Consist type	Maximum number of seats	Energy efficiency at 54% load factor (Btu/PM)
Old equipment, long distance service		
8 coaches	400	
2 sleepers	44	
1 bedroom car	12	
2 baggage cars	0	
1 diner	0	
1 lounge car	0	
3 E8 locomotives	0	
Total	456	2,500
New equipment, long-distance service		
6 bilevel coaches	516	
1 bilevel coach (high density)	104	
3 sleepers	66	
2 baggage cars	0	
1 diner	0	
2 SDP40 locomotives	0	
Total	686	1,500
New equipment, short-distance service		
5 Amcoaches	420	
1 Amcafe	60	
1 SDP40 locomotive	0	
Total	480	1,100

Source: Stanford Research Institute, *Energy Study of Rail Passenger Transportation*, Volume 2, Oakland, Calif., Aug. 1977.

Table 6.6. Amtrak Intercity Rail Circuities, 1972

One-way trip length (great-circle miles)	Number of trips (10^3)	Great-circle—passenger-miles (10^6)	Circuity ratio	Route—passenger-miles (10^6)
0—79	14,900	656	1.119	734
80—159	628	154	1.223	188
160—239	369	150	1.351	202
239—319	98	57	1.557	88
320—399	46	37	1.566	57
400—799	274	378	1.486	561
Over 800	329	860	1.405	1,208
Total	16,644	2,292	1.325	3,028

Source: Association of American Railroads, *Yearbook of Railroad Facts, 1978 Edition*, Washington, D.C., 1978; NTS 72 data appear in Appendix A for exact reference.

$$[\text{Great-Circle PM}]_{total} = \sum_{i=0}^{\infty} [\text{Great-Circle PM}]_i$$

$$[\text{Circuity}]_{total} = [\text{Route PM}]_{total}/[\text{Great-Circle PM}]_{total}$$

Unfortunately the average trip length of 182.5 route miles for 1972 shown in the table is not characteristic of years after 1972, when trips average slightly over 220 route miles. Therefore, the passenger-miles-weighted circuity for 1972 is not directly applicable to other years. However, as it is impossible to perform the necessary calculations for other years, the value of 1.325 may be used, but the results in that case should be interpreted as lower-bound rather than actual values. The actual circuity values for other years of operation are probably significantly higher.

6.1.3 Operational data

Virtually all intercity passenger rail operations are carried out by Amtrak. A number of commuters also ride the Amtrak system; however, it is felt that they are a fringe benefit of the intercity system and should not be subtracted out. Table 6.7 presents operating statistics and energy efficiencies for the Amtrak Intercity System.

6.2 Rail Transit Operations

Commonly rail transit systems are broken into the categories of heavy and light systems. A heavy rail system employs a "subway" type of transit vehicle operating over an exclusive right-of-way with high-level platform stations. Light rail systems are what are commonly referred to as streetcars, operating on city streets of semiprivate or exclusive private rights-of-way. As of 1976 there were 10 heavy and 9 light rail transit systems operating in the U.S. Table 6.8 shows the total stock of rail transit cars.

The American Public Transit Association is the standard source of prime data, publishing annual aggregates in the *Transit Fact Book* and individual systems data in the *Transit Operating Report*. Data from this

Table 6.7. Operating Statistics and Energy Efficiencies of the Amtrak Intercity Rail System, 1972–77

Equipment	Year					
	1972	1973	1974	1975	1976	1977
Rail motor cars						
VMT (10^6)	11.77	12.55	13.67	15.53	16.35	18.79
Energy use (10^{12} Btu)	1.39	1.11	1.17	2.00	2.36	2.92
Energy intensity (Btu/VMT)	117,900	89,000	85,600	128,800	144,100	155,300
Locomotive hauled trains:						
Passenger car miles (10^6)	200.6	226.0	245.9	237.6	246.5	242.1
Energy use (10^{12} Btu)	11.09	12.55	11.82	10.80	11.38	11.41
Energy intensity (Btu/VMT)	55,280	55,520	48,050	45,460	46,250	47110
Total passenger miles (10^9)	3.039	3.807	4.259	3.753	4.268	4.204
Percent commutation			3.7	3.7	3.1	3.0
Route-mile–based energy intensity						
Btu/VMT	58,760	57,270	50,020	50,570	52,270	54,900
Btu/PM	4,110	3,590	3,050	3,410	3,230	3,410
Lower-bound great-circle mile–based energy intensity[a]						
Btu/VMT	77,860	75,880	66,280	67,010	69,260	72,740
Btu/PM	5,450	4,760	4,040	4,520	4,280	4,520

[a]Because the average trip length for years after 1972 is greater than that for 1972, the year for which the circuity of 1.35 was calculated, these figures must be considered lower bounds.

Source: National Railroad Passenger Corporation, *Annual Report to the Interstate Commerce Commission*, Washington, D.C., 1972–77, Supplemented by personal communications with the National Railroad Passenger Corporation.

Table 6.8. Stock of Rail Transit Cars Owned and Leased, 1970–77

Year	Cars		
	Light rail	Heavy rail	Total
1970	1,262	9,338	10,600
1971	1,225	9,325	10,550
1972	1,176	9,423	10,599
1973	1,123	9,387	10,510
1974	1,068	9,403	10,471
1975	1,061	9,608	10,712[a]
1976	963	9,714	10,720[a]
1977[b]	992	9,639	10,674[a]

[a]Includes 45 PRT vehicles, 39 cable cars and 4 inclined plane cars.

[b]Preliminary data.

Source: American Public Transit Association, *Transit Fact Book, 1977-1978 Edition,* Washington, D.C., May 1978.

source are compiled for heavy rail systems in Table 6.9 and for light rail systems in Table 6.10. In addition to the general shortcomings of the data outlined in the quotation from Urban Mass Transportation Administration on page 5.11, other problems with the data become apparent on closer examination. The primary problem lies in differing interpretations on the part of the reporting systems of the "electricity used to operate vehicles." Some systems report total energy use including station heating and lighting, but others report traction energy use only. The average difference between total and traction energy use in 1975 was over 23%. Additional problems arise out of systems' inability to separate energy used in heavy and light rail operations accurately (Chomitz, 1978).

Table 6.9. VMT, Energy Use, and Energy Intensity of Heavy Rail Transit Systems, 1970–77

Year	Vehicle miles (10^6)	Energy use (10^6 kWhr)	Energy intensity	
			kWhr/VMT[a]	Btu/VMT[b]
1970	407.1	2,261	5.55	63,170
1971	407.4	2,262	5.55	63,150
1972	386.2	2,149	5.56	63,290
1973	407.3	2,098	5.15	58,580
1974	431.9	NA	NA	NA
1975	423.1	2,352	5.56	63,290
1976	407.0	NA	NA	NA
1977[c]	361.3	NA	NA	NA

NA — Not available.

[a]Electricity in kWhr, not including generation losses.

[b]Calculated assuming 30% efficiency for electrical generation and distribution.

[c]Preliminary data.

Source: American Public Transit Association, *Transit Fact Book, 1976–1978 Edition*, Washington, D.C., May 1978; K. Chomitz, C. Lave, *A Survey and Analysis of Energy Intensity Estimates for Urban Transportation Modes*, Irvine, Calif., 1978.

An additional problem, unique to the heavy rail aggregate energy intensity value, is the dominance of the New York Subway system. In 1975 this system accounted for over 71% of all heavy rail VMT and a corresponding percentage of energy use. Therefore, the user of aggregate heavy rail EI values should be cautious because they tend to represent the performance of the New York Subways, rather than heavy rail systems in general. In 1975, for example, traction energy requirements varied from 4.66 to 8.12 kWhr/VMT for individual systems, with a weighted mean

Table 6.10. VMT, Energy Use, and Energy Intensity of Light Rail Transit Systems, 1970–77

Year	Vehicle miles (10^6)	Energy use (10^6 kWhr)	Energy intensity	
			kWhr/VMT[a]	Btu/VMT[b]
1970	33.7	157	4.659	52,990
1971	32.7	153	4.679	53,210
1972	31.6	146	4.620	52,550
1973	31.2	140	4.487	51,030
1974	26.9	NA	NA	NA
1975	23.8	NA	NA	NA
1976	21.1	NA	NA	NA
1977[c]	20.4	NA	NA	NA

NA — Not available.

[a]Electricity in kWhr, not including generation losses.

[b]Calculated assuming 30% efficiency for electrical generation and distribution.

[c]Preliminary data.

Source: American Public Transit Association, *Transit Fact Book, 1977–78 Edition*, Washington, D.C., May 1978.

of 5.56 and an unweighted mean of 5.96. The corresponding value for the New York Subway was 5.55 KWhr/VMT.

As with other modes of transit operations, no consistent or accurate time series of passenger-mile or load factor data are available for rail transit systems. "Best guess" estimates on the part of the systems' operators of such data are all that are available. Utilizing these "best guess" values for 1975 yields (Chomitz, 1978):

Heavy rail energy intensity 1975 = 2600 Btu/PM*

*Traction energy only. If total operating energy were to be used this value would rise to 3100 Btu/PM.

System-by-system values vary from 1930 to 4090 Btu/PM, with an unweighted mean of 3040 Btu/PM (Chomitz, 1978).

Other authors in the past have separated and calculated individual energy intensity values for "new" and "old" heavy rail systems. This was done on the rationale that heavy rail systems constructed in the future would tend to be more like the "new" systems and that this separate value, therefore, needs to be calculated. This author feels that because each rail transit system is unique, the only way to approximate the operational energy intensity of a future system with any semblance of accuracy is through a detailed analysis of the individual proposed system layout, equipment, and related factors. The distinction between "new" and "old" systems is, accordingly, not made.

It is not possible to compute the corresponding aggregate values for light rail systems after 1973 because of the MBTA's (Massachusetts Bay Transportation Authority) inability to separate light and heavy rail energy use. The MBTA is responsible for a large fraction of total U.S. light rail VMT, and no meaningful average can be computed without their data.

Data for three individual systems for 1975 are available, yielding values of 1850, 5750 and 6100 Btu/PM with a weighted mean of 4020 Btu/PM (American Public Transit Association, 1976). A word of caution concerning the applicability of these values to new systems is warranted. Virtually all of the cars used in the above systems are of pre-1940s vintage. Tests of the new Boeing light rail vehicle in Boston yielded an average of 9.52 kWhr/VMT for combined above- and below-ground operations (Chomitz, 1978). If these new cars had been in use by those systems (while continuing the same load factors), the operating energy intensities would have risen to 4050, 11,100, and 6400 Btu/PM respectively.

Since it is primarily the lack of separate energy use statistics which precludes the calculation of EI values unique to heavy and light rail systems in later years, it is possible instead to calculate the complete time series of EI values for all rail transit systems.

Table 6.11. VMT, Energy Use, and Energy Intensity of Rail Transit Systems, 1970–77

Year	Vehicle miles (10^6)	Energy use (10^6 kWhr)	Energy Intensity	
			kWhr/VMT[a]	Btu/VMT[b]
1970	440.8	2,561	5.81	66,080
1971	440.0	2,556	5.81	66,070
1972	417.8	2,428	5.81	66,090
1973	438.5	2,331	5.32	60,460
1974	458.8	2,630	5.73	65,200
1975	446.9	2,646	5.92	67,340
1976	428.1	2,576	5.76	65,560
1977[c]	381.7[c]	2,303[c]	6.03[c]	68,620[c]

[a]Electricity in kWhr, not including generation or transmission losses.

[b]Calculated assuming 30% efficiency for electrical generation and distribution.

[c]Preliminary data.

Source: American Public Transit Association, *Transit Fact Book, 1977-78 Edition*, Washington, D.C., May 78.

In spite of the inavailability of reliable time-series passenger-mile data for rail transit systems, it may at times be necessary to estimate energy intensity on a passenger-mile basis. This can readily be achieved by assuming an average passenger trip length and utilizing the following relation:

$$EI = \frac{E}{PASS \cdot TL} ,$$

where

EI = energy intensity in Btu per passenger-mile,

E = energy use for the year, from Tables 6.9 and 6.10,

PASS = number of passengers, from Table 6.12,

TL = assumed passenger trip length in miles.

Table 6.12. Passengers on Rail Transit Systems, 1970–76

Year	Revenue passengers			Revenue as percent of total passengers		
	Light rail (10^6)	Heavy rail (10^6)	Total (10^6)	Light rail	Heavy rail	Total
1970	172.4	1573.5	1745.9	8.1	74.4	82.5
1971	155.1	1494.0	1649.1	7.8	74.7	82.5
1972	147.3	1445.7	1593.0	7.6	74.4	82.0
1973	143.5	1423.7	1567.2	7.5	74.1	81.6
1974	113.7	1435.1	1548.8	6.1	76.5	82.6
1975	94.0	1387.8	1492.5	5.2	76.7	82.5
1976[a]	86.0	1353.2	1450.2	4.9	76.9	82.4

[a]Preliminary data.

Source: American Public Transit Association, *Transit Fact Book, 1976–1977 Edition*, Washington, D.C., June 1977.

Estimated mean trip lengths for 1975 are (Stanford Research Institute, 1977):

Heavy rail — 7.02 miles
Light rail — 3.60 miles
All rail transit — 6.57 miles.

6.3 Commuter Rail

The statistical data presented in this section are based on the assumption that all intercity passengers are carried by Amtrak and the Autotrain Corporation. The remaining Class I railroads in their passenger operations are assumed to deal exclusively with commuter traffic. Although this assumption is not totally valid, as the Southern Railway and three others are engaged in intercity passenger movement,* the error introduced by it is very small. It was possible to quantify this error from disaggregate data available for 1975, the analysis yielding a less than 2% error. The author feels that this error is of the same magnitude,

---

*Furthermore, their engagement is constantly diminishing due to lack of profitability in providing the service.

if not smaller, than the reporting errors in the source data, and it is therefore negligible. Table 6.13 summarizes the operating statistics of commuter railroads.

Table 6.13. Operational Statistics and Energy Intensities of Commuter Railroads, 1972–77

	1972	1973	1974	1975	1976	1977
Rail motor cars						
VMT (10^6)	88.07	91.51	99.42	103.3	102.98	98.43
Energy use (10^{12} Btu)	8.61	10.71	10.24	10.36	9.69	11.57
Energy intensity (Btu/VMT)	97,800	117,100	103,000	100,300	94,100	117,600
Locomotive hauled trains						
Passenger car miles (10^6)	72.91	67.70	70.34	67.02	68.23	65.36
Energy use (10^{12} Btu)	16.50	14.27	15.29	12.89	10.22	10.36
Energy intensity (Btu/VMT)	226,300	210,800	217,400	192,300	149,800	163,300
Total passenger miles[a] (10^9)			5.80	5.92	5.76	5.87
Overall energy intensities						
Btu/VMT	156,000	156,900	150,400	136,500	116,300	135,800
Btu/PM			4,400	3,900	3,500	3,790

Source: Association of American Railroads, *Statistics of Railroads of Class I, Years 1967–1977*, Washington, D.C., September 1978; Auto-Train Corporation, *Annual Report to the Interstate Commerce Commission*, Washington, D.C., 1972–1977; National Railroad Passenger Corp., *Annual Report to the Interstate Commerce Commission*, Washington, D.C., 1972–1977.

Appendix A: U.S. DOMESTIC TRAVEL SOURCE DATA, 1972 AND 1976

Presented in this appendix are the source data on U.S. intercity travel for 1972 and 1976. The 1972 data are taken from the quinquennial *Census of Transportation, National Travel Survey,* conducted by the Bureau of the Census. Beginning in 1974, the U.S. Travel Data Center conducted similar surveys to bridge the gap between the Department of Commerce census years. However, the 1974 and 1975 results from the U.S. Travel Data Center are not based on a national probability sample and thus do not allow direct comparisons to the 1972 Census data. Therefore, they are not included here. The U.S. Travel Data Center survey data for 1976 are presented here.

Before using the data presented, the reader should be aware of several characteristics of these data sets.

1. The central unit of measure in both data sets is a "trip," defined as "each time a person goes to a place at least 100 miles away from home and returns." Thus all round trips of less than 200 miles are excluded. Also specifically excluded are travel (1) as part of an operating crew on a train, plane, bus, truck, or ship; (2) commuting to a place of work; (3) student trips to school or those taken while in school; and (4) travel while on active duty in a military service.
2. The person-miles presented in the original survey data are approximations of actual route-miles derived by taking the origin-destination great circle distances and adding to these the following mode-dependent circuity factors.

Air:	15%
Rail:	25%
Bus	25%
Auto/truck	56.3%

3. In the surveys, trips to places outside the United States were included under the person-trip headings but not under person-miles. In the following tables these trips were also deleted from the person-trip headings in the following manner:

   a. For all U.S. aggregate categories and the intramodal breakdowns by round-trip distance, the person-trips to foreign destinations were given and a straightforward deletion was possible.

   b. For the intramodal breakdowns by trip purpose, only the total trips outside the United States by the mode were given. The assumption was made that the intramodal trips outside the United States by trip category followed the same pattern as at the national intermodal level. For example: as 22.3% of all trips outside the United States were to "visit friends and relatives," it was assumed that also 22.3% of the trips outside the United States by each mode were also to "visit friends and relatives."

A summary of these deleted person-trips is given in Tables A.10 and A.11.

Because the data for 1972 and 1976 are based on sample sizes of approximately 24,000 and 6,000, respectively, sampling errors are possible and these are quantified in Table A.1.

Table A.1. 95% Confidence Intervals for 1972 and 1976 (National Travel Surveys)

	Number of person-trips[a]		95% Confidence interval	
	1972	1976	1972	1976
Total	458,483	705,699	±6%	±6%
Means of transport				
Auto/truck	390,678	595,008	±6%	±8%
Bus	8,413		±10%	
Air	53,891	79,370	±10%	±11%
Train	1,880		±24%	
Other	3,626	31,322	±12%	±14%
Purpose of trip				
Visit friends and relatives	175,868	252,697	±6%	±9%
Business and conventions	92,571	226,534	±10%	±9%
Outdoor recreation	57,090	150,468	±10%	±9%
Sightseeing and entertainment	60,774		±6%	
Other	72,179	76,008	±8%	±15%
Round-trip distance, miles				
200-399	189,018	266,436	±8%	±12%
400-599	91,663	139,987	±8%	±9%
600-799	45,454	117,301	±10%	±11%
800-999	25,345		±8%	
1,000-1,999	47,864	79,750	±8%	±12%
Over 2,000	40,703	73,895	±6%	±12%
Outside the U.S.	18,436	28,339	±10%	±23%

[a] Includes trips to destinations outside the United States.

Table A.2. U.S. Aggregate Domestic Travel Data, 1972[a]

By Mode

Mode of transportation	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
Auto/truck	382,019	86.8	2.10	256,545	70.8	672
Bus	7,990	1.8	1.35	5,862	1.6	734
Train	1,744	0.4	1.39	2,046	0.6	1,173
Air	45,585	10.4	1.25	93,742	25.8	2,056
Other	2,710	0.6	1.40	4,211	1.2	1,554
Total	440,047	100.0	1.94	362,406	100.0	824

By Round-Trip Distance

Round-trip length (miles)	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
200-399	189,018	43.0	2.02	54,895	15.2	290
400-599	91,663	20.8	1.97	43,922	12.1	479
600-799	45,454	10.3	1.91	30,718	8.5	676
800-999	25,345	5.8	1.87	22,125	6.1	873
1,000-1,999	47,864	10.9	1.84	65,769	18.1	1,374
Over 2,000	40,703	9.2	1.76	144,977	40.0	3,562
Total	440,047	100.0	1.94	362,406	100.0	824

By Trip Purpose

Purpose of trip	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
Visit friends and relatives	171,762	39.0	2.35	140,179	38.7	816
Business and conventions	90,063	20.5	1.23	79,895	22.0	887
Outdoor recreation	54,935	12.5	2.43	32,791	9.0	597
Sightseeing and entertainment	53,023	12.0	2.21	55,510	15.3	1,047
Other	70,264	16.0	2.08	54,031	15.0	769
Total	440,047	100.0	1.94	362,406	100.0	824

[a]All distance-related data include the circuity ratios listed on page A-2.

Source: U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Vol. 1, National Travel Survey*, Washington, D.C., February 1974.

Table A.3. U.S. Aggregate Domestic Travel Data, 1976[a]

By Mode

Mode of transportation	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
Auto/truck	580,829	85.8	2.18	431,735	71.0	743
Air	68,578	10.1	1.27	149,204	24.5	2,176
Other	27,962	4.1	1.53	27,163	4.5	971
Total	677,369	100.0	2.00	608,102	100.0	898

By Round-Trip Distance

Round-trip length (miles)	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
200-299	136,937	20.2	2.09	35,018	5.7	256
300-399	129,499	19.1	2.03	44,827	7.4	346
400-599	139,987	20.7	2.02	67,796	11.2	484
600-999	117,301	17.3	1.95	88,664	14.6	756
1,000-1,999	79,750	11.8	1.95	109,609	18.0	1,374
Over 2,000	73,895	10.9	1.86	262,195	43.1	3,548
Total	677,369	100.0	2.00	608,109	100.0	898

By Trip Purpose

Purpose of trip	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
Visit friends and relatives	248,971	36.7	2.33	228,165	37.5	919
Other pleasure	207,312	30.6	2.18	195,896	32.2	945
Business	146,734	21.7	1.46	127,687	21.0	870
Other	74,352	11.0	2.03	56,360	9.3	758
Total	677,369	100.0	2.00	608,108	100.0	898

[a]All distance-related data include the circuity ratios listed on page A-2.

Source: U.S. Travel Data Center, *1976 National Travel Survey, Full Year Report*, Washington, D.C., 1977.

Table A.4. Domestic Air Travel Data, 1972[a]

By Round-Trip Distance

Round-trip length (miles)	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
200-399	2,212	4.8	1.14	619	0.7	280
400-599	4,472	9.8	1.10	2,064	2.2	462
600-799	4,357	9.6	1.15	2,818	3.0	647
800-999	4,281	9.4	1.18	3,532	3.8	825
1,000-1,999	11,686	25.6	1.23	15,786	16.8	1,351
Over 2,000	18,576	40.8	1.39	68,923	73.5	3,710
Total	45,584	100.0	1.25	93,742	100.0	2,056

By Trip Purpose

Purpose of trip	Person-trips 10^3	Person-trips %	Persons per trip	Person-miles 10^6	Person-miles %	Mean round-trip length (miles)
Visit friends and relatives	10,959	24.0	1.51	25,775	27.5	2,352
Business and conventions	25,567	56.1	1.10	41,085	43.8	1,607
Outdoor recreation	390	0.9	2.62	1,885	2.0	4,833
Sightseeing and entertainment	3,321	7.3	1.72	13,119	14.0	3,951
Other	5,347	11.7	1.45	11,878	12.7	2,221
Total	45,584	100.0	1.25	93,742	100.0	2,056

[a]A circuity ratio of 1.15 over the great-circle distance is included in all distance-related data.

Source: U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Vol. 1, National Travel Survey*, Washington, D.C., February 1974.

Table A.5. Domestic Air Travel Data, 1976[a]

By Round-Trip Distance

Round-trip length (miles)	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
200-299	1,833	2.7	1.10	478	0.3	261
300-399	1,719	2.5	1.30	600	0.4	349
400-599	6,879	10.0	1.14	3,444	2.3	501
600-999	14,356	20.9	1.17	11,014	7.4	767
1,000-1,999	15,709	22.9	1.24	22,741	15.2	1,448
Over 2,000	28,083	41.0	1.39	110,928	74.4	3,950
Total	68,579	100.0	1.27	149,205	100.0	2,176

By Trip-Purpose

Purpose of trip	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
Visit friends and relatives	18,833	27.5	1.52	45,441	30.5	2,413
Other pleasure	13,562	19.8	1.53	42,632	28.6	3,143
Business	29,719	43.3	1.09	51,418	34.4	1,730
Other	6,465	9.4	1.19	9,714	6.5	1,503
Total	68,579	100.0	1.27	149,205	100.0	2,176

[a]A circuity ratio of 1.15 over the great-circle distance is included in all distance-related data.

Source: U.S. Travel Data Center, 1976 National Travel Survey, Full Year Report, Washington, D.C., 1977.

Table A.6. Domestic Auto/Truck Travel Data, 1972[a]
By Round-Trip Distance

Round-trip length (miles)	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
200-399	182,057	47.7	2.06	53,937	21.0	296
400-599	84,615	22.1	2.09	41,315	16.1	488
600-799	39,955	10.5	2.09	27,477	10.7	688
800-999	20,355	5.3	2.17	18,095	7.1	889
1,000-1,999	34,306	9.0	2.25	47,260	18.4	1,378
Over 2,000	20,732	5.4	2.34	68,461	26.7	3,302
Total	382,020	100.0	2.10	256,544	100.0	672

By Trip Purpose

Purpose of trip	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
Visit friends and relatives	156,749	41.0	2.49	110,620	43.1	706
Business and conventions	62,540	16.4	1.29	35,009	13.6	560
Outdoor recreation	53,627	14.0	2.45	30,741	12.0	573
Sightseeing and entertainment	46,529	12.2	2.35	40,202	15.7	864
Other	62,575	16.4	2.19	39,972	15.6	639
Total	382,020	100.0	2.11	256,544	100.0	672

[a]Circuity ratios of 1.56 over the great-circle distance are included in all distance-related data.

Source: U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Vol. 1, National Travel Survey*, Washington, D.C., February 1974.

Table A.7. Domestic Auto/Truck Travel Data, 1976[a]

By Round-Trip Distance

Round-trip length (miles)	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
200-299	129,288	22.2	2.17	33,078	7.7	256
300-399	124,261	21.4	2.08	43,017	10.0	346
400-599	126,960	21.9	2.15	61,298	14.2	483
600-999	97,526	16.8	2.18	73,611	17.0	755
1,000-1,999	60,154	10.4	2.32	81,374	18.8	1,353
Over 2,000	42,650	7.3	2.43	139,365	32.3	3,268
Total	580,839	100.0	2.18	431,743	100.0	743

By Trip Purpose

Purpose of trip	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
Visit friends and relatives	223,338	38.4	2.51	176,021	40.7	788
Other pleasure	177,751	30.6	2.31	137,593	31.9	774
Business	113,804	19.6	1.60	72,886	16.9	640
Other	65,945	11.4	2.20	45,241	10.5	686
Total	580,839	100.0	2.18	431,741	100.0	743

[a]Circuity ratios of 1.56 over the great-circle distance are included in in all distance-related data.

Source: U.S. Travel Data Center, 1976 National Travel Survey, Full Year Report, Washington, D.C., 1977.

Table A.8. Domestic Bus Travel Data, 1972[a]

By Round-Trip Distance

Round-trip length (miles)	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
200-399	3,525	44.1	1.37	1,109	18.9	315
400-599	1,854	23.2	1.29	970	16.6	523
600-799	746	9.3	1.31	555	9.5	744
800-999	438	5.5	1.47	420	7.2	959
1,000-1,999	1,039	13.0	1.37	1,533	26.1	1,475
Over 2,000	388	4.9	1.36	1,275	21.7	3,286
Total	7,990	100.0	1.35	5,862	100.0	734

By Trip Purpose

Purpose of trip	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
Visit friends and relatives	2,652	33.2	1.33	2,091	35.7	788
Business and conventions	966	12.0	1.27	713	12.2	738
Outdoor recreation	539	6.8	1.35	395	6.7	733
Sightseeing and enter entertainment	2,407	30.1	1.40	1,572	26.8	653
Other	1,426	17.9	1.35	1,091	18.6	765
Total	7,990	100.0	1.35	5,862	100.0	734

[a]A circuity ratio of 1.25 over the great-circle distance is included in all distance-related data.

Source: U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Vol. 1, National Travel Survey*, Washington, D.C., February 1974.

DUE TO THE SMALLER SAMPLE SIZE, NO BUS TRAVEL DATA ARE AVAILABLE FROM THE 1976 SURVEY

Table A.9. Domestic Rail Travel Data, 1972[a]

By Round-Trip Distance

Round-trip length (miles)	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
200-399	628	36.0	1.19	193	9.4	307
400-599	369	21.2	1.28	188	9.2	509
600-799	98	5.6	1.22	71	3.5	724
800-999	46	2.6	1.53	46	2.3	1,000
1,000-1,999	274	15.7	1.64	473	23.1	1,726
Over 2,000	329	18.9	2.08	1,075	52.5	3,267
Total	1,744	100.0	1.40	2,046	100.0	1,173

By Trip Purpose

Purpose of trip	Person-trips		Persons per trip	Person-miles		Mean round-trip length (miles)
	10^3	%		10^6	%	
Visit friends and relatives	720	41.3	1.43	1,047	51.2	1,454
Business and conventions	548	31.4	1.18	442	21.6	806
Outdoor recreation	24	1.4	1.60	62	3.0	2,583
Sightseeing and entertainment	265	15.2	1.83	298	14.6	1,125
Other	187	10.7	1.53	197	9.6	1,053
Total	1,744	100.0	1.39	2,046	100.0	1,173

[a]A circuity ratio of 1.25 over the great-circle distance is included in all distance-related data.

Source: U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Vol. 1, National Travel Survey*, Washington, D.C., February 1974.

DUE TO THE SMALLER SAMPLE SIZE, NO RAIL TRAVEL DATA ARE AVAILABLE FROM THE 1976 SURVEY

Table A.10. Person-Trips Outside U.S. Deleted from 1972 Data (person-trips × 10^3)

	Auto/truck	Air	Bus	Train	Other	Total
Visit friends and relatives	1,928	1,850	94	33	201	4,106
Business	1,177	1,130	58	18	125	2,508
Outdoor recreation	1,012	971	49	15	108	2,155
Sightseeing and entertainment	3,639	3,492	178	58	384	7,751
Other	898	863	44	13	97	1,915
Total	8,654	8,306	423	137	915	18,435

Table A.11. Person-Trips Outside U.S. Deleted from 1976 Data (person-trips × 10^3)

	Auto/truck	Air	Other	Total
Visit friends and relatives	1,863	1,419	444	3,726
Business	1,868	1,422	444	3,734
Other pleasure	9,618	7,319	2,285	19,222
Other	830	632	187	1,657
Total	14,179	10,792	3,368	28,339

Appendix B: INTERCITY MODAL CIRCUITIES SOURCE DATA

Because the statistics for all intercity passenger transportation modes except air are reported on a route-mile basis, any vehicle or passenger-mile data must be normalized to a common basis before any "fair" intermodal comparisons can be made. The great-circle intercity distances readily lend themselves to this task as they represent an accurate measure of the productive output of the modal movements. In order to ensure an adequate coverage of the transportation systems, the distances between the 50 largest SMSAs, as given in the *Statistical Abstract of the United States, 1975*, were calculated and subsequently aggregated to coincide roughly with the distance categories used in the *1972 Census of Transportation*.

Great-Circle Distances: The latitude and longitude of the city centers were taken from the *National Atlas of the United States of America* by the U.S. Geological Survey and utilized in a navigational formula to calculate the great-circle distances:

$$D = 60 \cos^{-1}[\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos(\lambda_2 - \lambda_1)][1.1508] ,$$

where

D = great-circle distance in statute miles,

L_1 and L_2 = latitudes of the city centers,

λ_1 and λ_2 = longitudes of the city centers,

1.1508 = conversion from nautical to statute miles.

The individual city-pair great-circle distances are given in Table B.4.

Aircraft Source Distances: All statistics for the air mode are published in terms of great-circle airport to airport distances, and no further adjustments are needed. A circuity of 1.0 was assigned to all air trips. It was felt that this was justified because this analysis deals only with the line haul portion of trips. The additional circuities encountered by the other modes in moving to the stations or city centers would be negligible in relation to the overall circuities encountered.

Automobile Source Distances: The automobile distances were calculated from mileage guides furnished by the American Automobile Association and revised to 1978 (Table B.1). These distances reflect thruway distances, which tend to minimize driving time and effort, rather than the shortest possible routes. The individual city-pair circuities for automobiles are given in Table B.5.

Table B.1. Mean Automobile Circuities by Distance Category

City-pair distance (miles)	Mean circuity ratio[a]	
	By GCD class	By route-mile class
0–99	1.222	1.130
100–149	1.149	1.126
150–199	1.214	1.141
200–299	1.274	1.156
300–499	1.230	1.210
500–999	1.214	1.221
Over 1,000	1.213	1.215
All	1.215	1.215

[a]Average circuity = $\frac{\Sigma \text{ route distance}}{\Sigma \text{ GCD}}$

Bus Source Distances: The routing were developed from the *Greyhound Lines, System Timetable, 1978* for the most direct or through bus routes and combined with the city-center to city-center mileages from the

Rand McNally Mileage Guide, 1976 (Table B.2). The mileages in the guide are for the shortest recommended truck routes, that is, the shortest permissable routes for large commercial vehicles. The individual city-pair circuities for buses are given in Table B.6.

Table B.2. Mean Bus Circuities by Distance Category

City-pair distance (miles)	Mean circuity ratio[a]	
	By GCD class	By route-mile class
0–99	1.176	1.089
100–149	1.121	1.103
150–199	1.127	1.149
200–299	1.200	1.127
300–499	1.208	1.183
500–999	1.207	1.204
Over 1,000	1.201	1.204
All	1.202	1.202

[a]Average circuity = $\frac{\Sigma \text{ route distance}}{\Sigma \text{ GCD}}$

<u>Rail Source Distances</u>: The station to station distances were taken directly from *The Official Railway Guide, North American Passenger Travel Edition, 1978* (Table B.3). It was justifiable to use the station to station distances because railroad stations tend to be relatively close to the city centers and any deviations from the city centers would tend to cancel themselves in the sample of 50. In any case, errors introduced through this assumption should be small compared to the line-haul distances involved. In the course of the analysis it became necessary to drop city-pairs for one of two reasons: (1) there was no rail service connecting them; or (2) the circuity involved was over 2.5, and it was

assumed that the corresponding travel time would be prohibitively high, thus effectively removing rail from competition for that city-pair.

Table B.3. Mean Passenger Rail Circuities by Distance Category

City-pair distance (miles)	Mean circuity ratio[a]	
	By GCD class	By route-mile class
0–99	1.102	1.097
100–149	1.310	1.115
150–199	1.322	1.127
200–299	1.507	1.168
300–499	1.538	1.292
500–999	1.455	1.390
Over 1,000	1.402	1.426
All	1.419	1.419

[a]Average circuity = $\frac{\Sigma \text{ route distance}}{\Sigma \text{ GCD}}$.

Route by route passenger-mile statistics were available for 1975, and from these a passenger-mile weighted circuity of 1.245 was calculated for the Amtrak network. However it is felt that this figure is of little value because it carried the implicit assumption that Amtrak riders never switched trains, or at least never traveled between cities not enjoying direct service. The individual city-pair circuities for rail are given in Table B.7.

Table B.4. City-Pair Great-Circle Distances

	NEW YORK	CHICAGO	LOS ANGELES	PHILADELPHIA	HOUSTON	DETROIT	BALTIMORE	DALLAS	SAN DIEGO	SAN ANTONIO	INDIANAPOLIS	WASHINGTON	MILWAUKEE	PHOENIX	SAN FRANCISCO	MEMPHIS	CLEVELAND
1. NEW YORK	0.	711.	2444.	81.	1416.	481.	170.	1371.	2426.	1581.	643.	204.	732.	2138.	2564.	954.	404.
2. CHICAGO	711.	0.	1742.	663.	941.	236.	604.	805.	1730.	1053.	165.	594.	81.	1451.	1854.	485.	307.
3. LOS ANGELES	2444.	1742.	0.	2387.	1371.	1978.	2313.	1236.	112.	1201.	1805.	2293.	1740.	357.	347.	1599.	2043.
4. PHILADELPHIA	81.	663.	2387.	0.	1338.	442.	90.	1297.	2366.	1504.	582.	124.	692.	2076.	2515.	879.	358.
5. HOUSTON	1416.	941.	1371.	1338.	0.	1105.	1249.	225.	1300.	190.	865.	1217.	1005.	1014.	1641.	482.	1113.
6. DETROIT	481.	236.	1978.	442.	1105.	0.	396.	999.	1967.	1238.	240.	395.	252.	1686.	2085.	624.	90.
7. BALTIMORE	170.	604.	2313.	90.	1249.	396.	0.	1211.	2290.	1416.	509.	35.	641.	1999.	2449.	792.	308.
8. DALLAS	1371.	805.	1236.	1297.	225.	999.	1211.	0.	1180.	252.	764.	1182.	857.	883.	1479.	419.	1024.
9. SAN DIEGO	2426.	1730.	112.	2366.	1300.	1967.	2290.	1180.	0.	1125.	1784.	2268.	1734.	298.	458.	1557.	2028.
10. SAN ANTONIO	1581.	1053.	1201.	1504.	190.	1238.	1416.	252.	1125.	0.	999.	1385.	1107.	846.	1486.	630.	1256.
11. INDIANAPOLIS	643.	165.	1805.	582.	865.	240.	509.	764.	1784.	999.	0.	491.	243.	1495.	1944.	385.	262.
12. WASHINGTON	204.	594.	2293.	124.	1217.	395.	35.	1182.	2268.	1385.	491.	0.	635.	1976.	2434.	763.	305.
13. MILWAUKEE	732.	81.	1740.	692.	1005.	252.	641.	857.	1734.	1107.	243.	635.	0.	1460.	1837.	558.	335.
14. PHOENIX	2138.	1451.	357.	2076.	1014.	1686.	1999.	883.	298.	846.	1495.	1976.	1460.	0.	652.	1259.	1744.
15. SAN FRANCISCO	2564.	1854.	347.	2515.	1641.	2085.	2449.	1479.	458.	1486.	1944.	2434.	1837.	652.	0.	1798.	2160.
16. MEMPHIS	954.	485.	1599.	879.	482.	624.	792.	419.	1557.	630.	385.	763.	558.	1259.	1798.	0.	631.
17. CLEVELAND	404.	307.	2043.	358.	1113.	90.	308.	1024.	2028.	1256.	262.	305.	335.	1744.	2160.	631.	0.
18. BOSTON	190.	848.	2589.	271.	1602.	611.	360.	1549.	2577.	1764.	805.	394.	855.	2293.	2691.	1135.	550.
19. JACKSONVILLE	835.	864.	2142.	758.	820.	832.	681.	907.	2086.	1009.	699.	647.	943.	1790.	2368.	589.	771.
20. NEW ORLEANS	1167.	834.	1669.	1087.	318.	939.	997.	443.	1604.	507.	712.	963.	911.	1313.	1921.	356.	923.
21. SAN JOSE	2547.	1837.	304.	2497.	1607.	2069.	2430.	1447.	416.	1450.	1924.	2414.	1821.	613.	42.	1771.	2143.
22. COLUMBUS	476.	275.	1972.	415.	991.	164.	343.	912.	1951.	1139.	168.	327.	331.	1663.	2107.	510.	126.
23. ST. LOUIS	871.	263.	1585.	808.	679.	454.	730.	548.	1560.	792.	230.	708.	328.	1269.	1741.	241.	491.
24. SEATTLE	2401.	1732.	958.	2372.	1888.	1932.	2326.	1678.	1063.	1784.	1866.	2321.	1686.	1113.	678.	1863.	2019.
25. DENVER	1627.	918.	829.	1574.	878.	1153.	1505.	662.	832.	802.	998.	1488.	912.	585.	947.	877.	1223.
26. KANSAS CITY	1093.	412.	1354.	1034.	646.	643.	960.	454.	1333.	704.	451.	940.	441.	1047.	1502.	370.	697.
27. PITTSBURGH	316.	408.	2130.	258.	1135.	205.	196.	1068.	2111.	1289.	328.	191.	445.	1823.	2258.	659.	115.
28. NASHVILLE	758.	398.	1776.	683.	665.	470.	595.	617.	1739.	823.	251.	566.	479.	1442.	1957.	197.	458.
29. ATLANTA	745.	589.	1932.	665.	700.	597.	576.	720.	1886.	881.	427.	541.	669.	1588.	2134.	336.	555.
30. CINCINNATI	567.	252.	1891.	501.	892.	236.	423.	813.	1867.	1038.	99.	402.	324.	1576.	2037.	410.	222.
31. BUFFALO	292.	451.	2192.	279.	1285.	216.	275.	1198.	2182.	1429.	434.	292.	457.	1901.	2293.	803.	173.
32. EL PASO	1899.	1251.	700.	1831.	674.	1476.	1748.	569.	627.	501.	1262.	1722.	1277.	346.	993.	973.	1522.
33. MINNEAPOLIS	1016.	354.	1521.	983.	1057.	542.	936.	864.	1530.	1112.	511.	931.	298.	1278.	1580.	701.	629.
34. OMAHA	1145.	435.	1309.	1094.	796.	670.	1028.	589.	1303.	831.	527.	1014.	431.	1032.	1421.	534.	740.
35. TOLEDO	500.	211.	1949.	453.	1053.	54.	398.	951.	1935.	1187.	188.	392.	243.	1652.	2064.	572.	96.
36. OKLAHOMA CITY	1322.	691.	1179.	1255.	415.	907.	1173.	192.	1138.	423.	687.	1148.	730.	840.	1385.	420.	947.
37. MIAMI	1091.	1190.	2334.	1021.	966.	1155.	956.	1110.	2266.	1147.	1026.	924.	1269.	1977.	2589.	872.	1089.
38. FORT WORTH	1396.	823.	1209.	1323.	236.	1020.	1236.	28.	1152.	240.	786.	1208.	874.	855.	1453.	446.	1047.
39. PORTLAND	2435.	1751.	825.	2401.	1831.	1960.	2351.	1627.	932.	1716.	1877.	2343.	1711.	1004.	536.	1843.	2045.
40. HONOLULU	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
41. NEWARK	9.	701.	2435.	75.	1409.	472.	163.	1363.	2417.	1573.	634.	198.	723.	2130.	2555.	946.	395.
42. LOUISVILLE	649.	270.	1825.	580.	802.	316.	497.	726.	1797.	949.	107.	473.	349.	1504.	1981.	321.	311.
43. LONG BEACH	2449.	1747.	20.	2391.	1365.	1984.	2317.	1234.	94.	1194.	1809.	2296.	1747.	352.	364.	1599.	2048.
44. TULSA	1222.	594.	1267.	1155.	443.	808.	1073.	239.	1230.	489.	586.	1049.	637.	934.	1462.	336.	847.
45. OAKLAND	2556.	1845.	343.	2507.	1634.	2077.	2441.	1471.	455.	1479.	1935.	2425.	1828.	646.	8.	1789.	2152.
46. AUSTIN	1509.	978.	1224.	1434.	147.	1163.	1345.	181.	1153.	74.	925.	1314.	1034.	868.	1498.	558.	1182.
47. TUCSON	2118.	1443.	440.	2053.	938.	1675.	1973.	825.	362.	764.	1475.	1949.	1458.	107.	752.	1216.	1729.
48. BATON ROUGE	1193.	814.	1595.	1114.	254.	936.	1024.	368.	1532.	443.	703.	991.	888.	1239.	1846.	329.	927.
49. NORFOLK	294.	697.	2349.	223.	1202.	522.	170.	1194.	2318.	1378.	571.	147.	748.	2022.	2508.	778.	432.
50. CHARLOTTE	531.	588.	2114.	451.	924.	505.	365.	928.	2075.	1103.	428.	329.	659.	1777.	2295.	520.	436.

Table B.4, continued.

	BOSTON	JACKSONVILLE	NEW ORLEANS	SAN JOSE	COLUMBUS	ST. LOUIS	SEATTLE	DENVER	KANSAS CITY	PITTSBURGH	NASHVILLE	ATLANTA	CINCINNATI	BUFFALO	EL PASO	MINNEAPOLI	OMAHA
1. NEW YORK	190.	835.	1167.	2547.	476.	871.	2401.	1627.	1093.	316.	758.	745.	567.	292.	1899.	1016.	1145.
2. CHICAGO	848.	864.	834.	1837.	275.	263.	1732.	918.	412.	408.	398.	589.	252.	451.	1251.	354.	435.
3. LOS ANGELES	2589.	2142.	1669.	304.	1972.	1585.	958.	829.	1354.	2130.	1776.	1932.	1891.	2192.	700.	1521.	1309.
4. PHILADELPHIA	271.	758.	1087.	2497.	415.	808.	2372.	1574.	1034.	258.	683.	665.	501.	279.	1831.	983.	1094.
5. HOUSTON	1602.	820.	318.	1607.	991.	679.	1888.	878.	646.	1135.	665.	700.	892.	1285.	674.	1057.	796.
6. DETROIT	611.	832.	939.	2069.	164.	454.	1932.	1153.	643.	205.	470.	597.	236.	216.	1476.	542.	670.
7. BALTIMORE	360.	681.	997.	2430.	343.	730.	2326.	1505.	960.	196.	595.	576.	423.	275.	1748.	936.	1028.
8. DALLAS	1549.	907.	443.	1447.	912.	548.	1678.	662.	454.	1068.	617.	720.	813.	1198.	569.	864.	589.
9. SAN DIEGO	2577.	2086.	1604.	416.	1951.	1560.	1063.	832.	1333.	2111.	1739.	1886.	1867.	2182.	627.	1530.	1303.
10. SAN ANTONIO	1764.	1009.	507.	1450.	1139.	792.	1784.	802.	704.	1289.	823.	881.	1038.	1429.	501.	1112.	831.
11. INDIANAPOLIS	805.	699.	712.	1924.	168.	230.	1866.	998.	451.	328.	251.	427.	99.	434.	1262.	511.	527.
12. WASHINGTON	394.	647.	963.	2414.	327.	708.	2321.	1488.	940.	191.	566.	541.	402.	292.	1722.	931.	1014.
13. MILWAUKEE	855.	943.	911.	1821.	331.	328.	1686.	912.	441.	445.	479.	669.	324.	457.	1277.	298.	431.
14. PHOENIX	2293.	1790.	1313.	613.	1663.	1269.	1113.	585.	1047.	1823.	1442.	1588.	1576.	1901.	346.	1278.	1032.
15. SAN FRANCISCO	2691.	2368.	1921.	42.	2107.	1741.	678.	947.	1502.	2258.	1957.	2134.	2037.	2293.	993.	1580.	1421.
16. MEMPHIS	1135.	589.	356.	1771.	510.	241.	1863.	877.	370.	659.	197.	336.	410.	803.	973.	701.	534.
17. CLEVELAND	550.	771.	923.	2143.	126.	491.	2019.	1223.	697.	115.	458.	555.	222.	173.	1522.	629.	740.
18. BOSTON	0.	1017.	1357.	2676.	642.	1035.	2484.	1764.	1247.	482.	941.	935.	738.	399.	2067.	1120.	1281.
19. JACKSONVILLE	1017.	0.	502.	2339.	669.	750.	2450.	1464.	949.	704.	500.	285.	627.	880.	1469.	1191.	1101.
20. NEW ORLEANS	1357.	502.	0.	1888.	797.	598.	2097.	1079.	681.	918.	468.	423.	705.	1085.	980.	1052.	849.
21. SAN JOSE	2676.	2339.	1888.	0.	2088.	1719.	709.	926.	1481.	2240.	1933.	2107.	2017.	2278.	955.	1569.	1403.
22. COLUMBUS	642.	669.	797.	2088.	0.	395.	2007.	1163.	619.	161.	333.	436.	100.	294.	1425.	626.	687.
23. ST. LOUIS	1035.	750.	598.	1719.	395.	0.	1720.	795.	238.	556.	253.	466.	307.	661.	1032.	467.	359.
24. SEATTLE	2484.	2450.	2097.	709.	2007.	1720.	0.	1018.	1502.	2131.	1969.	2177.	1965.	2109.	1375.	1390.	1361.
25. DENVER	1764.	1464.	1079.	926.	1163.	795.	1018.	0.	557.	1316.	1020.	1209.	1091.	1366.	558.	698.	483.
26. KANSAS CITY	1247.	949.	681.	1481.	619.	238.	1502.	557.	0.	778.	472.	675.	539.	858.	839.	412.	169.
27. PITTSBURGH	482.	704.	918.	2240.	161.	556.	2131.	1316.	778.	0.	471.	521.	256.	179.	1586.	741.	836.
28. NASHVILLE	941.	500.	468.	1933.	333.	253.	1969.	1020.	472.	471.	0.	215.	238.	626.	1166.	697.	610.
29. ATLANTA	935.	285.	423.	2107.	436.	466.	2177.	1209.	675.	521.	215.	0.	369.	698.	1288.	908.	821.
30. CINCINNATI	738.	627.	705.	2017.	100.	307.	1965.	1091.	539.	256.	238.	369.	0.	393.	1332.	605.	624.
31. BUFFALO	399.	880.	1085.	2278.	294.	661.	2109.	1366.	858.	179.	626.	698.	393.	0.	1689.	729.	883.
32. EL PASO	2067.	1469.	980.	955.	1425.	1032.	1375.	558.	839.	1586.	1166.	1288.	1332.	1689.	0.	1157.	876.
33. MINNEAPOLIS	1120.	1191.	1052.	1569.	626.	467.	1390.	698.	412.	741.	697.	908.	605.	729.	1157.	0.	290.
34. OMAHA	1281.	1101.	849.	1403.	687.	359.	1361.	483.	169.	836.	610.	821.	624.	883.	876.	290.	0.
35. TOLEDO	642.	788.	885.	2048.	120.	409.	1929.	1128.	606.	202.	417.	547.	183.	253.	1435.	540.	645.
36. OKLAHOMA CITY	1490.	984.	576.	1357.	849.	457.	1521.	503.	296.	1010.	602.	754.	755.	1117.	577.	692.	408.
37. MIAMI	1257.	327.	668.	2557.	993.	1060.	2729.	1724.	1242.	1012.	816.	605.	954.	1184.	1639.	1512.	1401.
38. FORT WORTH	1574.	934.	468.	1421.	936.	568.	1659.	645.	464.	1093.	643.	748.	837.	1220.	541.	872.	593.
39. PORTLAND	2528.	2432.	2056.	567.	2024.	1716.	143.	978.	1490.	2155.	1962.	2165.	1976.	2146.	1285.	1419.	1360.
40. HONOLULU	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
41. NEWARK	196.	832.	1160.	2538.	468.	863.	2392.	1617.	1084.	307.	750.	739.	559.	284.	1890.	1007.	1135.
42. LOUISVILLE	823.	594.	622.	1959.	189.	241.	1937.	1035.	479.	342.	154.	320.	89.	483.	1251.	605.	582.
43. LONG BEACH	2595.	2140.	1665.	322.	1976.	1589.	978.	837.	1357.	2135.	1777.	1931.	1895.	2198.	693.	1530.	1316.
44. TULSA	1390.	915.	545.	1435.	748.	356.	1560.	552.	216.	909.	509.	672.	655.	1017.	677.	625.	354.
45. OAKLAND	2683.	2360.	1913.	39.	2099.	1732.	676.	938.	1494.	2249.	1949.	2126.	2029.	2285.	986.	1572.	1413.
46. AUSTIN	1692.	958.	459.	1463.	1065.	718.	1767.	770.	635.	1216.	752.	817.	965.	1355.	527.	1044.	766.
47. TUCSON	2278.	1729.	1244.	712.	1641.	1246.	1218.	617.	1033.	1803.	1404.	1539.	1552.	1890.	265.	1295.	1035.
48. BATON ROUGE	1382.	567.	75.	1814.	802.	567.	2026.	1008.	627.	932.	469.	458.	707.	1094.	908.	1010.	795.
49. NORFOLK	471.	545.	924.	2487.	422.	768.	2429.	1561.	1006.	319.	584.	504.	474.	439.	1750.	1046.	1098.
50. CHARLOTTE	721.	341.	647.	2271.	348.	566.	2279.	1355.	801.	363.	339.	226.	335.	540.	1491.	938.	921.

Table B.4, continued.

	TOLEDO	OKLAHOMA CITY	MIAMI	FORT WORTH	PORTLAND	HONOLULU	NEWARK	LOUISVILLE	LONG BEACH	TULSA	OAKLAND	AUSTIN	TUCSON	BATON ROUGE	NORFOLK	CHARLOTTE
1. NEW YORK	500.	1322.	1091.	1396.	2435.	0.	9.	649.	2449.	1222.	2556.	1509.	2118.	1193.	294.	531.
2. CHICAGO	211.	691.	1190.	823.	1751.	0.	701.	270.	1747.	594.	1845.	978.	1443.	814.	697.	588.
3. LOS ANGELES	1949.	1179.	2334.	1209.	825.	0.	2435.	1825.	20.	1267.	343.	1224.	440.	1595.	2349.	2114.
4. PHILADELPHIA	453.	1255.	1021.	1323.	2401.	0.	75.	580.	2391.	1155.	2507.	1434.	2053.	1114.	223.	451.
5. HOUSTON	1053.	415.	966.	236.	1831.	0.	1409.	802.	1365.	443.	1634.	147.	938.	254.	1202.	924.
6. DETROIT	54.	907.	1155.	1020.	1960.	0.	472.	316.	1984.	808.	2077.	1163.	1675.	936.	522.	505.
7. BALTIMORE	398.	1173.	956.	1236.	2351.	0.	163.	497.	2317.	1073.	2441.	1345.	1973.	1024.	170.	365.
8. DALLAS	951.	192.	1110.	28.	1627.	0.	1363.	726.	1234.	239.	1471.	181.	825.	368.	1194.	928.
9. SAN DIEGO	1935.	1138.	2266.	1152.	932.	0.	2417.	1797.	94.	1230.	455.	1153.	362.	1532.	2318.	2075.
10. SAN ANTONIO	1187.	423.	1147.	240.	1716.	0.	1573.	949.	1194.	489.	1479.	74.	764.	443.	1378.	1103.
11. INDIANAPOLIS	188.	687.	1026.	786.	1877.	0.	634.	107.	1809.	586.	1935.	925.	1475.	703.	571.	428.
12. WASHINGTON	392.	1148.	924.	1208.	2343.	0.	198.	473.	2296.	1049.	2425.	1314.	1949.	991.	147.	329.
13. MILWAUKEE	243.	730.	1269.	874.	1711.	0.	723.	349.	1747.	637.	1828.	1034.	1458.	888.	748.	659.
14. PHOENIX	1652.	840.	1977.	855.	1004.	0.	2130.	1504.	352.	934.	646.	868.	107.	1239.	2022.	1777.
15. SAN FRANCISCO	2064.	1385.	2589.	1453.	536.	0.	2555.	1981.	364.	1462.	8.	1498.	752.	1846.	2508.	2295.
16. MEMPHIS	572.	420.	872.	446.	1843.	0.	946.	321.	1599.	336.	1789.	558.	1216.	329.	778.	520.
17. CLEVELAND	96.	947.	1089.	1047.	2045.	0.	395.	311.	2048.	847.	2152.	1182.	1729.	927.	432.	436.
18. BOSTON	642.	1490.	1257.	1574.	2528.	0.	196.	823.	2595.	1390.	2683.	1692.	2278.	1382.	471.	721.
19. JACKSONVILLE	788.	984.	327.	934.	2432.	0.	832.	594.	2140.	915.	2360.	958.	1729.	567.	545.	341.
20. NEW ORLEANS	885.	576.	668.	468.	2056.	0.	1160.	622.	1665.	545.	1913.	459.	1244.	75.	924.	647.
21. SAN JOSE	2048.	1357.	2557.	1421.	567.	0.	2538.	1959.	322.	1435.	39.	1463.	712.	1814.	2487.	2271.
22. COLUMBUS	120.	849.	993.	936.	2024.	0.	468.	189.	1976.	748.	2099.	1065.	1641.	802.	422.	348.
23. ST. LOUIS	409.	457.	1060.	568.	1716.	0.	863.	241.	1589.	356.	1732.	718.	1246.	567.	768.	566.
24. SEATTLE	1929.	1521.	2729.	1659.	143.	0.	2392.	1937.	978.	1560.	676.	1767.	1218.	2026.	2429.	2279.
25. DENVER	1128.	503.	1724.	645.	978.	0.	1617.	1035.	837.	552.	938.	770.	617.	1008.	1561.	1355.
26. KANSAS CITY	606.	296.	1242.	464.	1490.	0.	1084.	479.	1357.	216.	1494.	635.	1033.	627.	1006.	801.
27. PITTSBURGH	202.	1010.	1012.	1093.	2155.	0.	307.	342.	2135.	909.	2249.	1216.	1803.	932.	319.	363.
28. NASHVILLE	417.	602.	816.	643.	1962.	0.	750.	154.	1777.	509.	1949.	752.	1404.	469.	584.	339.
29. ATLANTA	547.	754.	605.	748.	2165.	0.	739.	320.	1931.	672.	2126.	817.	1539.	458.	504.	226.
30. CINCINNATI	183.	755.	954.	837.	1976.	0.	559.	89.	1895.	655.	2029.	965.	1552.	707.	474.	335.
31. BUFFALO	253.	1117.	1184.	1220.	2146.	0.	284.	483.	2198.	1017.	2285.	1355.	1890.	1094.	439.	540.
32. EL PASO	1435.	577.	1639.	541.	1285.	0.	1890.	1251.	693.	677.	986.	527.	265.	908.	1750.	1491.
33. MINNEAPOLIS	540.	692.	1512.	872.	1419.	0.	1007.	605.	1530.	625.	1572.	1044.	1295.	1010.	1046.	938.
34. OMAHA	645.	408.	1401.	593.	1360.	0.	1135.	582.	1316.	354.	1413.	766.	1035.	795.	1098.	921.
35. TOLEDO	0.	864.	1112.	972.	1953.	0.	491.	263.	1954.	764.	2056.	1113.	1639.	882.	510.	467.
36. OKLAHOMA CITY	864.	0.	1225.	190.	1481.	0.	1314.	675.	1179.	100.	1377.	360.	804.	505.	1184.	937.
37. MIAMI	1112.	1225.	0.	1135.	2701.	0.	1089.	920.	2329.	1172.	2581.	1113.	1904.	743.	798.	653.
38. FORT WORTH	972.	190.	1135.	0.	1607.	0.	1388.	750.	1206.	248.	1446.	172.	797.	393.	1222.	956.
39. PORTLAND	1953.	1481.	2701.	1607.	0.	0.	2426.	1942.	845.	1528.	534.	1704.	1110.	1984.	2445.	2281.
40. HONOLULU	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
41. NEWARK	491.	1314.	1089.	1388.	2426.	0.	0.	641.	2440.	1214.	2547.	1502.	2109.	1187.	292.	526.
42. LOUISVILLE	263.	675.	920.	750.	1942.	0.	641.	0.	1827.	576.	1973.	876.	1476.	620.	527.	343.
43. LONG BEACH	1954.	1179.	2329.	1206.	845.	0.	2440.	1827.	0.	1268.	360.	1219.	431.	1591.	2351.	2115.
44. TULSA	764.	100.	1172.	248.	1528.	0.	1214.	576.	1268.	0.	1454.	419.	901.	479.	1088.	846.
45. OAKLAND	2056.	1377.	2581.	1446.	534.	0.	2547.	1973.	360.	1454.	0.	1491.	746.	1838.	2500.	2287.
46. AUSTIN	1113.	360.	1113.	172.	1704.	0.	1502.	876.	1219.	419.	1491.	0.	792.	391.	1311.	1037.
47. TUCSON	1639.	804.	1904.	797.	1110.	0.	2109.	1476.	431.	901.	746.	792.	0.	1171.	1987.	1736.
48. BATON ROUGE	882.	505.	743.	393.	1984.	0.	1187.	620.	1591.	479.	1838.	391.	1171.	0.	962.	684.
49. NORFOLK	510.	1184.	798.	1222.	2445.	0.	292.	527.	2351.	1088.	2500.	1311.	1987.	962.	0.	278.
50. CHARLOTTE	467.	937.	653.	956.	2281.	0.	526.	343.	2115.	846.	2287.	1037.	1736.	684.	278.	0.

Table B.5. City-Pair Circuities, Automobile

	NEW YORK	CHICAGO	LOS ANGELES	PHILADELPHIA	HOUSTON	DETROIT	BALTIMORE	DALLAS	SAN DIEGO	SAN ANTONIO	INDIANAPOLIS	WASHINGTON	MILWAUKEE	PHOENIX	SAN FRANCISCO	MEMPHIS	CLEVELAND
1. NEW YORK	0.000	1.169	1.163	1.254	1.201	1.360	1.173	1.150	1.170	1.170	1.141	1.098	1.259	1.161	1.221	1.177	1.178
2. CHICAGO	1.169	0.000	1.213	1.206	1.243	1.214	1.287	1.159	1.248	1.146	1.073	1.243	1.122	1.244	1.324	1.203	1.158
3. LOS ANGELES	1.163	1.213	0.000	1.167	1.126	1.206	1.194	1.153	1.050	1.130	1.168	1.188	1.208	1.101	1.203	1.157	1.188
4. PHILADELPHIA	1.254	1.206	1.167	0.000	1.206	1.431	1.091	1.148	1.175	1.171	1.161	1.108	1.287	1.168	1.222	1.178	1.267
5. HOUSTON	1.201	1.243	1.126	1.206	0.000	1.259	1.214	1.054	1.158	1.002	1.288	1.214	1.255	1.134	1.194	1.357	1.257
6. DETROIT	1.360	1.214	1.206	1.431	1.259	0.000	1.536	1.155	1.211	1.153	1.156	1.444	1.503	1.202	1.283	1.210	1.972
7. BALTIMORE	1.173	1.287	1.194	1.091	1.214	1.536	0.000	1.149	1.204	1.175	1.283	1.103	1.354	1.202	1.246	1.184	1.401
8. DALLAS	1.150	1.159	1.153	1.148	1.054	1.155	1.149	0.000	1.176	1.083	1.148	1.144	1.194	1.169	1.203	1.080	1.170
9. SAN DIEGO	1.170	1.248	1.050	1.175	1.158	1.211	1.204	1.176	0.000	1.172	1.180	1.198	1.244	1.190	1.167	1.182	1.196
10. SAN ANTONIO	1.170	1.146	1.130	1.171	1.002	1.153	1.175	1.083	1.172	0.000	1.151	1.174	1.171	1.139	1.194	1.152	1.172
11. INDIANAPOLIS	1.141	1.073	1.168	1.161	1.288	1.156	1.283	1.148	1.180	1.151	0.000	1.251	1.101	1.170	1.234	1.300	1.225
12. WASHINGTON	1.098	1.243	1.188	1.108	1.214	1.444	1.103	1.144	1.198	1.174	1.251	0.000	1.306	1.196	1.238	1.178	1.286
13. MILWAUKEE	1.259	1.122	1.208	1.287	1.255	1.503	1.354	1.194	1.244	1.171	1.101	1.306	0.000	1.235	1.335	1.207	1.332
14. PHOENIX	1.161	1.244	1.101	1.168	1.134	1.202	1.202	1.169	1.190	1.139	1.170	1.196	1.235	0.000	1.242	1.180	1.187
15. SAN FRANCISCO	1.221	1.324	1.203	1.222	1.194	1.283	1.246	1.203	1.167	1.194	1.234	1.238	1.335	1.242	0.000	1.190	1.259
16. MEMPHIS	1.177	1.203	1.157	1.178	1.357	1.210	1.184	1.080	1.182	1.152	1.300	1.178	1.207	1.180	1.190	0.000	1.181
17. CLEVELAND	1.178	1.158	1.188	1.267	1.257	1.972	1.401	1.170	1.196	1.172	1.225	1.286	1.332	1.187	1.259	1.181	0.000
18. BOSTON	1.152	1.197	1.183	1.182	1.198	1.371	1.163	1.159	1.186	1.172	1.184	1.124	1.293	1.178	1.245	1.182	1.201
19. JACKSONVILLE	1.170	1.246	1.148	1.174	1.119	1.308	1.163	1.151	1.161	1.097	1.285	1.164	1.238	1.155	1.192	1.213	1.262
20. NEW ORLEANS	1.156	1.178	1.142	1.161	1.143	1.165	1.167	1.170	1.164	1.091	1.178	1.168	1.180	1.153	1.196	1.122	1.173
21. SAN JOSE	1.252	1.346	1.183	1.254	1.184	1.320	1.279	1.234	1.148	1.184	1.276	1.271	1.352	1.228	1.353	1.240	1.295
22. COLUMBUS	1.201	1.101	1.160	1.198	1.260	1.258	1.383	1.149	1.170	1.160	1.068	1.331	1.190	1.160	1.223	1.166	1.191
23. ST. LOUIS	1.122	1.141	1.176	1.139	1.282	1.147	1.229	1.156	1.192	1.144	1.060	1.211	1.193	1.186	1.238	1.173	1.152
24. SEATTLE	1.227	1.221	1.292	1.229	1.254	1.243	1.243	1.270	1.276	1.281	1.228	1.229	1.206	1.300	1.256	1.279	1.223
25. DENVER	1.120	1.141	1.285	1.121	1.188	1.157	1.157	1.218	1.423	1.199	1.090	1.143	1.136	1.554	1.567	1.194	1.114
26. KANSAS CITY	1.123	1.334	1.193	1.132	1.148	1.200	1.195	1.112	1.208	1.105	1.094	1.179	1.244	1.199	1.267	1.223	1.169
27. PITTSBURGH	1.229	1.193	1.160	1.215	1.262	1.557	1.476	1.153	1.169	1.167	1.107	1.316	1.299	1.159	1.223	1.182	1.230
28. NASHVILLE	1.207	1.182	1.159	1.213	1.297	1.163	1.227	1.072	1.178	1.135	1.166	1.222	1.172	1.174	1.199	1.054	1.172
29. ATLANTA	1.155	1.227	1.160	1.164	1.200	1.231	1.174	1.132	1.168	1.169	1.276	1.177	1.215	1.163	1.187	1.171	1.307
30. CINCINNATI	1.193	1.130	1.172	1.201	1.283	1.123	1.330	1.159	1.185	1.171	1.091	1.302	1.159	1.178	1.230	1.194	1.148
31. BUFFALO	1.385	1.216	1.196	1.812	1.240	1.726	2.198	1.162	1.200	1.165	1.186	2.006	1.402	1.191	1.270	1.169	1.118
32. EL PASO	1.130	1.173	1.138	1.140	1.108	1.143	1.155	1.104	1.211	1.118	1.118	1.150	1.220	1.168	1.222	1.111	1.138
33. MINNEAPOLIS	1.241	1.213	1.307	1.252	1.139	1.324	1.289	1.119	1.355	1.116	1.189	1.254	1.173	1.344	1.497	1.174	1.248
34. OMAHA	1.132	1.162	1.228	1.165	1.119	1.182	1.216	1.110	1.311	1.100	1.293	1.196	1.145	1.312	1.408	1.212	1.107
35. TOLEDO	1.194	1.166	1.210	1.269	1.326	1.099	1.386	1.240	1.243	1.223	1.720	1.309	1.388	1.242	1.308	1.298	1.264
36. OKLAHOMA CITY	1.114	1.151	1.167	1.128	1.054	1.120	1.187	1.043	1.205	1.087	1.076	1.179	1.214	1.209	1.202	1.128	1.119
37. MIAMI	1.234	1.185	1.196	1.233	1.292	1.232	1.215	1.239	1.215	1.254	1.202	1.214	1.183	1.213	1.218	1.200	1.232
38. FORT WORTH	1.151	1.171	1.153	1.149	1.137	1.161	1.150	1.102	1.177	1.111	1.155	1.145	1.207	1.170	1.205	1.086	1.174
39. PORTLAND	1.242	1.276	1.288	1.250	1.260	1.286	1.267	1.272	1.267	1.297	1.267	1.255	1.258	1.266	1.263	1.268	1.246
40. HONOLULU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41. NEWARK	1.301	1.168	1.162	1.182	1.209	1.361	1.144	1.158	1.169	1.177	1.138	1.141	1.258	1.160	1.221	1.189	1.175
42. LOUISVILLE	1.200	1.075	1.164	1.215	1.299	1.161	1.335	1.158	1.179	1.173	1.053	1.321	1.090	1.173	1.218	1.209	1.148
43. LONG BEACH	1.173	1.226	1.505	1.177	1.152	1.218	1.205	1.180	1.011	1.161	1.182	1.199	1.221	1.201	1.228	1.176	1.200
44. TULSA	1.132	1.187	1.166	1.147	1.111	1.147	1.213	1.066	1.197	1.080	1.107	1.204	1.250	1.197	1.209	1.714	1.145
45. OAKLAND	1.229	1.335	1.188	1.230	1.193	1.293	1.254	1.216	1.155	1.193	1.244	1.246	1.347	1.239	1.190	1.201	1.268
46. AUSTIN	1.172	1.151	1.174	1.173	1.111	1.158	1.178	1.068	1.213	1.074	1.157	1.175	1.177	1.203	1.237	1.159	1.177
47. TUCSON	1.166	1.241	1.149	1.174	1.140	1.201	1.188	1.154	1.290	1.157	1.176	1.182	1.291	1.048	1.226	1.155	1.189
48. BATON ROUGE	1.196	1.183	1.139	1.203	1.079	1.213	1.213	1.167	1.162	1.047	1.253	1.214	1.187	1.149	1.196	1.154	1.213
49. NORFOLK	1.467	1.298	1.197	1.544	1.203	1.488	1.450	1.189	1.211	1.186	1.296	1.408	1.331	1.212	1.236	1.256	1.385
50. CHARLOTTE	1.152	1.343	1.169	1.164	1.178	1.369	1.171	1.146	1.181	1.160	1.458	1.178	1.336	1.179	1.203	1.195	1.317

Table B.5, continued.

	BOSTON	JACKSONVILLE	NEW ORLEANS	SAN JOSE	COLUMBUS	ST. LOUIS	SEATTLE	DENVER	KANSAS CITY	PITTSBURGH	NASHVILLE	ATLANTA	CINCINNATI	BUFFALO	EL PASO	MINNEAPOLIS	OMAHA
1. NEW YORK	1.152	1.170	1.156	1.252	1.201	1.122	1.227	1.120	1.123	1.229	1.207	1.155	1.193	1.385	1.130	1.241	1.132
2. CHICAGO	1.197	1.246	1.178	1.346	1.101	1.141	1.221	1.141	1.334	1.193	1.182	1.227	1.130	1.216	1.173	1.213	1.162
3. LOS ANGELES	1.183	1.148	1.142	1.183	1.160	1.176	1.292	1.285	1.193	1.160	1.159	1.160	1.172	1.196	1.138	1.307	1.228
4. PHILADELPHIA	1.182	1.174	1.161	1.254	1.198	1.139	1.229	1.121	1.132	1.215	1.213	1.164	1.201	1.812	1.140	1.252	1.165
5. HOUSTON	1.198	1.119	1.143	1.184	1.260	1.282	1.254	1.188	1.148	1.262	1.297	1.200	1.283	1.240	1.108	1.139	1.119
6. DETROIT	1.371	1.308	1.165	1.320	1.258	1.147	1.243	1.157	1.200	1.557	1.163	1.231	1.123	1.726	1.143	1.324	1.182
7. BALTIMORE	1.163	1.163	1.167	1.279	1.383	1.229	1.243	1.157	1.195	1.476	1.227	1.174	1.330	2.198	1.155	1.289	1.216
8. DALLAS	1.159	1.151	1.170	1.234	1.149	1.156	1.270	1.218	1.112	1.153	1.072	1.132	1.159	1.162	1.104	1.119	1.110
9. SAN DIEGO	1.186	1.161	1.164	1.148	1.170	1.192	1.276	1.423	1.208	1.169	1.178	1.168	1.185	1.200	1.211	1.355	1.311
10. SAN ANTONIO	1.172	1.097	1.091	1.184	1.160	1.144	1.281	1.199	1.105	1.167	1.135	1.169	1.171	1.165	1.118	1.116	1.100
11. INDIANAPOLIS	1.184	1.285	1.178	1.276	1.068	1.060	1.228	1.090	1.094	1.107	1.166	1.276	1.091	1.186	1.118	1.189	1.293
12. WASHINGTON	1.124	1.164	1.168	1.271	1.331	1.211	1.229	1.143	1.179	1.316	1.222	1.177	1.302	2.006	1.150	1.254	1.196
13. MILWAUKEE	1.293	1.238	1.180	1.352	1.190	1.193	1.206	1.136	1.244	1.299	1.172	1.215	1.159	1.402	1.220	1.173	1.145
14. PHOENIX	1.178	1.155	1.153	1.228	1.160	1.186	1.300	1.554	1.199	1.159	1.174	1.163	1.178	1.191	1.168	1.344	1.312
15. SAN FRANCISCO	1.245	1.192	1.196	1.353	1.223	1.238	1.256	1.567	1.267	1.223	1.199	1.187	1.230	1.270	1.222	1.497	1.408
16. MEMPHIS	1.182	1.213	1.122	1.240	1.166	1.173	1.279	1.194	1.223	1.182	1.054	1.171	1.194	1.169	1.111	1.174	1.212
17. CLEVELAND	1.201	1.262	1.173	1.295	1.191	1.152	1.223	1.114	1.169	1.230	1.172	1.307	1.148	1.118	1.138	1.248	1.107
18. BOSTON	0.000	1.176	1.156	1.273	1.232	1.156	1.260	1.146	1.160	1.259	1.205	1.155	1.214	1.169	1.144	1.290	1.155
19. JACKSONVILLE	1.176	0.000	1.132	1.206	1.322	1.269	1.265	1.203	1.230	1.327	1.213	1.242	1.315	1.325	1.132	1.252	1.237
20. NEW ORLEANS	1.156	1.132	0.000	1.200	1.171	1.143	1.263	1.227	1.243	1.217	1.166	1.153	1.174	1.177	1.132	1.163	1.225
21. SAN JOSE	1.273	1.206	1.200	0.000	1.262	1.287	1.282	1.540	1.324	1.258	1.244	1.229	1.271	1.304	1.211	1.497	1.402
22. COLUMBUS	1.232	1.322	1.171	1.262	0.000	1.070	1.204	1.090	1.087	1.141	1.162	1.320	1.049	1.170	1.116	1.170	1.176
23. ST. LOUIS	1.156	1.269	1.143	1.287	1.070	0.000	1.268	1.062	1.050	1.091	1.370	1.282	1.146	1.149	1.131	1.156	1.238
24. SEATTLE	1.260	1.265	1.263	1.282	1.204	1.268	0.000	1.325	1.285	1.221	1.283	1.276	1.221	1.263	1.258	1.211	1.275
25. DENVER	1.146	1.203	1.227	1.540	1.090	1.062	1.325	0.000	1.067	1.103	1.167	1.192	1.097	1.139	1.289	1.348	1.122
26. KANSAS CITY	1.160	1.230	1.243	1.324	1.087	1.050	1.285	1.067	0.000	1.102	1.263	1.254	1.117	1.177	1.220	1.122	1.151
27. PITTSBURGH	1.259	1.327	1.217	1.258	1.141	1.091	1.221	1.103	1.102	0.000	1.214	1.458	1.128	1.872	1.118	1.238	1.149
28. NASHVILLE	1.205	1.213	1.166	1.244	1.162	1.370	1.283	1.167	1.263	1.214	0.000	1.174	1.187	1.168	1.105	1.271	1.296
29. ATLANTA	1.155	1.242	1.153	1.229	1.320	1.282	1.276	1.192	1.254	1.458	1.174	0.000	1.272	1.317	1.120	1.254	1.268
30. CINCINNATI	1.214	1.315	1.174	1.271	1.049	1.146	1.221	1.097	1.117	1.128	1.187	1.272	0.000	1.142	1.141	1.183	1.266
31. BUFFALO	1.169	1.325	1.177	1.304	1.170	1.149	1.263	1.139	1.177	1.872	1.168	1.317	1.142	0.000	1.140	1.343	1.148
32. EL PASO	1.144	1.132	1.132	1.211	1.116	1.131	1.258	1.289	1.220	1.118	1.105	1.120	1.141	1.140	0.000	1.280	1.224
33. MINNEAPOLIS	1.290	1.252	1.163	1.497	1.170	1.156	1.211	1.348	1.122	1.238	1.271	1.254	1.183	1.343	1.280	0.000	1.405
34. OMAHA	1.155	1.237	1.225	1.402	1.176	1.238	1.275	1.122	1.151	1.149	1.296	1.268	1.266	1.148	1.224	1.405	0.000
35. TOLEDO	1.217	1.309	1.221	1.328	1.228	1.336	1.224	1.147	1.313	1.297	1.282	1.319	1.376	1.244	1.193	1.253	1.164
36. OKLAHOMA CITY	1.135	1.209	1.246	1.269	1.082	1.084	1.322	1.313	1.185	1.092	1.133	1.151	1.122	1.123	1.165	1.175	1.113
37. MIAMI	1.245	1.129	1.347	1.233	1.263	1.213	1.257	1.214	1.207	1.287	1.152	1.137	1.214	1.297	1.216	1.207	1.209
38. FORT WORTH	1.160	1.150	1.174	1.234	1.153	1.170	1.267	1.207	1.155	1.156	1.076	1.131	1.163	1.166	1.104	1.145	1.090
39. PORTLAND	1.269	1.255	1.259	1.293	1.253	1.244	1.224	1.319	1.264	1.248	1.264	1.262	1.258	1.278	1.300	1.270	1.271
40. HONOLULU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41. NEWARK	1.178	1.177	1.164	1.252	1.198	1.120	1.226	1.119	1.122	1.226	1.222	1.167	1.190	1.469	1.128	1.240	1.131
42. LOUISVILLE	1.212	1.322	1.167	1.261	1.093	1.075	1.241	1.066	1.063	1.142	1.166	1.351	1.140	1.142	1.140	1.191	1.207
43. LONG BEACH	1.192	1.164	1.163	1.212	1.173	1.193	1.296	1.310	1.212	1.172	1.175	1.175	1.186	1.207	1.193	1.319	1.245
44. TULSA	1.153	1.411	1.418	1.271	1.107	1.136	1.355	1.381	1.159	1.113	1.476	1.442	1.156	1.145	1.143	1.140	1.255
45. OAKLAND	1.253	1.200	1.206	1.209	1.233	1.249	1.275	1.570	1.281	1.232	1.209	1.196	1.240	1.279	1.221	1.511	1.424
46. AUSTIN	1.175	1.127	1.146	1.228	1.165	1.151	1.295	1.253	1.100	1.172	1.136	1.228	1.177	1.170	1.215	1.111	1.089
47. TUCSON	1.180	1.149	1.152	1.215	1.166	1.196	1.280	1.654	1.304	1.164	1.149	1.148	1.188	1.190	1.224	1.394	1.349
48. BATON ROUGE	1.191	1.133	1.188	1.200	1.216	1.170	1.263	1.226	1.317	1.244	1.253	1.235	1.231	1.206	1.123	1.191	1.283
49. NORFOLK	1.379	1.252	1.183	1.270	1.426	1.231	1.243	1.146	1.189	1.436	1.317	1.201	1.334	1.806	1.170	1.277	1.266
50. CHARLOTTE	1.153	1.171	1.139	1.240	1.396	1.340	1.274	1.183	1.260	1.473	1.219	1.104	1.538	1.423	1.135	1.299	1.306

Table B.5, continued.

	TOLEDO	OKLAHOMA CITY	MIAMI	FORT WORTH	PORTLAND	HONOLULU	NEWARK	LOUISVILLE	LONG BEACH	TULSA	OAKLAND	AUSTIN	TUCSON	BATON ROUGE	NORFOLK	CHARLOTTE
1. NEW YORK	1.194	1.114	1.234	1.151	1.242	0.000	1.301	1.200	1.173	1.132	1.229	1.172	1.166	1.196	1.467	1.152
2. CHICAGO	1.166	1.151	1.185	1.171	1.276	0.000	1.168	1.075	1.226	1.187	1.335	1.151	1.241	1.183	1.298	1.343
3. LOS ANGELES	1.210	1.167	1.196	1.153	1.288	0.000	1.162	1.164	1.506	1.166	1.188	1.174	1.149	1.139	1.197	1.169
4. PHILADELPHIA	1.269	1.128	1.233	1.149	1.250	0.000	1.182	1.215	1.177	1.147	1.230	1.173	1.174	1.203	1.544	1.164
5. HOUSTON	1.326	1.054	1.292	1.137	1.260	0.000	1.209	1.299	1.152	1.111	1.193	1.111	1.140	1.079	1.203	1.178
6. DETROIT	1.098	1.120	1.232	1.161	1.286	0.000	1.361	1.161	1.218	1.147	1.293	1.158	1.201	1.213	1.488	1.369
7. BALTIMORE	1.386	1.187	1.215	1.150	1.267	0.000	1.144	1.335	1.205	1.213	1.254	1.178	1.188	1.213	1.450	1.171
8. DALLAS	1.240	1.043	1.239	1.102	1.272	0.000	1.158	1.158	1.180	1.066	1.216	1.068	1.154	1.167	1.189	1.146
9. SAN DIEGO	1.243	1.205	1.215	1.177	1.267	0.000	1.169	1.179	1.011	1.197	1.155	1.213	1.290	1.162	1.211	1.181
10. SAN ANTONIO	1.223	1.087	1.254	1.111	1.297	0.000	1.177	1.173	1.161	1.080	1.193	1.074	1.157	1.047	1.186	1.160
11. INDIANAPOLIS	1.720	1.076	1.202	1.155	1.267	0.000	1.138	1.053	1.182	1.107	1.244	1.157	1.176	1.253	1.296	1.458
12. WASHINGTON	1.309	1.179	1.214	1.145	1.255	0.000	1.141	1.321	1.199	1.204	1.246	1.175	1.182	1.214	1.408	1.178
13. MILWAUKEE	1.388	1.214	1.183	1.207	1.258	0.000	1.258	1.090	1.221	1.250	1.347	1.177	1.291	1.187	1.331	1.336
14. PHOENIX	1.242	1.209	1.213	1.170	1.266	0.000	1.160	1.173	1.201	1.197	1.239	1.203	1.048	1.149	1.212	1.179
15. SAN FRANCISCO	1.308	1.202	1.218	1.205	1.263	0.000	1.221	1.218	1.228	1.209	1.188	1.237	1.226	1.196	1.236	1.203
16. MEMPHIS	1.298	1.128	1.200	1.086	1.268	0.000	1.189	1.209	1.176	1.714	1.201	1.159	1.155	1.154	1.256	1.195
17. CLEVELAND	1.264	1.119	1.232	1.174	1.246	0.000	1.175	1.148	1.200	1.145	1.268	1.177	1.189	1.213	1.385	1.317
18. BOSTON	1.217	1.135	1.245	1.160	1.269	0.000	1.178	1.212	1.192	1.153	1.253	1.175	1.180	1.191	1.379	1.153
19. JACKSONVILLE	1.309	1.209	1.129	1.150	1.255	0.000	1.177	1.322	1.164	1.411	1.200	1.127	1.149	1.133	1.252	1.171
20. NEW ORLEANS	1.221	1.246	1.347	1.174	1.259	0.000	1.164	1.167	1.163	1.418	1.206	1.146	1.152	1.188	1.183	1.139
21. SAN JOSE	1.328	1.269	1.233	1.234	1.293	0.000	1.252	1.261	1.212	1.271	1.209	1.228	1.215	1.200	1.270	1.240
22. COLUMBUS	1.228	1.082	1.263	1.153	1.253	0.000	1.198	1.093	1.173	1.107	1.233	1.165	1.166	1.216	1.426	1.396
23. ST. LOUIS	1.336	1.084	1.213	1.170	1.244	0.000	1.120	1.075	1.193	1.136	1.249	1.151	1.196	1.170	1.231	1.340
24. SEATTLE	1.224	1.322	1.257	1.267	1.224	0.000	1.226	1.241	1.296	1.355	1.275	1.295	1.280	1.263	1.243	1.274
25. DENVER	1.147	1.313	1.214	1.207	1.319	0.000	1.119	1.066	1.310	1.381	1.570	1.253	1.654	1.226	1.146	1.183
26. KANSAS CITY	1.313	1.185	1.207	1.155	1.264	0.000	1.122	1.063	1.212	1.159	1.281	1.100	1.304	1.317	1.189	1.260
27. PITTSBURGH	1.297	1.092	1.287	1.156	1.248	0.000	1.226	1.142	1.172	1.113	1.232	1.172	1.164	1.244	1.436	1.473
28. NASHVILLE	1.282	1.133	1.152	1.076	1.264	0.000	1.222	1.166	1.175	1.476	1.209	1.136	1.149	1.253	1.317	1.219
29. ATLANTA	1.319	1.151	1.137	1.131	1.262	0.000	1.167	1.351	1.175	1.442	1.196	1.228	1.148	1.235	1.201	1.104
30. CINCINNATI	1.376	1.122	1.214	1.163	1.258	0.000	1.190	1.140	1.186	1.156	1.240	1.177	1.188	1.231	1.334	1.538
31. BUFFALO	1.244	1.123	1.297	1.166	1.278	0.000	1.469	1.142	1.207	1.145	1.279	1.170	1.190	1.206	1.806	1.423
32. EL PASO	1.193	1.165	1.216	1.104	1.300	0.000	1.128	1.140	1.193	1.143	1.221	1.215	1.224	1.123	1.170	1.135
33. MINNEAPOLIS	1.253	1.175	1.207	1.145	1.270	0.000	1.240	1.191	1.319	1.140	1.511	1.111	1.394	1.191	1.277	1.299
34. OMAHA	1.164	1.113	1.209	1.090	1.271	0.000	1.131	1.207	1.245	1.255	1.424	1.089	1.349	1.283	1.266	1.306
35. TOLEDO	0.000	1.205	1.259	1.244	1.269	0.000	1.192	1.349	1.222	1.245	1.318	1.233	1.243	1.272	1.412	1.355
36. OKLAHOMA CITY	1.205	0.000	1.241	1.017	1.317	0.000	1.112	1.117	1.193	1.015	1.216	1.055	1.239	1.246	1.217	1.169
37. MIAMI	1.259	1.241	0.000	1.238	1.253	0.000	1.238	1.217	1.211	1.384	1.226	1.268	1.217	1.311	1.318	1.176
38. FORT WORTH	1.244	1.017	1.238	0.000	1.270	0.000	1.159	1.162	1.181	1.152	1.218	1.084	1.156	1.171	1.188	1.146
39. PORTLAND	1.269	1.317	1.253	1.270	0.000	0.000	1.242	1.232	1.293	1.343	1.287	1.308	1.246	1.260	1.260	1.268
40. HONOLULU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41. NEWARK	1.192	1.112	1.238	1.159	1.242	0.000	0.000	1.198	1.173	1.130	1.229	1.179	1.165	1.204	1.484	1.167
42. LOUISVILLE	1.349	1.117	1.217	1.162	1.232	0.000	1.198	0.000	1.179	1.153	1.228	1.180	1.186	1.238	1.303	1.665
43. LONG BEACH	1.222	1.193	1.211	1.181	1.293	0.000	1.173	1.179	0.000	1.189	1.213	1.204	1.240	1.161	1.208	1.183
44. TULSA	1.245	1.015	1.384	1.152	1.343	0.000	1.130	1.153	1.189	0.000	1.223	1.068	1.219	1.428	1.242	1.375
45. OAKLAND	1.318	1.216	1.226	1.218	1.287	0.000	1.229	1.228	1.213	1.223	0.000	1.237	1.223	1.207	1.244	1.211
46. AUSTIN	1.233	1.055	1.268	1.084	1.308	0.000	1.179	1.180	1.204	1.068	1.237	0.000	1.218	1.118	1.226	1.207
47. TUCSON	1.243	1.239	1.217	1.156	1.246	0.000	1.165	1.186	1.240	1.219	1.223	1.218	0.000	1.147	1.194	1.162
48. BATON ROUGE	1.272	1.246	1.311	1.171	1.260	0.000	1.204	1.238	1.161	1.428	1.207	1.118	1.147	0.000	1.217	1.192
49. NORFOLK	1.412	1.217	1.318	1.188	1.260	0.000	1.484	1.303	1.208	1.242	1.244	1.226	1.194	1.217	0.000	1.279
50. CHARLOTTE	1.355	1.169	1.176	1.146	1.268	0.000	1.167	1.665	1.183	1.375	1.211	1.207	1.162	1.192	1.279	0.000

Table B.6. City-Pair Circuities, Bus

	NEW YORK 1	CHICAGO 2	LOS ANGELES 3	PHILADELPHIA 4	HOUSTON 5	DETROIT 6	BALTIMORE 7	DALLAS 8	SAN DIEGO 9	SAN ANTONIO 10
1. NEW YORK	0.0	1.137	1.148	1.241	1.173	1.337	1.156	1.148	1.160	1.167
2. CHICAGO	1.137	0.0	1.209	1.139	1.259	1.125	1.143	1.170	1.245	1.151
3. LOS ANGELES	1.148	1.209	0.0	1.143	1.164	1.199	1.166	1.142	1.112	1.165
4. PHILADELPHIA	1.241	1.139	1.143	0.0	1.166	1.327	1.069	1.136	1.157	1.159
5. HOUSTON	1.173	1.259	1.164	1.166	0.0	1.314	1.173	1.080	1.157	1.039
6. DETROIT	1.337	1.125	1.199	1.327	1.314	0.0	1.405	1.209	1.231	1.194
7. BALTIMORE	1.156	1.143	1.166	1.069	1.173	1.405	0.0	1.138	1.181	1.164
8. DALLAS	1.148	1.170	1.142	1.136	1.080	1.209	1.138	0.0	1.148	1.071
9. SAN DIEGO	1.160	1.245	1.112	1.157	1.157	1.231	1.181	1.148	0.0	1.162
10. SAN ANTONIO	1.167	1.151	1.165	1.159	1.039	1.194	1.164	1.071	1.162	0.0
11. INDIANAPOLIS	1.122	1.098	1.155	1.106	1.308	1.160	1.201	1.162	1.173	1.159
12. WASHINGTON	1.142	1.154	1.197	1.076	1.173	1.317	1.047	1.135	1.176	1.163
13. MILWAUKEE	1.222	1.073	1.260	1.216	1.266	1.403	1.212	1.200	1.292	1.226
14. PHOENIX	1.150	1.235	1.090	1.147	1.190	1.221	1.175	1.173	1.190	1.194
15. SAN FRANCISCO	1.150	1.156	1.094	1.152	1.233	1.155	1.156	1.204	1.100	1.229
16. MEMPHIS	1.159	1.106	1.171	1.144	1.475	1.147	1.149	1.116	1.170	1.171
17. CLEVELAND	1.170	1.093	1.172	1.161	1.295	1.884	1.258	1.170	1.185	1.169
18. BOSTON	1.084	1.142	1.187	1.131	1.285	1.313	1.118	1.149	1.172	1.162
19. JACKSONVILLE	1.148	1.196	1.171	1.133	1.112	1.237	1.120	1.273	1.158	1.098
20. NEW ORLEANS	1.119	1.110	1.171	1.109	1.121	1.136	1.112	1.353	1.159	1.091
21. SAN JOSE	1.175	1.190	1.101	1.178	1.204	1.185	1.183	1.261	1.189	1.254
22. COLUMBUS	1.157	1.163	1.144	1.141	1.308	1.172	1.284	1.161	1.160	1.162
23. ST. LOUIS	1.098	1.099	1.167	1.088	1.321	1.222	1.159	1.192	1.191	1.165
24. SEATTLE	1.198	1.194	1.180	1.190	1.324	1.208	1.185	1.350	1.182	1.305
25. DENVER	1.120	1.085	1.502	1.029	1.278	1.094	1.120	1.341	1.481	1.187
26. KANSAS CITY	1.119	1.271	1.273	1.108	1.156	1.880	1.159	1.110	1.282	1.099
27. PITTSBURGH	1.169	1.137	1.144	1.129	1.280	1.460	1.150	1.156	1.159	1.167
28. NASHVILLE	1.198	1.157	1.171	1.238	1.345	1.123	1.259	1.096	1.167	1.149
29. ATLANTA	1.155	1.235	1.174	1.145	1.193	1.171	1.155	1.200	1.176	1.263
30. CINCINNATI	1.161	1.138	1.158	1.159	1.332	1.097	1.226	1.162	1.178	1.170
31. BUFFALO	1.525	1.156	1.198	1.439	1.267	1.656	1.365	1.157	1.187	1.158
32. EL PASO	1.132	1.185	1.180	1.132	1.143	1.184	1.143	1.090	1.171	1.144
33. MINNEAPOLIS	1.194	1.143	1.317	1.181	1.131	1.239	1.169	1.103	1.342	1.100
34. OMAHA	1.107	1.056	1.257	1.110	1.194	1.082	1.117	1.202	1.302	1.177
35. TOLEDO	1.168	1.100	1.182	1.163	1.283	1.099	1.157	1.164	1.195	1.160
36. OKLAHOMA CITY	1.103	1.144	1.145	1.100	1.083	1.164	1.149	1.075	1.193	1.125
37. MIAMI	1.199	1.161	1.210	1.183	1.270	1.176	1.164	1.324	1.205	1.242
38. FORT WORTH	1.150	1.194	1.170	1.138	1.112	1.214	1.140	1.097	1.149	1.106
39. PORTLAND	1.220	1.235	1.162	1.215	1.327	1.239	1.213	1.287	1.297	1.329
40. HONOLULU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41. NEWARK	1.091	1.166	1.157	1.195	1.172	1.384	1.138	1.148	1.169	1.166
42. LOUISVILLE	1.256	1.083	1.158	1.177	1.324	1.138	1.245	1.162	1.180	1.173
43. LONG BEACH	1.547	1.194	1.148	1.133	1.152	1.191	1.155	1.134	1.080	1.161
44. TULSA	1.107	1.153	1.147	1.104	1.129	1.178	1.157	1.074	1.188	1.078
45. OAKLAND	1.152	1.158	1.123	1.153	1.235	1.156	1.173	1.206	1.122	1.233
46. AUSTIN	1.171	1.160	1.205	1.163	1.118	1.204	1.168	1.068	1.200	1.033
47. TUCSON	1.187	1.324	1.153	1.130	1.161	1.209	1.174	1.113	1.147	1.168
48. BATON ROUGE	1.161	1.236	1.175	1.154	1.095	1.225	1.161	1.417	1.163	1.248
49. NORFOLK	1.413	1.304	1.182	1.414	1.241	1.371	1.291	1.302	1.176	1.191
50. CHARLOTTE	1.225	1.367	1.137	1.167	1.158	1.280	1.179	1.184	1.134	1.149

Table B.6, continued.

	INDIANAPOLIS 11	WASHINGTON 12	MILWAUKEE 13	PHOENIX 14	SAN FRANCISCO 15	MEMPHIS 16	CLEVELAND 17	BOSTON 18	JACKSONVILLE 19	NEW ORLEANS 20
1. NEW YORK	1.122	1.142	1.222	1.150	1.150	1.159	1.170	1.084	1.148	1.119
2. CHICAGO	1.098	1.154	1.073	1.235	1.156	1.106	1.093	1.142	1.196	1.110
3. LOS ANGELES	1.155	1.197	1.260	1.090	1.094	1.171	1.172	1.187	1.171	1.171
4. PHILADELPHIA	1.106	1.076	1.216	1.147	1.152	1.144	1.161	1.131	1.133	1.109
5. HOUSTON	1.308	1.173	1.266	1.190	1.233	1.475	1.295	1.285	1.112	1.121
6. DETROIT	1.160	1.317	1.403	1.221	1.155	1.147	1.884	1.313	1.237	1.136
7. BALTIMORE	1.201	1.047	1.212	1.175	1.156	1.149	1.258	1.118	1.120	1.112
8. DALLAS	1.162	1.135	1.200	1.173	1.204	1.116	1.170	1.149	1.273	1.353
9. SAN DIEGO	1.173	1.176	1.292	1.190	1.100	1.170	1.185	1.172	1.158	1.159
10. SAN ANTONIO	1.159	1.163	1.226	1.194	1.229	1.171	1.169	1.162	1.098	1.091
11. INDIANAPOLIS	0.0	1.196	1.101	1.162	1.195	1.136	1.183	1.153	1.182	1.147
12. WASHINGTON	1.196	0.0	1.216	1.170	1.162	1.144	1.148	1.114	1.123	1.113
13. MILWAUKEE	1.101	1.216	0.0	1.287	1.127	1.564	1.261	1.234	1.188	1.113
14. PHOENIX	1.162	1.170	1.287	0.0	1.253	1.212	1.174	1.162	1.183	1.191
15. SAN FRANCISCO	1.195	1.162	1.127	1.253	0.0	1.213	1.147	1.156	1.217	1.215
16. MEMPHIS	1.136	1.144	1.564	1.212	1.213	0.0	1.186	1.156	1.191	1.094
17. CLEVELAND	1.183	1.148	1.261	1.174	1.147	1.186	0.0	1.236	1.267	1.142
18. BOSTON	1.153	1.114	1.234	1.162	1.156	1.156	1.236	0.0	1.146	1.114
19. JACKSONVILLE	1.182	1.123	1.188	1.183	1.217	1.191	1.267	1.146	0.0	1.105
20. NEW ORLEANS	1.147	1.113	1.113	1.191	1.215	1.094	1.142	1.114	1.105	0.0
21. SAN JOSE	1.221	1.189	1.223	1.319	1.044	1.206	1.176	1.178	1.217	1.213
22. COLUMBUS	1.020	1.234	1.230	1.148	1.168	1.146	1.103	1.179	1.252	1.148
23. ST. LOUIS	1.020	1.142	1.147	1.184	1.240	1.182	1.111	1.124	1.155	1.130
24. SEATTLE	1.204	1.186	1.212	1.296	1.191	1.286	1.190	1.222	1.215	1.302
25. DENVER	1.101	1.124	1.158	1.499	1.361	1.310	1.088	1.113	1.181	1.374
26. KANSAS CITY	1.110	1.143	1.326	1.294	1.255	1.487	1.163	1.146	1.192	1.300
27. PITTSBURGH	1.077	1.159	1.234	1.147	1.154	1.164	1.126	1.193	1.257	1.195
28. NASHVILLE	1.110	1.259	1.143	1.144	1.265	1.054	1.126	1.263	1.097	1.149
29. ATLANTA	1.220	1.160	1.217	1.210	1.207	1.177	1.367	1.141	1.073	1.132
30. CINCINNATI	1.071	1.198	1.153	1.170	1.192	1.162	1.112	1.172	1.190	1.145
31. BUFFALO	1.144	1.410	1.334	1.175	1.162	1.164	1.078	1.119	1.322	1.143
32. EL PASO	1.131	1.139	1.275	1.264	1.263	1.118	1.142	1.140	1.145	1.149
33. MINNEAPOLIS	1.148	1.170	1.116	1.386	1.291	1.396	1.177	1.226	1.207	1.266
34. OMAHA	1.214	1.262	1.203	1.371	1.184	1.415	1.072	1.114	1.214	1.282
35. TOLEDO	1.162	1.176	1.313	1.156	1.150	1.150	1.160	1.159	1.232	1.138
36. OKLAHOMA CITY	1.072	1.142	1.282	1.192	1.196	1.378	1.104	1.116	1.302	1.397
37. MIAMI	1.117	1.163	1.157	1.231	1.238	1.210	1.218	1.205	1.067	1.304
38. FORT WORTH	1.169	1.136	1.280	1.199	1.262	1.119	1.174	1.151	1.255	1.321
39. PORTLAND	1.248	1.215	1.303	1.265	1.187	1.334	1.221	1.238	1.251	1.378
40. HONOLULU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41. NEWARK	1.154	1.126	1.252	1.193	1.151	1.158	1.223	1.101	1.141	1.116
42. LOUISVILLE	1.035	1.230	1.084	1.174	1.222	1.172	1.119	1.173	1.204	1.134
43. LONG BEACH	1.142	1.187	1.244	1.068	1.105	1.159	1.160	1.177	1.166	1.156
44. TULSA	1.077	1.149	1.305	1.185	1.205	1.411	1.111	1.122	1.285	1.412
45. OAKLAND	1.197	1.164	1.129	1.256	1.188	1.215	1.148	1.157	1.219	1.216
46. AUSTIN	1.169	1.167	1.239	1.253	1.271	1.186	1.177	1.166	1.122	1.133
47. TUCSON	1.184	1.170	1.335	1.104	1.245	1.157	1.190	1.174	1.156	1.162
48. BATON ROUGE	1.276	1.163	1.219	1.199	1.247	1.381	1.197	1.151	1.119	1.068
49. NORFOLK	1.283	1.333	1.328	1.201	1.309	1.162	1.263	1.317	1.447	1.228
50. CHARLOTTE	1.470	1.193	1.348	1.157	1.181	1.214	1.363	1.189	1.124	1.104

Table B.6, continued.

	SAN JOSE 21	COLUMBUS 22	ST. LOUIS 23	SEATTLE 24	DENVER 25	KANSAS CITY 26	PITTSBURGH 27	NASHVILLE 28	ATLANTA 29	CINCINNATI 30
1. NEW YORK	1.175	1.157	1.098	1.198	1.120	1.119	1.169	1.198	1.155	1.161
2. CHICAGO	1.190	1.163	1.099	1.194	1.085	1.271	1.137	1.157	1.235	1.138
3. LOS ANGELES	1.101	1.144	1.167	1.180	1.502	1.273	1.144	1.171	1.174	1.158
4. PHILADELPHIA	1.178	1.141	1.088	1.190	1.029	1.108	1.129	1.238	1.145	1.159
5. HOUSTON	1.204	1.308	1.321	1.324	1.278	1.156	1.280	1.345	1.193	1.332
6. DETROIT	1.185	1.172	1.222	1.208	1.094	1.880	1.460	1.123	1.171	1.097
7. BALTIMORE	1.183	1.284	1.159	1.185	1.120	1.159	1.150	1.259	1.155	1.226
8. DALLAS	1.261	1.161	1.192	1.350	1.341	1.110	1.156	1.096	1.200	1.162
9. SAN DIEGO	1.189	1.160	1.191	1.182	1.481	1.282	1.159	1.167	1.176	1.178
10. SAN ANTONIO	1.254	1.162	1.165	1.305	1.187	1.099	1.167	1.149	1.263	1.170
11. INDIANAPOLIS	1.221	1.020	1.020	1.204	1.101	1.110	1.077	1.110	1.220	1.071
12. WASHINGTON	1.189	1.234	1.142	1.186	1.124	1.143	1.159	1.259	1.160	1.198
13. MILWAUKEE	1.223	1.230	1.147	1.212	1.158	1.326	1.234	1.143	1.217	1.153
14. PHOENIX	1.319	1.148	1.184	1.296	1.499	1.294	1.147	1.144	1.210	1.170
15. SAN FRANCISCO	1.044	1.168	1.240	1.191	1.361	1.255	1.154	1.265	1.207	1.192
16. MEMPHIS	1.206	1.146	1.182	1.286	1.310	1.487	1.164	1.054	1.177	1.162
17. CLEVELAND	1.176	1.103	1.111	1.190	1.088	1.163	1.126	1.126	1.367	1.112
18. BOSTON	1.178	1.179	1.124	1.222	1.113	1.146	1.193	1.263	1.141	1.172
19. JACKSONVILLE	1.217	1.252	1.155	1.215	1.181	1.192	1.257	1.097	1.073	1.190
20. NEW ORLEANS	1.213	1.148	1.130	1.302	1.374	1.300	1.195	1.149	1.132	1.145
21. SAN JOSE	0.0	1.199	1.230	1.202	1.418	1.291	1.163	1.213	1.202	1.217
22. COLUMBUS	1.199	0.0	1.027	1.189	1.092	1.086	1.129	1.132	1.258	1.079
23. ST. LOUIS	1.230	1.027	0.0	1.233	1.087	1.117	1.057	1.259	1.201	1.110
24. SEATTLE	1.202	1.189	1.233	0.0	1.352	1.262	1.188	1.239	1.232	1.198
25. DENVER	1.418	1.092	1.087	1.352	0.0	1.074	1.103	1.289	1.178	1.105
26. KANSAS CITY	1.291	1.086	1.117	1.262	1.074	0.0	1.098	1.237	1.223	1.126
27. PITTSBURGH	1.163	1.129	1.057	1.188	1.103	1.098	0.0	1.188	1.415	1.132
28. NASHVILLE	1.213	1.132	1.259	1.239	1.289	1.237	1.188	0.0	1.127	1.019
29. ATLANTA	1.202	1.258	1.201	1.232	1.178	1.223	1.415	1.127	0.0	1.191
30. CINCINNATI	1.217	1.079	1.110	1.198	1.105	1.126	1.132	1.019	1.191	0.0
31. BUFFALO	1.189	1.109	1.108	1.227	1.111	1.164	1.229	1.123	1.253	1.104
32. EL PASO	1.304	1.122	1.156	1.365	1.225	1.245	1.123	1.111	1.152	1.152
33. MINNEAPOLIS	1.316	1.157	1.486	1.231	1.280	1.090	1.173	1.155	1.247	1.145
34. OMAHA	1.217	1.134	1.311	1.189	1.112	1.210	1.104	1.293	1.255	1.299
35. TOLEDO	1.181	1.111	1.111	1.192	1.089	1.188	1.188	1.126	1.170	1.092
36. OKLAHOMA CITY	1.215	1.069	1.097	1.353	1.353	1.188	1.079	1.308	1.292	1.115
37. MIAMI	1.237	1.196	1.150	1.224	1.209	1.196	1.219	1.104	1.089	1.152
38. FORT WORTH	1.225	1.164	1.205	1.348	1.334	1.153	1.159	1.100	1.198	1.166
39. PORTLAND	1.198	1.226	1.265	1.203	1.337	1.279	1.219	1.269	1.264	1.239
40. HONOLULU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41. NEWARK	1.176	1.200	1.121	1.206	1.132	1.137	1.236	1.223	1.151	1.197
42. LOUISVILLE	1.213	1.103	1.091	1.218	1.180	1.105	1.142	1.089	1.282	1.129
43. LONG BEACH	1.113	1.132	1.153	1.180	1.466	1.255	1.133	1.160	1.167	1.146
44. TULSA	1.222	1.072	1.111	1.387	1.423	1.145	1.082	1.340	1.294	1.126
45. OAKLAND	1.131	1.170	1.242	1.204	1.366	1.258	1.156	1.267	1.209	1.194
46. AUSTIN	1.296	1.176	1.179	1.361	1.362	1.098	1.174	1.156	1.223	1.179
47. TUCSON	1.302	1.167	1.213	1.281	1.614	1.320	1.165	1.150	1.172	1.194
48. BATON ROUGE	1.265	1.182	1.142	1.337	1.397	1.283	1.212	1.215	1.220	1.255
49. NORFOLK	1.244	1.334	1.274	1.225	1.180	1.238	1.307	1.192	1.372	1.323
50. CHARLOTTE	1.174	1.307	1.351	1.259	1.203	1.288	1.382	1.319	1.042	1.851

Table B.6, continued.

	BUFFALO 31	EL PASO 32	MINNEAPOLIS 33	OMAHA 34	TOLEDO 35	OKLAHOMA CITY 36	MIAMI 37	FORT WORTH 38	PORTLAND 39	HONOLULU 40
1. NEW YORK	1.525	1.132	1.194	1.107	1.168	1.103	1.199	1.150	1.220	0.0
2. CHICAGO	1.156	1.185	1.143	1.056	1.100	1.144	1.161	1.194	1.235	0.0
3. LOS ANGELES	1.198	1.180	1.317	1.257	1.182	1.145	1.210	1.170	1.162	0.0
4. PHILADELPHIA	1.439	1.132	1.181	1.110	1.163	1.100	1.183	1.138	1.215	0.0
5. HOUSTON	1.267	1.143	1.131	1.194	1.283	1.083	1.270	1.112	1.327	0.0
6. DETROIT	1.656	1.184	1.239	1.082	1.099	1.164	1.176	1.214	1.239	0.0
7. BALTIMORE	1.365	1.143	1.169	1.117	1.157	1.149	1.164	1.140	1.213	0.0
8. DALLAS	1.157	1.090	1.103	1.202	1.164	1.075	1.324	1.097	1.287	0.0
9. SAN DIEGO	1.187	1.171	1.342	1.302	1.195	1.193	1.205	1.149	1.297	0.0
10. SAN ANTONIO	1.158	1.144	1.100	1.177	1.160	1.125	1.242	1.106	1.329	0.0
11. INDIANAPOLIS	1.144	1.131	1.148	1.214	1.162	1.072	1.117	1.169	1.248	0.0
12. WASHINGTON	1.410	1.139	1.170	1.262	1.176	1.142	1.163	1.136	1.215	0.0
13. MILWAUKEE	1.334	1.275	1.116	1.203	1.313	1.282	1.157	1.280	1.303	0.0
14. PHOENIX	1.175	1.264	1.386	1.371	1.156	1.192	1.231	1.199	1.265	0.0
15. SAN FRANCISCO	1.162	1.263	1.291	1.184	1.150	1.196	1.238	1.262	1.187	0.0
16. MEMPHIS	1.164	1.118	1.396	1.415	1.150	1.378	1.210	1.119	1.334	0.0
17. CLEVELAND	1.078	1.142	1.177	1.072	1.160	1.104	1.218	1.174	1.221	0.0
18. BOSTON	1.119	1.140	1.226	1.114	1.159	1.116	1.205	1.151	1.238	0.0
19. JACKSONVILLE	1.322	1.145	1.207	1.214	1.232	1.302	1.067	1.255	1.251	0.0
20. NEW ORLEANS	1.143	1.149	1.266	1.282	1.138	1.397	1.304	1.321	1.378	0.0
21. SAN JOSE	1.189	1.304	1.316	1.217	1.181	1.215	1.237	1.225	1.198	0.0
22. COLUMBUS	1.109	1.122	1.157	1.134	1.111	1.069	1.196	1.164	1.226	0.0
23. ST. LOUIS	1.108	1.156	1.486	1.311	1.111	1.097	1.150	1.205	1.265	0.0
24. SEATTLE	1.227	1.365	1.231	1.189	1.192	1.353	1.224	1.348	1.203	0.0
25. DENVER	1.111	1.225	1.280	1.112	1.089	1.353	1.209	1.334	1.337	0.0
26. KANSAS CITY	1.164	1.245	1.090	1.210	1.188	1.188	1.196	1.153	1.279	0.0
27. PITTSBURGH	1.229	1.123	1.173	1.104	1.188	1.079	1.219	1.159	1.219	0.0
28. NASHVILLE	1.123	1.111	1.155	1.293	1.126	1.308	1.104	1.100	1.269	0.0
29. ATLANTA	1.253	1.152	1.247	1.255	1.170	1.292	1.089	1.198	1.264	0.0
30. CINCINNATI	1.104	1.152	1.145	1.299	1.092	1.115	1.152	1.166	1.239	0.0
31. BUFFALO	0.0	1.140	1.272	1.111	1.176	1.104	1.225	1.161	1.251	0.0
32. EL PASO	1.140	0.0	1.290	1.310	1.147	1.200	1.216	1.090	1.326	0.0
33. MINNEAPOLIS	1.272	1.290	0.0	1.229	1.181	1.157	1.182	1.129	1.337	0.0
34. OMAHA	1.111	1.310	1.229	0.0	1.071	1.363	1.206	1.245	1.252	0.0
35. TOLEDO	1.176	1.147	1.181	1.071	0.0	1.106	1.168	1.170	1.226	0.0
36. OKLAHOMA CITY	1.104	1.200	1.157	1.363	1.106	0.0	1.334	1.249	1.343	0.0
37. MIAMI	1.225	1.216	1.182	1.206	1.168	1.334	0.0	1.311	1.255	0.0
38. FORT WORTH	1.161	1.090	1.129	1.245	1.170	1.249	1.311	0.0	1.287	0.0
39. PORTLAND	1.251	1.326	1.337	1.252	1.226	1.343	1.255	1.287	0.0	0.0
40. HONOLULU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41. NEWARK	1.606	1.132	1.214	1.125	1.211	1.117	1.192	1.164	1.228	0.0
42. LOUISVILLE	1.109	1.164	1.153	1.259	1.147	1.328	1.162	1.166	1.254	0.0
43. LONG BEACH	1.186	1.173	1.951	1.237	1.272	1.133	1.207	1.162	1.219	0.0
44. TULSA	1.110	1.177	1.114	1.275	1.113	1.045	1.305	1.160	1.370	0.0
45. OAKLAND	1.163	1.569	1.294	1.187	1.152	1.199	1.240	1.271	1.203	0.0
46. AUSTIN	1.164	1.234	1.098	1.177	1.168	1.108	1.250	1.096	1.325	0.0
47. TUCSON	1.131	1.205	1.400	1.487	1.200	1.258	1.216	1.140	1.250	0.0
48. BATON ROUGE	1.186	1.154	1.242	1.269	1.155	1.426	1.280	1.375	1.401	0.0
49. NORFOLK	1.353	1.138	1.256	1.320	1.365	1.250	1.426	1.149	1.256	0.0
50. CHARLOTTE	1.337	1.086	1.287	1.290	1.259	1.185	1.121	1.078	1.287	0.0

Table B.6, continued.

	NEWARK 41	LOUISVILLE 42	LONG BEACH 43	TULSA 44	OAKLAND 45	AUSTIN 46	TUCSON 47	BATON ROUGE 48	NORFOLK 49	CHARLOTTE 50
1. NEW YORK	1.091	1.256	1.547	1.107	1.152	1.171	1.187	1.161	1.413	1.225
2. CHICAGO	1.166	1.083	1.194	1.153	1.158	1.160	1.324	1.236	1.304	1.367
3. LOS ANGELES	1.157	1.158	1.148	1.147	1.123	1.205	1.153	1.175	1.182	1.137
4. PHILADELPHIA	1.195	1.177	1.133	1.104	1.153	1.163	1.130	1.154	1.414	1.167
5. HOUSTON	1.172	1.324	1.152	1.129	1.235	1.118	1.161	1.095	1.241	1.158
6. DETROIT	1.384	1.138	1.191	1.178	1.156	1.204	1.209	1.225	1.371	1.280
7. BALTIMORE	1.138	1.245	1.155	1.157	1.173	1.168	1.174	1.161	1.291	1.179
8. DALLAS	1.148	1.162	1.134	1.074	1.206	1.068	1.113	1.417	1.302	1.184
9. SAN DIEGO	1.169	1.180	1.080	1.188	1.122	1.200	1.147	1.163	1.176	1.134
10. SAN ANTONIO	1.166	1.173	1.161	1.078	1.233	1.033	1.168	1.248	1.191	1.149
11. INDIANAPOLIS	1.154	1.035	1.142	1.077	1.197	1.169	1.184	1.276	1.283	1.470
12. WASHINGTON	1.126	1.230	1.187	1.149	1.164	1.167	1.170	1.163	1.333	1.193
13. MILWAUKEE	1.252	1.084	1.244	1.305	1.129	1.239	1.335	1.219	1.328	1.348
14. PHOENIX	1.193	1.174	1.068	1.185	1.256	1.253	1.104	1.199	1.201	1.157
15. SAN FRANCISCO	1.151	1.222	1.105	1.205	1.188	1.271	1.245	1.247	1.309	1.181
16. MEMPHIS	1.158	1.172	1.159	1.411	1.215	1.186	1.157	1.381	1.162	1.214
17. CLEVELAND	1.223	1.119	1.160	1.111	1.148	1.177	1.190	1.197	1.263	1.363
18. BOSTON	1.101	1.173	1.177	1.122	1.157	1.166	1.174	1.151	1.317	1.189
19. JACKSONVILLE	1.141	1.204	1.166	1.285	1.219	1.122	1.156	1.119	1.447	1.124
20. NEW ORLEANS	1.116	1.134	1.166	1.412	1.216	1.133	1.162	1.068	1.228	1.104
21. SAN JOSE	1.176	1.213	1.113	1.222	1.131	1.296	1.302	1.265	1.244	1.174
22. COLUMBUS	1.200	1.103	1.132	1.072	1.170	1.176	1.167	1.182	1.334	1.307
23. ST. LOUIS	1.121	1.091	1.153	1.111	1.242	1.179	1.213	1.142	1.274	1.351
24. SEATTLE	1.206	1.218	1.180	1.387	1.204	1.361	1.281	1.337	1.225	1.259
25. DENVER	1.132	1.180	1.466	1.423	1.366	1.362	1.614	1.397	1.180	1.203
26. KANSAS CITY	1.137	1.105	1.255	1.145	1.258	1.098	1.320	1.283	1.238	1.288
27. PITTSBURGH	1.236	1.142	1.133	1.082	1.156	1.174	1.165	1.212	1.307	1.382
28. NASHVILLE	1.223	1.089	1.160	1.340	1.267	1.156	1.150	1.215	1.192	1.319
29. ATLANTA	1.151	1.282	1.167	1.294	1.209	1.223	1.172	1.220	1.372	1.042
30. CINCINNATI	1.197	1.129	1.146	1.126	1.194	1.179	1.194	1.255	1.323	1.851
31. BUFFALO	1.606	1.109	1.186	1.110	1.163	1.164	1.131	1.186	1.353	1.337
32. EL PASO	1.132	1.164	1.173	1.177	1.569	1.234	1.205	1.154	1.138	1.086
33. MINNEAPOLIS	1.214	1.153	1.951	1.114	1.294	1.098	1.400	1.242	1.256	1.287
34. OMAHA	1.125	1.259	1.237	1.275	1.187	1.177	1.487	1.269	1.320	1.290
35. TOLEDO	1.211	1.147	1.272	1.113	1.152	1.168	1.200	1.155	1.365	1.259
36. OKLAHOMA CITY	1.117	1.328	1.133	1.045	1.199	1.108	1.258	1.426	1.250	1.185
37. MIAMI	1.192	1.162	1.207	1.305	1.240	1.250	1.216	1.280	1.426	1.121
38. FORT WORTH	1.164	1.166	1.162	1.160	1.271	1.096	1.140	1.375	1.149	1.078
39. PORTLAND	1.228	1.254	1.219	1.370	1.203	1.325	1.250	1.401	1.256	1.287
40. HONOLULU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41. NEWARK	0.0	1.288	1.557	1.123	1.152	1.190	1.196	1.580	1.388	1.218
42. LOUISVILLE	1.288	0.0	1.196	1.144	1.224	1.184	1.203	1.189	1.358	1.490
43. LONG BEACH	1.557	1.196	0.0	1.136	1.132	1.201	1.145	1.170	1.172	1.127
44. TULSA	1.123	1.144	1.136	0.0	1.208	1.073	1.239	1.440	1.264	1.188
45. OAKLAND	1.152	1.224	1.132	1.208	0.0	1.273	1.247	1.249	1.311	1.183
46. AUSTIN	1.190	1.184	1.201	1.073	1.273	0.0	1.224	1.331	1.193	1.149
47. TUCSON	1.196	1.203	1.145	1.239	1.247	1.224	0.0	1.167	1.163	1.117
48. BATON ROUGE	1.580	1.189	1.170	1.440	1.249	1.331	1.167	0.0	1.263	1.161
49. NORFOLK	1.388	1.358	1.172	1.264	1.311	1.193	1.163	1.263	0.0	1.096
50. CHARLOTTE	1.218	1.490	1.127	1.188	1.183	1.149	1.117	1.161	1.096	0.0

Table B.7. City-Pair Circuities, Rail

	NEW YORK	CHICAGO	LOS ANGELES	PHILADELPHIA	HOUSTON	DETROIT	BALTIMORE	DALLAS	SAN DIEGO	SAN ANTONIO	INDIANAPOLIS	WASHINGTON	MILWAUKEE	PHOENIX	SAN FRANCISCO	MEMPHIS	CLEVELAND
1. NEW YORK	0.000	1.276	1.267	1.117	1.229	1.406	1.085	1.276	1.329	1.235	1.257	1.098	1.355	1.392	1.295	1.338	1.532
2. CHICAGO	1.276	0.000	1.268	1.232	1.366	1.180	1.431	1.222	1.350	1.231	2.062	1.418	1.048	1.599	1.302	1.091	1.115
3. LOS ANGELES	1.267	1.268	0.000	1.260	1.210	1.257	1.320	1.423	1.139	1.206	1.268	1.330	1.318	1.188	1.376	1.511	1.248
4. PHILADELPHIA	1.117	1.232	1.260	0.000	1.234	1.734	1.047	1.279	1.325	1.238	1.235	1.084	1.303	1.390	1.285	1.349	1.979
5. HOUSTON	1.229	1.366	1.210	1.234	0.000	1.417	1.247	1.547	1.374	1.113	1.415	1.247	1.365	1.218	1.301	1.570	1.463
6. DETROIT	1.406	1.180	1.257	1.734	1.417	0.000	2.170	1.264	1.330	1.273	2.583	2.280	1.447	1.542	1.291	1.295	4.642
7. BALTIMORE	1.085	1.431	1.320	1.047	1.247	2.170	0.000	1.409	1.390	1.249	1.505	1.132	1.480	1.397	1.338	1.557	2.610
8. DALLAS	1.276	1.222	1.423	1.279	1.547	1.264	1.409	0.000	1.601	1.238	1.231	1.477	1.247	1.513	1.513	2.635	1.294
9. SAN DIEGO	1.329	1.350	1.139	1.325	1.374	1.330	1.390	1.601	0.000	1.401	1.354	1.401	1.396	1.851	1.320	1.634	1.320
10. SAN ANTONIO	1.235	1.231	1.206	1.238	1.113	1.273	1.249	1.238	1.401	0.000	1.253	1.248	1.247	1.210	1.295	1.536	1.305
11. INDIANAPOLIS	1.257	2.062	1.268	1.235	1.415	2.583	1.505	1.231	1.354	1.253	0.000	1.643	1.747	1.522	1.417	1.212	2.602
12. WASHINGTON	1.098	1.418	1.330	1.084	1.247	2.280	1.132	1.477	1.401	1.248	1.643	0.000	1.460	1.393	1.338	1.669	2.766
13. MILWAUKEE	1.355	1.048	1.318	1.303	1.365	1.447	1.480	1.247	1.396	1.247	1.747	1.460	0.000	1.647	1.361	1.100	1.276
14. PHOENIX	1.392	1.599	1.188	1.390	1.218	1.542	1.397	1.513	1.851	1.210	1.522	1.393	1.647	0.000	1.382	1.583	1.526
15. SAN FRANCISCO	1.295	1.302	1.376	1.285	1.301	1.291	1.338	1.513	1.320	1.295	1.417	1.338	1.361	1.382	0.000	1.609	1.276
16. MEMPHIS	1.338	1.091	1.511	1.349	1.570	1.295	1.557	2.635	1.634	1.536	1.212	1.669	1.100	1.583	1.609	0.000	1.381
17. CLEVELAND	1.532	1.115	1.248	1.979	1.463	4.642	2.610	1.294	1.320	1.305	2.602	2.766	1.276	1.526	1.276	1.381	0.000
18. BOSTON	1.220	1.217	1.251	1.190	1.231	1.232	1.157	1.279	1.307	1.238	1.293	1.157	1.306	1.399	1.281	1.328	1.267
19. JACKSONVILLE	1.170	1.381	1.334	1.170	1.462	1.768	1.164	1.705	1.431	1.396	2.192	1.164	1.356	1.359	1.408	2.086	1.991
20. NEW ORLEANS	1.181	1.107	1.212	1.185	1.143	1.281	1.197	1.606	1.340	1.132	1.209	1.198	1.107	1.217	1.301	1.106	1.371
21. SAN JOSE	1.317	1.333	1.390	1.307	1.296	1.318	1.363	1.509	1.324	1.290	1.409	1.363	1.391	1.381	1.282	1.603	1.302
22. COLUMBUS	1.318	1.893	1.252	1.297	1.418	4.885	1.707	1.229	1.331	1.259	1.080	1.913	1.831	1.478	1.393	1.270	6.850
23. ST. LOUIS	1.201	1.072	1.293	1.185	1.547	1.235	1.376	1.282	1.396	1.280	1.034	1.474	1.120	1.606	1.452	1.770	1.272
24. SEATTLE	1.328	1.317	1.423	1.306	1.601	1.325	1.351	1.862	1.404	1.576	1.404	1.345	1.302	1.607	1.337	1.508	1.299
25. DENVER	1.193	1.127	2.215	1.176	2.334	1.139	1.261	2.665	2.361	2.511	1.377	1.260	1.228	3.866	1.458	1.782	1.125
26. KANSAS CITY	1.211	1.055	1.310	1.194	1.399	1.111	1.335	1.361	1.426	1.232	1.141	1.358	1.180	1.808	1.498	1.900	1.114
27. PITTSBURGH	1.388	1.149	1.248	1.350	1.405	3.651	2.011	1.227	1.320	1.259	1.132	2.281	1.245	1.452	1.277	1.272	7.076
28. NASHVILLE	1.616	1.285	1.452	1.662	1.384	1.680	1.750	2.056	1.557	1.374	3.386	1.770	1.246	1.494	1.494	4.817	1.861
29. ATLANTA	1.150	1.493	1.316	1.154	1.263	1.939	1.169	1.711	1.416	1.243	2.855	1.169	1.441	1.335	1.415	2.719	2.202
30. CINCINNATI	1.355	1.178	1.324	1.355	1.776	2.441	1.384	1.575	1.410	1.534	6.433	1.357	1.178	1.660	1.331	2.013	2.877
31. BUFFALO	1.497	1.145	1.243	1.890	1.403	1.104	2.263	1.253	1.308	1.269	1.973	2.266	1.318	1.492	1.278	1.302	1.043
32. EL PASO	1.346	1.519	1.205	1.347	1.210	1.476	1.357	1.611	1.551	1.206	1.471	1.354	1.554	1.215	1.330	1.615	1.473
33. MINNEAPOLIS	1.305	1.182	1.728	1.258	1.613	1.289	1.370	1.624	1.801	1.543	1.487	1.354	1.122	2.144	1.752	1.352	1.210
34. OMAHA	1.226	1.141	1.814	1.200	1.898	1.156	1.322	2.080	1.921	1.776	1.586	1.320	1.347	2.423	1.349	1.921	1.132
35. TOLEDO	1.454	1.109	1.253	1.803	1.444	9.551	2.287	1.281	1.328	1.288	3.047	2.426	1.313	1.546	1.283	1.335	1.129
36. OKLAHOMA CITY	1.291	1.184	1.515	1.289	1.256	1.209	1.419	1.226	1.682	1.146	1.308	1.447	1.237	1.796	1.634	2.587	1.224
37. MIAMI	1.270	1.345	1.399	1.269	1.662	1.628	1.257	1.761	1.497	1.585	1.892	1.256	1.328	1.437	1.445	1.878	1.784
38. FORT WORTH	1.275	1.233	1.430	1.278	1.345	1.268	1.405	1.102	1.612	1.169	1.235	1.471	1.259	1.526	1.518	2.409	1.296
39. PORTLAND	1.385	1.409	1.427	1.367	1.550	1.401	1.416	1.805	1.401	1.531	1.495	1.412	1.392	1.596	1.345	1.625	1.373
40. HONOLULU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41. NEWARK	1.084	1.279	1.268	1.062	1.229	1.454	1.065	1.276	1.330	1.235	1.259	1.080	1.358	1.393	1.296	1.338	1.592
42. LOUISVILLE	1.906	1.224	1.391	1.979	1.372	1.926	2.401	1.810	1.484	1.382	6.245	2.477	1.187	1.553	1.385	2.677	2.162
43. LONG BEACH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44. TULSA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45. OAKLAND	1.295	1.303	1.363	1.285	1.301	1.292	1.339	1.514	1.309	1.295	1.418	1.339	1.361	1.380	1.190	1.611	1.276
46. AUSTIN	1.312	1.243	1.248	1.319	1.786	1.285	1.352	1.284	1.436	1.074	1.267	1.353	1.259	1.272	1.338	1.828	1.318
47. TUCSON	1.349	1.526	1.235	1.348	1.189	1.480	1.355	1.476	1.854	1.185	1.462	1.351	1.568	1.114	1.357	1.540	1.471
48. BATON ROUGE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49. NORFOLK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50. CHARLOTTE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B.7, continued.

	BOSTON	JACKSONVILLE	NEW ORLEANS	SAN JOSE	COLUMBUS	ST. LOUIS	SEATTLE	DENVER	KANSAS CITY	PITTSBURGH	NASHVILLE	ATLANTA	CINCINNATI	BUFFALO	EL PASO	MINNEAPOLIS	OMAHA
1. NEW YORK	1.220	1.170	1.181	1.317	1.318	1.201	1.328	1.193	1.211	1.388	1.616	1.150	1.355	1.497	1.346	1.305	1.226
2. CHICAGO	1.217	1.381	1.107	1.333	1.893	1.072	1.317	1.127	1.055	1.149	1.285	1.493	1.178	1.145	1.519	1.182	1.141
3. LOS ANGELES	1.251	1.334	1.212	1.390	1.252	1.293	1.423	2.215	1.310	1.248	1.452	1.316	1.324	1.243	1.205	1.728	1.814
4. PHILADELPHIA	1.190	1.170	1.185	1.307	1.297	1.185	1.306	1.176	1.194	1.350	1.662	1.154	1.355	1.890	1.347	1.258	1.200
5. HOUSTON	1.231	1.462	1.143	1.296	1.418	1.547	1.601	2.334	1.399	1.405	1.384	1.263	1.776	1.403	1.210	1.613	1.898
6. DETROIT	1.232	1.768	1.281	1.318	4.885	1.235	1.325	1.139	1.111	3.651	1.680	1.939	2.441	1.104	1.476	1.289	1.156
7. BALTIMORE	1.157	1.164	1.197	1.363	1.707	1.376	1.351	1.261	1.335	2.011	1.750	1.169	1.384	2.263	1.357	1.370	1.322
8. DALLAS	1.279	1.705	1.606	1.509	1.229	1.282	1.862	2.665	1.361	1.227	2.056	1.711	1.575	1.253	1.611	1.624	2.080
9. SAN DIEGO	1.307	1.431	1.340	1.324	1.331	1.396	1.404	2.361	1.426	1.320	1.557	1.416	1.410	1.308	1.551	1.801	1.921
10. SAN ANTONIO	1.238	1.396	1.132	1.290	1.259	1.280	1.576	2.511	1.232	1.259	1.374	1.243	1.534	1.269	1.206	1.543	1.776
11. INDIANAPOLIS	1.293	2.192	1.209	1.409	1.080	1.034	1.404	1.377	1.141	1.132	3.386	2.855	6.433	1.973	1.471	1.487	1.586
12. WASHINGTON	1.157	1.164	1.198	1.363	1.913	1.474	1.345	1.260	1.358	2.281	1.770	1.169	1.357	2.266	1.354	1.354	1.320
13. MILWAUKEE	1.306	1.356	1.107	1.391	1.831	1.120	1.302	1.228	1.180	1.245	1.246	1.441	1.178	1.318	1.554	1.122	1.347
14. PHOENIX	1.399	1.359	1.217	1.381	1.478	1.606	1.607	3.866	1.808	1.452	1.494	1.335	1.660	1.492	1.215	2.144	2.423
15. SAN FRANCISCO	1.281	1.408	1.301	1.282	1.393	1.452	1.337	1.458	1.498	1.277	1.494	1.415	1.331	1.278	1.330	1.752	1.349
16. MEMPHIS	1.328	2.086	1.106	1.603	1.270	1.770	1.508	1.782	1.900	1.272	4.817	2.719	2.013	1.302	1.615	1.352	1.921
17. CLEVELAND	1.267	1.991	1.371	1.302	6.850	1.272	1.299	1.125	1.114	7.076	1.861	2.202	2.877	1.043	1.473	1.210	1.132
18. BOSTON	0.000	1.189	1.187	1.300	1.340	1.236	1.333	1.171	1.177	1.390	1.548	1.164	1.356	1.292	1.349	1.296	1.193
19. JACKSONVILLE	1.189	0.000	1.662	1.402	2.059	1.967	1.418	1.521	1.715	1.688	1.365	2.266	1.937	1.607	1.371	1.353	1.534
20. NEW ORLEANS	1.187	1.662	0.000	1.295	1.307	1.374	1.528	1.813	1.613	1.342	1.189	1.231	1.730	1.327	1.202	1.276	1.671
21. SAN JOSE	1.300	1.402	1.295	0.000	1.385	1.439	1.327	1.527	1.483	1.302	1.531	1.407	1.361	1.302	1.326	1.786	1.391
22. COLUMBUS	1.340	2.059	1.307	1.385	0.000	1.060	1.396	1.338	1.125	1.178	3.099	2.888	8.172	3.531	1.429	1.501	1.480
23. ST. LOUIS	1.236	1.967	1.374	1.439	1.060	0.000	1.490	1.656	1.163	1.094	3.140	2.490	1.885	1.209	1.568	1.501	2.170
24. SEATTLE	1.333	1.418	1.528	1.327	1.396	1.490	0.000	1.605	1.808	1.290	1.417	1.451	1.311	1.326	1.606	1.339	1.597
25. DENVER	1.171	1.521	1.813	1.527	1.338	1.656	1.605	0.000	2.057	1.142	1.515	1.582	1.220	1.135	4.693	2.081	1.114
26. KANSAS CITY	1.177	1.715	1.613	1.483	1.125	1.163	1.808	2.057	0.000	1.139	2.004	1.946	1.358	1.110	1.755	2.074	3.601
27. PITTSBURGH	1.390	1.688	1.342	1.302	1.178	1.094	1.290	1.142	1.139	0.000	2.083	2.051	2.989	4.894	1.404	1.198	1.154
28. NASHVILLE	1.548	1.365	1.189	1.531	3.099	3.140	1.417	1.515	2.004	2.083	0.000	1.714	3.401	1.642	1.488	1.334	1.652
29. ATLANTA	1.164	2.266	1.231	1.407	2.888	2.490	1.451	1.582	1.946	2.051	1.714	0.000	2.541	1.857	1.319	1.430	1.675
30. CINCINNATI	1.356	1.937	1.730	1.361	8.172	1.885	1.311	1.220	1.358	2.989	3.401	2.541	0.000	2.070	1.650	1.184	1.270
31. BUFFALO	1.292	1.607	1.327	1.302	3.531	1.209	1.326	1.135	1.110	4.894	1.642	1.857	2.070	0.000	1.431	1.284	1.147
32. EL PASO	1.349	1.371	1.202	1.326	1.429	1.568	1.606	4.693	1.755	1.404	1.488	1.319	1.650	1.431	0.000	2.004	2.372
33. MINNEAPOLIS	1.296	1.353	1.276	1.786	1.501	1.501	1.339	2.081	2.074	1.198	1.334	1.430	1.184	1.284	2.004	0.000	3.150
34. OMAHA	1.193	1.534	1.671	1.391	1.480	2.170	1.597	1.114	3.601	1.154	1.652	1.675	1.270	1.147	2.372	3.150	0.000
35. TOLEDO	1.253	1.810	1.308	1.310	6.306	1.263	1.303	1.125	1.104	3.479	1.788	2.034	2.900	1.141	1.487	1.210	1.132
36. OKLAHOMA CITY	1.241	1.747	1.534	1.628	1.271	1.445	2.037	3.036	1.293	1.257	2.208	1.863	1.477	1.196	1.888	1.787	2.427
37. MIAMI	1.287	1.248	1.861	1.443	1.799	1.776	1.422	1.529	1.640	1.576	1.336	1.742	1.701	1.540	1.477	1.336	1.497
38. FORT WORTH	1.279	1.621	1.454	1.514	1.231	1.291	1.864	2.686	1.265	1.228	1.924	1.605	1.567	1.256	1.637	1.645	2.012
39. PORTLAND	1.384	1.505	1.556	1.330	1.476	1.601	1.301	1.481	1.741	1.362	1.518	1.545	1.398	1.390	1.574	1.442	1.461
40. HONOLULU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41. NEWARK	1.234	1.163	1.179	1.318	1.322	1.202	1.328	1.194	1.212	1.396	1.619	1.146	1.358	1.578	1.347	1.307	1.227
42. LOUISVILLE	1.654	1.452	1.186	1.418	4.492	2.539	1.347	1.318	1.598	2.334	1.173	1.717	7.010	1.755	1.531	1.239	1.418
43. LONG BEACH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44. TULSA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45. OAKLAND	1.281	1.408	1.301	1.131	1.394	1.453	1.327	1.460	1.499	1.277	1.496	1.416	1.331	1.279	1.329	1.754	1.350
46. AUSTIN	1.308	1.524	1.362	1.333	1.270	1.301	1.636	2.509	1.242	1.269	1.573	1.403	1.568	1.279	1.298	1.566	1.822
47. TUCSON	1.356	1.338	1.189	1.357	1.424	1.540	1.566	3.856	1.717	1.402	1.450	1.300	1.610	1.438	1.137	2.024	2.299
48. BATON ROUGE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49. NORFOLK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50. CHARLOTTE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B.7, continued.

	TOLEDO	OKLAHOMA CITY	MIAMI	FORT WORTH	PORTLAND	HONOLULU	NEWARK	LOUISVILLE	LONG BEACH	TULSA	OAKLAND	AUSTIN	TUCSON	BATON ROUGE	NORFOLK	CHARLOTTE
1. NEW YORK	1.454	1.291	1.270	1.275	1.385	0.000	1.084	1.906	0.000	0.000	1.295	1.312	1.349	0.000	0.000	0.000
2. CHICAGO	1.109	1.184	1.345	1.233	1.409	0.000	1.279	1.224	0.000	0.000	1.303	1.243	1.526	0.000	0.000	0.000
3. LOS ANGELES	1.253	1.515	1.399	1.430	1.427	0.000	1.268	1.391	0.000	0.000	1.363	1.248	1.235	0.000	0.000	0.000
4. PHILADELPHIA	1.803	1.289	1.269	1.278	1.367	0.000	1.062	1.979	0.000	0.000	1.285	1.319	1.348	0.000	0.000	0.000
5. HOUSTON	1.444	1.256	1.662	1.345	1.550	0.000	1.229	1.372	0.000	0.000	1.301	1.786	1.189	0.000	0.000	0.000
6. DETROIT	9.551	1.209	1.628	1.268	1.401	0.000	1.454	1.926	0.000	0.000	1.292	1.285	1.480	0.000	0.000	0.000
7. BALTIMORE	2.287	1.419	1.257	1.405	1.416	0.000	1.065	2.401	0.000	0.000	1.339	1.352	1.355	0.000	0.000	0.000
8. DALLAS	1.281	1.226	1.761	1.102	1.805	0.000	1.276	1.810	0.000	0.000	1.514	1.284	1.476	0.000	0.000	0.000
9. SAN DIEGO	1.328	1.682	1.497	1.612	1.401	0.000	1.330	1.484	0.000	0.000	1.309	1.436	1.854	0.000	0.000	0.000
10. SAN ANTONIO	1.288	1.146	1.585	1.169	1.531	0.000	1.235	1.382	0.000	0.000	1.295	1.074	1.185	0.000	0.000	0.000
11. INDIANAPOLIS	3.047	1.308	1.892	1.235	1.495	0.000	1.259	6.245	0.000	0.000	1.418	1.267	1.462	0.000	0.000	0.000
12. WASHINGTON	2.426	1.447	1.256	1.471	1.412	0.000	1.080	2.477	0.000	0.000	1.339	1.353	1.351	0.000	0.000	0.000
13. MILWAUKEE	1.313	1.237	1.328	1.259	1.392	0.000	1.358	1.187	0.000	0.000	1.361	1.259	1.568	0.000	0.000	0.000
14. PHOENIX	1.546	1.796	1.437	1.526	1.596	0.000	1.393	1.553	0.000	0.000	1.380	1.272	1.114	0.000	0.000	0.000
15. SAN FRANCISCO	1.283	1.634	1.445	1.518	1.345	0.000	1.296	1.385	0.000	0.000	1.188	1.338	1.357	0.000	0.000	0.000
16. MEMPHIS	1.335	2.587	1.878	2.409	1.625	0.000	1.338	2.677	0.000	0.000	1.611	1.828	1.540	0.000	0.000	0.000
17. CLEVELAND	1.129	1.224	1.784	1.296	1.373	0.000	1.592	2.162	0.000	0.000	1.276	1.318	1.471	0.000	0.000	0.000
18. BOSTON	1.253	1.241	1.287	1.279	1.384	0.000	1.234	1.654	0.000	0.000	1.281	1.308	1.356	0.000	0.000	0.000
19. JACKSONVILLE	1.810	1.747	1.248	1.621	1.505	0.000	1.163	1.452	0.000	0.000	1.408	1.524	1.338	0.000	0.000	0.000
20. NEW ORLEANS	1.308	1.534	1.861	1.454	1.556	0.000	1.179	1.186	0.000	0.000	1.301	1.362	1.189	0.000	0.000	0.000
21. SAN JOSE	1.310	1.628	1.443	1.514	1.330	0.000	1.318	1.418	0.000	0.000	1.132	1.333	1.357	0.000	0.000	0.000
22. COLUMBUS	6.306	1.271	1.799	1.231	1.476	0.000	1.322	4.492	0.000	0.000	1.394	1.270	1.424	0.000	0.000	0.000
23. ST. LOUIS	1.263	1.445	1.776	1.291	1.601	0.000	1.202	2.539	0.000	0.000	1.453	1.301	1.540	0.000	0.000	0.000
24. SEATTLE	1.303	2.037	1.422	1.864	1.301	0.000	1.328	1.347	0.000	0.000	1.327	1.636	1.566	0.000	0.000	0.000
25. DENVER	1.125	3.036	1.529	2.686	1.481	0.000	1.194	1.318	0.000	0.000	1.460	2.509	3.856	0.000	0.000	0.000
26. KANSAS CITY	1.104	1.293	1.640	1.265	1.741	0.000	1.212	1.598	0.000	0.000	1.499	1.242	1.717	0.000	0.000	0.000
27. PITTSBURGH	3.479	1.257	1.576	1.228	1.362	0.000	1.396	2.334	0.000	0.000	1.277	1.269	1.402	0.000	0.000	0.000
28. NASHVILLE	1.788	2.208	1.336	1.924	1.518	0.000	1.619	1.173	0.000	0.000	1.496	1.573	1.450	0.000	0.000	0.000
29. ATLANTA	2.034	1.863	1.742	1.605	1.545	0.000	1.146	1.717	0.000	0.000	1.416	1.403	1.300	0.000	0.000	0.000
30. CINCINNATI	2.900	1.477	1.701	1.567	1.398	0.000	1.358	7.010	0.000	0.000	1.331	1.568	1.610	0.000	0.000	0.000
31. BUFFALO	1.141	1.196	1.540	1.256	1.390	0.000	1.578	1.755	0.000	0.000	1.279	1.279	1.438	0.000	0.000	0.000
32. EL PASO	1.487	1.888	1.477	1.637	1.574	0.000	1.347	1.531	0.000	0.000	1.329	1.298	1.137	0.000	0.000	0.000
33. MINNEAPOLIS	1.210	1.787	1.336	1.645	1.442	0.000	1.307	1.239	0.000	0.000	1.754	1.566	2.024	0.000	0.000	0.000
34. OMAHA	1.132	2.427	1.497	2.012	1.461	0.000	1.227	1.418	0.000	0.000	1.350	1.822	2.299	0.000	0.000	0.000
35. TOLEDO	0.000	1.218	1.650	1.285	1.382	0.000	1.502	2.149	0.000	0.000	1.283	1.303	1.486	0.000	0.000	0.000
36. OKLAHOMA CITY	1.218	0.000	1.736	1.075	2.002	0.000	1.292	1.700	0.000	0.000	1.636	1.125	1.729	0.000	0.000	0.000
37. MIAMI	1.650	1.736	0.000	1.694	1.506	0.000	1.262	1.381	0.000	0.000	1.446	1.679	1.429	0.000	0.000	0.000
38. FORT WORTH	1.285	1.075	1.694	0.000	1.809	0.000	1.275	1.792	0.000	0.000	1.519	1.166	1.489	0.000	0.000	0.000
39. PORTLAND	1.382	2.002	1.506	1.809	0.000	0.000	1.386	1.440	0.000	0.000	1.332	1.588	1.550	0.000	0.000	0.000
40. HONOLULU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41. NEWARK	1.502	1.292	1.262	1.275	1.386	0.000	0.000	1.916	0.000	0.000	1.296	1.312	1.350	0.000	0.000	0.000
42. LOUISVILLE	2.149	1.700	1.381	1.792	1.440	0.000	1.916	0.000	0.000	0.000	1.386	1.556	1.502	0.000	0.000	0.000
43. LONG BEACH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44. TULSA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45. OAKLAND	1.283	1.636	1.446	1.519	1.332	0.000	1.296	1.386	0.000	0.000	0.000	1.338	1.354	0.000	0.000	0.000
46. AUSTIN	1.303	1.125	1.679	1.166	1.588	0.000	1.312	1.556	0.000	0.000	1.338	0.000	1.244	0.000	0.000	0.000
47. TUCSON	1.486	1.729	1.429	1.489	1.550	0.000	1.350	1.502	0.000	0.000	1.354	1.244	0.000	0.000	0.000	0.000
48. BATON ROUGE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49. NORFOLK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50. CHARLOTTE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix C: AIR PASSENGER SOURCE DATA

All data presented in this appendix were derived from the *Domestic Origin Destination Survey of Airline Passenger Traffic* which is carried out by the Civil Aeronautics Board on a continuous basis from the flight coupons of individual passenger trips. Definitions and notes pertinent to the table contents are given below.

- All data pertain to certificated route air carrier traffic.
- Domestic operations are those within the 50 states with purely intra-Alaskan traffic excluded. Domestic portions of interational/territorial itineraries are included.
- Round trips and other itineraries involving movement in two directions are treated as two one-way trips.
- Passenger-miles are the summation of the number of passengers times the great-circle airport to airport distance for each air carrier flight coupon state in each itinerary.
- The mileage intervals are based on the airport to airport great-circle distance.

Table C.1. Passenger-miles and Number of Trips by Trip Length, 1975

DOMESTIC PASSENGER ONE-WAY TRIP LENGTH (MILES)	CITY PAIRS			PASSENGERS			PASSENGER-MILES		
		PERCENT			PERCENT			PERCENT	
	NUMBER	SIMPLE	CUMULATIVE	OUTBOUND & INBOUND (1000)	SIMPLE	CUMULATIVE	OUTBOUND & INBOUND (1000)	SIMPLE	CUMULATIVE
0 - 49	98	0.2	0.2	65	0.1	0.1	2,300	&	&
50 - 99	413	0.7	0.9	946	0.7	0.8	79,283	&	0.1
100 - 149	774	1.3	2.2	3,584	2.8	3.6	435,302	0.3	0.4
150 - 199	1,164	2.0	4.1	6,848	5.3	8.9	1,271,175	1.0	1.5
200 - 249	1,495	2.5	6.6	8,550	6.6	15.5	1,972,675	1.6	3.2
250 - 299	1,726	2.9	9.5	7,255	5.6	21.2	2,074,356	1.7	4.9
300 - 349	1,864	3.1	12.7	7,312	5.7	26.8	2,496,179	2.1	7.0
350 - 399	1,960	3.3	16.0	4,372	3.4	30.2	1,750,991	1.4	8.5
400 - 449	2,055	3.5	19.4	6,030	4.7	34.9	2,653,826	2.2	10.7
450 - 499	2,086	3.5	23.0	4,972	3.9	38.8	2,507,197	2.1	12.8
500 - 549	2,131	3.6	26.5	3,809	3.0	41.7	2,162,936	1.8	14.7
550 - 599	2,166	3.6	30.2	4,861	3.8	45.5	2,989,766	2.5	17.2
600 - 649	2,196	3.7	33.9	3,642	2.8	48.3	2,432,157	2.0	19.2
650 - 699	2,198	3.7	37.6	4,057	3.2	51.5	2,895,306	2.4	21.7
700 - 749	2,117	3.6	41.1	4,008	3.1	54.6	3,052,503	2.5	24.2
750 - 799	2,060	3.5	44.6	2,958	2.3	56.9	2,436,079	2.0	26.3
800 - 849	2,034	3.4	48.0	3,302	2.6	59.5	2,871,542	2.4	28.7
850 - 899	1,932	3.3	51.3	3,115	2.4	61.9	2,853,749	2.4	31.1
900 - 949	1,880	3.2	54.5	3,788	2.9	64.8	3,666,795	3.0	34.2
950 - 999	1,712	2.9	57.3	3,339	2.6	67.4	3,387,518	2.8	37.1
1000 - 1049	1,676	2.8	60.2	3,565	2.8	70.2	3,773,901	3.1	40.2
1050 - 1099	1,493	2.5	62.7	4,459	3.5	73.6	4,916,024	4.1	44.4
1100 - 1149	1,415	2.4	65.1	1,908	1.5	75.1	2,241,513	1.8	46.3
1150 - 1199	1,321	2.2	67.3	2,500	1.9	77.1	3,048,553	2.5	48.8
1200 - 1249	1,249	2.1	69.4	1,896	1.5	78.5	2,413,795	2.0	50.9
1250 - 1299	1,150	1.9	71.3	1,072	0.8	79.4	1,421,671	1.1	52.1
1300 - 1349	1,115	1.9	73.2	1,101	0.9	80.2	1,514,504	1.2	53.3
1350 - 1399	980	1.6	74.8	1,471	1.1	81.4	2,098,335	1.7	55.1
1400 - 1449	823	1.4	76.2	1,427	1.1	82.5	2,109,927	1.7	56.9
1450 - 1499	816	1.4	77.6	946	0.7	83.2	1,463,683	1.2	58.1
1500 - 1549	776	1.3	78.9	1,336	1.0	84.2	2,093,140	1.7	59.9
1550 - 1599	745	1.3	80.2	1,013	0.8	85.0	1,659,671	1.3	61.3
1600 - 1649	744	1.3	81.4	974	0.8	85.8	1,643,545	1.3	62.7
1650 - 1699	711	1.2	82.6	644	0.5	86.3	1,126,950	0.9	63.6
1700 - 1749	654	1.1	83.7	966	0.8	87.0	1,733,093	1.4	65.1
1750 - 1799	663	1.1	84.8	1,340	1.0	88.1	2,430,524	2.0	67.1
1800 - 1849	580	1.0	85.8	738	0.6	88.6	1,396,873	1.1	68.3
1850 - 1899	604	1.0	86.8	760	0.6	89.2	1,479,509	1.2	69.5
1900 - 1949	524	0.9	87.7	703	0.5	89.8	1,406,415	1.1	70.7
1950 - 1999	538	0.9	88.6	855	0.7	90.4	1,756,383	1.4	72.2
2000 - 2049	402	0.7	89.3	340	0.3	90.7	724,403	0.6	72.8
2050 - 2099	364	0.6	89.9	630	0.5	91.2	1,357,510	1.1	74.0
2100 - 2149	384	0.6	90.5	705	0.5	91.7	1,552,458	1.3	75.3
2150 - 2199	379	0.6	91.2	459	0.4	92.1	1,046,277	0.8	76.1
2200 - 2249	363	0.6	91.8	431	0.3	92.4	993,564	0.8	77.0
2250 - 2299	366	0.6	92.4	385	0.3	92.7	905,595	0.7	77.7
2300 - 2349	381	0.6	93.1	1,131	0.9	93.6	2,720,792	2.2	80.0
2350 - 2399	367	0.6	93.7	700	0.5	94.2	1,723,087	1.4	81.5
2400 - 2449	336	0.6	94.2	1,192	0.9	95.1	2,978,572	2.5	84.0
2450 - 2499	315	0.5	94.8	1,563	1.2	96.3	3,964,062	3.3	87.3
2500 - 2549	252	0.4	95.2	453	0.4	96.7	1,190,311	1.0	88.3
2550 - 2599	212	0.4	95.5	1,652	1.3	97.9	4,349,865	3.6	92.0
2600 - 2649	159	0.3	95.8	629	0.5	98.4	1,685,440	1.4	93.4
2650 - 2699	128	0.2	96.0	209	0.2	98.6	579,518	0.4	93.9
2700 - 2749	128	0.2	96.2	276	0.2	98.8	768,967	0.6	94.6
2750 - 2799	103	0.2	96.4	95	0.1	98.9	288,385	0.2	94.8
2800 - 2849	86	0.1	96.6	21	&	98.9	66,173	&	94.9
2850 - 2899	86	0.1	96.7	45	&	98.9	139,905	0.1	95.0
2900 - 2949	67	0.1	96.8	35	&	99.0	107,891	&	95.1
2950 - 2999	60	0.1	96.9	34	&	99.0	106,558	&	95.2
3000 - 3049	66	0.1	97.0	28	&	99.0	92,210	&	95.2
3050 - 3099	70	0.1	97.2	15	&	99.0	51,611	&	95.3
3100 - 3149	70	0.1	97.3	11	&	99.0	39,141	&	95.3
3150 - 3199	74	0.1	97.4	13	&	99.0	46,242	&	95.3
3200 - 3249	67	0.1	97.5	18	&	99.0	61,025	&	95.4
3250 - 3299	64	0.1	97.6	41	&	99.1	145,157	0.1	95.5
3300 - 3349	66	0.1	97.7	12	&	99.1	44,128	&	95.6

Table C.1. (Cont'd)

DOMESTIC PASSENGER ONE-WAY TRIP LENGTH (MILES)	CITY PAIRS NUMBER	CITY PAIRS PERCENT SIMPLE	CITY PAIRS PERCENT CUMULATIVE	PASSENGERS OUTBOUND & INBOUND (1000)	PASSENGERS PERCENT SIMPLE	PASSENGERS PERCENT CUMULATIVE	PASSENGER-MILES OUTBOUND & INBOUND 1000	PASSENGER-MILES PERCENT SIMPLE	PASSENGER-MILES PERCENT CUMULATIVE
3350 - 3399	51	0.1	97.8	62	&	99.1	218,553	0.1	95.7
3400 - 3449	75	0.1	97.9	18	&	99.1	67,041	&	95.8
3450 - 3499	39	0.1	98.0	6	&	99.2	22,531	&	95.8
3500 - 3549	40	0.1	98.1	5	&	99.2	20,280	&	95.8
3550 - 3599	34	0.1	98.1	*	&	99.2	9,924	&	95.8
3600 - 3649	38	0.1	98.2	*	&	99.2	16,941	&	95.9
3650 - 3699	44	0.1	98.3	9	&	99.2	35,548	&	95.9
3700 - 3749	40	0.1	98.3	30	&	99.2	119,983	0.1	96.0
3750 - 3799	50	0.1	98.4	59	&	99.2	196,451	0.1	96.2
3800 - 3849	39	0.1	98.5	32	&	99.3	127,850	0.1	96.3
3850 - 3899	32	0.1	98.5	24	&	99.3	98,491	&	96.3
3900 - 3949	40	0.1	98.6	45	&	99.3	183,525	0.1	96.5
3950 - 3999	38	0.1	98.7	51	&	99.3	207,081	0.1	96.7
4000 - 4049	41	0.1	98.7	14	&	99.4	59,295	&	96.7
4050 - 4099	38	0.1	98.8	10	&	99.4	43,476	&	96.8
4100 - 4149	40	0.1	98.9	25	&	99.4	107,869	&	96.9
4150 - 4199	42	0.1	98.9	57	&	99.4	251,437	0.2	97.1
4200 - 4249	43	0.1	99.0	30	&	99.5	130,694	0.1	97.2
4250 - 4299	47	0.1	99.1	123	0.1	99.6	531,906	0.4	97.6
4300 - 4349	45	0.1	99.2	18	&	99.6	79,154	&	97.7
4350 - 4399	45	0.1	99.2	25	&	99.6	113,859	&	97.8
4400 - 4449	48	0.1	99.3	32	&	99.6	148,468	0.1	97.9
4450 - 4499	26	&	99.4	37	&	99.6	169,003	0.1	98.1
4500 - 4549	32	0.1	99.4	31	&	99.7	142,095	0.1	98.2
4550 - 4599	30	0.1	99.5	28	&	99.7	128,343	0.1	98.3
4600 - 4649	48	0.1	99.6	14	&	99.7	68,304	&	98.3
4650 - 4699	34	0.1	99.6	38	&	99.7	179,645	0.1	98.5
4700 - 4749	33	0.1	99.7	17	&	99.7	83,115	&	98.6
4750 - 4799	49	0.1	99.7	23	&	99.8	111,138	&	98.7
4800 - 4849	34	0.1	99.8	48	&	99.8	235,443	0.1	98.9
4850 - 4899	32	0.1	99.9	46	&	99.8	231,379	0.1	99.0
4900 - 4949	24	&	99.9	48	&	99.9	243,874	0.2	99.3
4950 - 4999	20	&	99.9	114	0.1	100.0	577,147	0.4	99.7
5000 - 5049	11	&	100.0	22	&	100.0	110,933	&	99.8
5050 - 5099	15	&	100.0	36	&	100.0	185,451	0.1	100.0
5100 - 5149	9	&	100.0	*	&	100.0	14,089	&	100.0
5150 - 5199	4	&	100.0	*	&	100.0	1,226	&	100.0
ALL TRIPS	59,403	100.0	100.0	128,790	100.0	100.0	118,720,034	100.0	100.0
MEDIAN TRIP LENGTH (MILES)				673					
MEAN TRIP LENGTH (MILES)				921					

* LESS THAN 500.

& LESS THAN 0.05 PERCENT.

NOTES.

ROUND TRIPS AND OTHER ITINERARIES INVOLVING MOVMENT IN TWO DIRECTIONS ARE TREATED AS TWO ONE-WAY TRIPS.
DOMESTIC OPERATIONS ARE THOSE WITHIN THE 50 U.S. STATES WITH PURELY INTRA-ALASKA TRAFFIC EXCLUDED.
(PRIOR TO 1968 DOMESTIC INCLUDED ONLY THE 48 CONTIGUOUS U. S. STATES.)
DOMESTIC PORTIONS OF DOMESTIC-INTERNATIONAL/TERRITORIAL ITINERARIES ARE INCLUDED IN THE TABULATION.
TRAFFIC IS CATEGORIZED BY CLASS INTERVAL OF DISTANCE BASED UPON THE NONSTOP AIRPORT-TO-AIRPORT GREAT-CIRCLE DISTANCE.
PASSENGER-MILES ARE THE SUMMATION OF THE NUMBER OF PASSENGERS MULTIPLIED BY THE GREAT-CIRCLE AIRPORT-TO-AIRPORT MILEAGE FOR EACH AIR CARRIER FLIGHT-COUPON STAGE IN EACH INDIVIDUAL ITINERARY.

SOURCE.

DERIVED FROM CIVIL AERONAUTICS BOARD, DOMESTIC ORIGIN-DESTINATION SURVEY OF AIRLINE PASSENGER TRAFFIC, VOLUME VIII-4-1, FOURTH QUARTER 1975, TABLE 5 (PUBLISHED BY THE AIR TRANSPORT ASSOCIATION OF AMERICA).

Source: Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement*, Washington, D.C., December 1977.

Table C.2. Top 100 City Pairs Ranked by Number of Passengers, 1975

CITY PAIR IN BOTH DIRECTIONS (IN ORDER OF PASSENGER RANK)		INTER-CITY DISTANCE (MILES)	PASSENGERS				PASSENGER-MILES			
			NUMBER (1000)	PERCENT SIMPLE	PERCENT CUMU-LA-TIVE	RANK	NUMBER (1000)	PERCENT SIMPLE	PERCENT CUMU-LA-TIVE	RANK
BOSTON, MASSACHUSETTS	-NEW YORK, NEW YORK	191	1,685	1.3	1.3	1	319,002	0.3	0.3	41
CHICAGO, ILLINOIS	-NEW YORK, NEW YORK	722	1,598	1.2	2.5	2	1,177,591	1.0	1.3	7
NEW YORK, N.Y./NEWARK, N.J.	-WASHINGTON, D. C.	212	1,569	1.2	3.8	3	335,913	0.3	1.5	37
MIAMI, FLORIDA	-NEW YORK, NEW YORK	1,091	1,448	1.1	4.9	4	1,597,851	1.3	2.9	3
LOS ANGELES, CALIFORNIA	-NEW YORK, NEW YORK	2,465	1,169	0.9	5.8	5	2,934,008	2.5	5.4	1
FORT LAUDERDALE, FLORIDA	-NEW YORK, NEW YORK	1,070	1,126	0.9	6.7	6	1,209,509	1.0	6.4	6
LOS ANGELES, CALIFORNIA	-SAN FRANCISCO,CALIF.	347	919	0.7	7.4	7	316,668	0.3	6.6	43
NEW YORK, N.Y./NEWARK, N.J.	-SAN FRANCISCO,CALIF.	2,576	822	0.6	8.0	8	2,163,244	1.8	8.5	2
CHICAGO, ILLINOIS	-LOS ANGELES, CALIF.	1,751	694	0.5	8.6	9	1,235,756	1.0	9.5	4
DETROIT&ANN ARBOR, MICHIGAN	-NEW YORK, NEW YORK	491	655	0.5	9.1	10	330,208	0.3	9.8	39
LAS VEGAS, NEVADA	-LOS ANGELES, CALIF.	236	636	0.5	9.6	11	150,350	0.1	9.9	108
NEW YORK, N.Y./NEWARK, N.J.	-PITTSBURGH, PENNA.	323	577	0.4	10.0	12	192,823	0.2	10.1	83
HONOLULU, OAHU, HAWAII	-LIHUE, KAUAI, HAWAII	102	573	0.4	10.5	13	59,881	0.1	10.1	327
BOSTON, MASSACHUSETTS	-WASHINGTON, D. C.	403	559	0.4	10.9	14	224,683	0.2	10.3	68
ATLANTA, GEORGIA	-NEW YORK, NEW YORK	755	552	0.4	11.3	15	434,563	0.4	10.7	24
CHICAGO, ILLINOIS	-MINNEAPOLIS, MINN.	345	544	0.4	11.7	16	187,520	0.2	10.8	87
CHICAGO, ILLINOIS	-DETROIT, MICHIGAN	237	511	0.4	12.1	17	119,909	0.1	10.9	145
CLEVELAND, OHIO	-NEW YORK, NEW YORK	411	509	0.4	12.5	18	213,921	0.2	11.1	71
HILO, HAWAII, HAWAII	-HONOLULU,OAHU,HAWAII	216	480	0.4	12.9	19	113,312	0.1	11.2	158
BUFFALO&NIAGARA FALLS,NEW YORK	-NEW YORK, NEW YORK	291	479	0.4	13.3	20	140,336	0.1	11.3	116
HONOLULU, OAHU, HAWAII	-LOS ANGELES, CALIF.	2,556	477	0.4	13.7	21	1,235,464	1.0	12.4	5
CHICAGO, ILLINOIS	-WASHINGTON, D. C.	595	472	0.4	14.0	22	292,227	0.2	12.6	52
HONOLULU, OAHU, HAWAII	-KAHULUI, MAUI,HAWAII	100	449	0.3	14.4	23	44,944	*	12.7	434
NEW YORK, N.Y./NEWARK, N.J.	-TAMPA, FLORIDA	1,006	441	0.3	14.7	24	450,981	0.4	13.0	22
CHICAGO, ILLINOIS	-ST. LOUIS, MISSOURI	256	441	0.3	15.1	25	114,751	0.1	13.1	153
CHICAGO, ILLINOIS	-SAN FRANCISCO,CALIF.	1,855	397	0.3	15.4	26	754,605	0.6	13.8	9
CHICAGO, ILLINOIS	-MIAMI, FLORIDA	1,187	385	0.3	15.7	27	465,873	0.4	14.2	21
DALLAS&FT. WORTH, TEXAS	-NEW YORK, NEW YORK	1,379	384	0.3	16.0	28	544,793	0.5	14.6	15
LOS ANGELES, CALIFORNIA	-SEATTLE, WASHINGTON	956	382	0.3	16.3	29	368,065	0.3	14.9	29
BOSTON, MASSACHUSETTS	-PHILADELPHIA, PENNA	271	369	0.3	16.5	30	104,402	0.1	15.0	179
BOSTON, MASSACHUSETTS	-CHICAGO, ILLINOIS	860	369	0.3	16.8	31	322,875	0.3	15.3	40
DENVER, COLORADO	-LOS ANGELES, CALIF.	849	368	0.3	17.1	32	316,686	0.3	15.6	42
NEW YORK, N.Y./NEWARK, N.J.	-ORLANDO, FLORIDA	941	359	0.3	17.4	33	348,920	0.3	15.9	33
NEW YORK, N.Y./NEWARK, N.J.	-ROCHESTER, NEW YORK	253	350	0.3	17.7	34	89,519	0.1	15.9	211
SAN FRANCISCO, CALIFORNIA	-SEATTLE, WASHINGTON	672	342	0.3	17.9	35	233,967	0.2	16.1	65
LOS ANGELES, CALIFORNIA	-WASHINGTON, D. C.	2,304	341	0.3	18.2	36	796,694	0.7	16.8	8
HOUSTON, TEXAS	-NEW YORK, NEW YORK	1,416	340	0.3	18.5	37	490,373	0.4	17.2	19
CHICAGO, ILLINOIS	-PHILADELPHIA, PENNA	673	339	0.3	18.7	38	233,165	0.2	17.4	66
CHICAGO, ILLINOIS	-CLEVELAND, OHIO	311	334	0.3	19.0	39	106,318	0.1	17.5	172
CHICAGO, ILLINOIS	-DENVER, COLORADO	908	334	0.3	19.2	40	306,143	0.3	17.8	45
NEW YORK, N.Y./NEWARK, N.J.	-WEST PALM BEACH,FLA.	1,029	331	0.3	19.5	41	347,844	0.3	18.0	34
DALLAS&FT. WORTH, TEXAS	-LOS ANGELES, CALIF.	1,241	326	0.3	19.7	42	410,836	0.3	18.4	25
LOS ANGELES, CALIFORNIA	-PHOENIX, ARIZONA	370	323	0.3	20.0	43	120,129	0.1	18.5	144
NEW YORK, N.Y./NEWARK, N.J.	-ST. LOUIS, MISSOURI	883	310	0.2	20.2	44	278,948	0.2	18.7	54
CHICAGO, ILLINOIS	-DALLAS&FT.WORTH, TEX	800	293	0.2	20.5	45	241,721	0.2	18.9	64
HONOLULU, OAHU, HAWAII	-SAN FRANCISCO,CALIF.	2,397	290	0.2	20.7	46	711,593	0.6	19.5	11
DENVER, COLORADO	-NEW YORK, NEW YORK	1,628	288	0.2	20.9	47	477,976	0.4	19.9	20
PHILADELPHIA, PA./CAMDEN, N.J.	-PITTSBURGH, PENNA.	264	286	0.2	21.1	48	76,987	0.1	20.0	259
CHICAGO, ILLINOIS	-KANSAS CITY,MISSOURI	407	283	0.2	21.4	49	116,525	0.1	20.1	147
BOSTON, MASSACHUSETTS	-LOS ANGELES, CALIF.	2,611	271	0.2	21.6	50	716,142	0.6	20.7	10
NEW YORK, N.Y./NEWARK, N.J.	-SYRACUSE, NEW YORK	199	270	0.2	21.8	51	54,196	*	20.7	366
CHICAGO, ILLINOIS	-PITTSBURGH, PENNA.	413	270	0.2	22.0	52	113,224	0.1	20.8	159
HOUSTON, TEXAS	-NEW ORLEANS, LA.	304	261	0.2	22.2	53	80,145	0.1	20.9	245
CHICAGO, ILLINOIS	-TAMPA, FLORIDA	1,008	261	0.2	22.4	54	265,346	0.2	21.1	55
CHICAGO, ILLINOIS	-FORT LAUDERDALE,FLA.	1,172	256	0.2	22.6	55	303,514	0.3	21.4	46
MINNEAPOLIS/ST. PAUL,MINNESOTA	-NEW YORK, NEW YORK	1,018	252	0.2	22.8	56	260,303	0.2	21.6	57
SAN FRANCISCO, CALIFORNIA	-WASHINGTON, D. C.	2,436	251	0.2	23.0	57	625,895	0.5	22.1	12
CHICAGO, ILLINOIS	-LAS VEGAS, NEVADA	1,521	249	0.2	23.2	58	380,198	0.3	22.5	27
ATLANTA, GEORGIA	-CHICAGO, ILLINOIS	596	248	0.2	23.4	59	157,375	0.1	22.6	103
NEW ORLEANS, LOUISIANA	-NEW YORK, NEW YORK	1,177	247	0.2	23.6	60	298,464	0.3	22.8	49
ATLANTA, GEORGIA	-WASHINGTON, D. C.	543	246	0.2	23.7	61	138,363	0.1	23.0	119
ATLANTA, GEORGIA	-MIAMI, FLORIDA	595	245	0.2	23.9	62	147,854	0.1	23.1	110
HOUSTON, TEXAS	-LOS ANGELES, CALIF.	1,384	244	0.2	24.1	63	341,072	0.3	23.4	36
CHICAGO, ILLINOIS	-PHOENIX, ARIZONA	1,445	242	0.2	24.3	64	354,750	0.3	23.7	32
DETROIT&ANN ARBOR, MICHIGAN	-LOS ANGELES, CALIF.	1,988	242	0.2	24.5	65	491,446	0.4	24.1	18

Table C.2. (Cont'd)

CITY PAIR IN BOTH DIRECTIONS (IN ORDER OF PASSENGER RANK)		INTER-CITY DISTANCE (MILES)	PASSENGERS				PASSENGER-MILES			
			NUMBER (1000)	PERCENT SIMPLE	PERCENT CUMU-LA-TIVE	RANK	NUMBER (1000)	PERCENT SIMPLE	PERCENT CUMU-LA-TIVE	RANK
MIAMI, FLORIDA	-PHILADELPHIA, PENNA	1,021	241	0.2	24.7	66	248,413	0.2	24.3	62
CINCINNATI, OHIO	-NEW YORK, NEW YORK	580	234	0.2	24.9	67	138,628	0.1	24.4	117
LOS ANGELES, CALIFORNIA	-MINNEAPOLIS, MINN.	1,536	233	0.2	25.1	68	363,937	0.3	24.7	31
PORTLAND, OREGON	-SEATTLE, WASHINGTON	132	233	0.2	25.2	69	30,145	*	24.7	654
BOSTON, MASSACHUSETTS	-MIAMI, FLORIDA	1,258	233	0.2	25.4	70	295,617	0.2	25.0	50
DALLAS&FT. WORTH, TEXAS	-HOUSTON, TEXAS	232	228	0.2	25.6	71	52,148	*	25.0	378
LOS ANGELES, CALIFORNIA	-SAN DIEGO,CALIFORNIA	109	225	0.2	25.8	72	24,617	*	25.1	788
MIAMI, FLORIDA	-WASHINGTON, D. C.	920	223	0.2	25.9	73	210,538	0.2	25.2	73
CHICAGO, ILLINOIS	-HOUSTON, TEXAS	932	217	0.2	26.1	74	208,415	0.2	25.4	74
HONOLULU, OAHU, HAWAII	-KONA, HAWAII, HAWAII	169	214	0.2	26.3	75	37,583	*	25.4	516
COLUMBUS, OHIO	-NEW YORK, NEW YORK	473	212	0.2	26.4	76	102,476	0.1	25.5	184
LOS ANGELES, CALIFORNIA	-PHILADELPHIA, PENNA	2,407	212	0.2	26.6	77	516,708	0.4	26.0	16
LOS ANGELES, CALIFORNIA	-MIAMI, FLORIDA	2,342	207	0.2	26.8	78	502,552	0.4	26.4	17
DETROIT&ANN ARBOR, MICHIGAN	-WASHINGTON, D. C.	391	204	0.2	26.9	79	82,668	0.1	26.5	234
DENVER, COLORADO	-SAN FRANCISCO,CALIF.	957	204	0.2	27.1	80	199,459	0.2	26.6	79
MIAMI, FLORIDA	-TAMPA, FLORIDA	198	203	0.2	27.2	81	41,557	*	26.7	469
SEATTLE, WASHINGTON	-SPOKANE, WASHINGTON	223	202	0.2	27.4	82	45,311	*	26.7	431
BOSTON, MASSACHUSETTS	-SAN FRANCISCO,CALIF.	2,704	200	0.2	27.6	83	550,281	0.5	27.2	13
LOS ANGELES, CALIFORNIA	-PORTLAND, OREGON	834	199	0.2	27.7	84	167,507	0.1	27.3	96
CHICAGO, ILLINOIS	-CINCINNATI, OHIO	254	194	0.2	27.9	85	51,483	*	27.3	383
PORTLAND, OREGON	-SAN FRANCISCO,CALIF.	541	193	0.1	28.0	86	107,381	0.1	27.4	170
CHARLOTTE, NORTH CAROLINA	-NEW YORK, NEW YORK	537	192	0.1	28.2	87	104,805	0.1	27.5	178
DETROIT&ANN ARBOR, MICHIGAN	-TAMPA, FLORIDA	994	188	0.1	28.3	88	185,737	0.2	27.7	88
NEW YORK, N.Y./NEWARK, N.J.	-NORFOLK, VIRGINIA	290	187	0.1	28.4	89	54,956	*	27.7	358
LOS ANGELES, CALIFORNIA	-SACRAMENTO, CALIF.	373	184	0.1	28.6	90	69,114	0.1	27.8	295
INDIANAPOLIS, INDIANA	-NEW YORK, NEW YORK	655	183	0.1	28.7	91	121,615	0.1	27.9	141
MIAMI, FLORIDA	-ORLANDO, FLORIDA	196	182	0.1	28.9	92	35,227	*	27.9	553
LOS ANGELES, CALIFORNIA	-ST. LOUIS, MISSOURI	1,592	182	0.1	29.0	93	294,230	0.2	28.2	51
CHICAGO, ILLINOIS	-ORLANDO, FLORIDA	991	179	0.1	29.2	94	182,929	0.2	28.3	90
BOSTON, MASSACHUSETTS	-FORT LAUDERDALE,FLA.	1,237	179	0.1	29.3	95	222,493	0.2	28.5	69
LAS VEGAS, NEVADA	-NEW YORK, NEW YORK	2,238	178	0.1	29.4	96	409,643	0.3	28.8	26
LOS ANGELES, CALIFORNIA	-SALT LAKE CITY, UTAH	590	177	0.1	29.6	97	106,297	0.1	28.9	173
ATLANTA, GEORGIA	-TAMPA, FLORIDA	412	177	0.1	29.7	98	73,194	0.1	29.0	275
NEW YORK, N.Y./NEWARK, N.J.	-RALEIGH/DURHAM, N.C.	424	174	0.1	29.8	99	74,713	0.1	29.1	269
FORT LAUDERDALE, FLORIDA	-PHILADELPHIA, PENNA	996	173	0.1	30.0	100	173,671	0.1	29.2	95
TOP 100 CITY PAIRS (RANKED IN ORDER OF PASSENGERS)		XXX	38,607	30.0	30.0	XXX	34,674,706	29.2	29.2	XXX
ALL CITY PAIRS		XXX	128,789	100.0	100.0	XXX	118,720,034	100.0	100.0	XXX

NOTES.

DOMESTIC OPERATIONS ARE THOSE WITHIN THE 50 U.S. STATES, WITH PURELY INTRA-ALASKA TRAFFIC EXCLUDED. (PRIOR TO 1968 DOMESTIC INCLUDED ONLY THE 48 CONTIGUOUS U.S. STATES.)
PASSENGER AMOUNTS ARE THE SUM OF PASSENGER JOURNEYS MOVING IN BOTH DIRECTIONS BETWEEN THE CITY PAIRS, ON A DIRECTIONAL ORIGIN-DESTINATION BASIS, REGARDLESS OF THE NUMBER OF TRANSFER POINTS OF AIRLINES USED, WITH ROUND TRIPS AND OTHER ITINERARIES INVOLVING MOVEMENT IN TWO DIRECTIONS TREATED AS TWO ONE-WAY JOURNEYS.
DOMESTIC PORTIONS OF DOMESTIC-INTERNATIONAL/TERRITORIAL ITINERARIES ARE INCLUDED IN THIS TABLE.
PASSENGER-MILES ARE THE SUMMATION OF THE NUMBER OF PASSENGERS MULTIPLIED BY THE GREAT-CIRCLE AIRPORT-TO-AIRPORT MILEAGE FOR EACH AIR CARRIER FLIGHT-COUPON STAGE IN THE INDIVIDUAL ITINERARIES MOVING BETWEEN THE CITY PAIRS.

SOURCE.

DERIVED FROM CIVIL AERONAUTICS BOARD, <u>DOMESTIC ORIGIN-DESTINATION SURVEY OF AIRLINE PASSENGER TRAFFIC</u>, VOLUME VIII-4-1, FOURTH QUARTER 1975, TABLES 1, 6, AND 8, RESPECTIVELY (PUBLISHED BY THE AIR TRANSPORT ASSOCIATION OF AMERICA).

* LESS THAN 0.05 PERCENT.

Source: Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement*, Washington, D.C., December 1977.

Table C.3. Top 100 City Pairs Ranked by Passenger-miles, 1975

CITY PAIR IN BOTH DIRECTIONS (IN ORDER OF PASSENGER-MILE RANK)		INTER-CITY DISTANCE (MILES)	PASSENGER-MILES NUMBER (1000)	PASSENGER-MILES PERCENT SIMPLE	PASSENGER-MILES PERCENT CUMU-LA-TIVE	PASSENGER-MILES RANK	PASSENGERS NUMBER (1000)	PASSENGERS PERCENT SIMPLE	PASSENGERS PERCENT CUMU-LA-TIVE	PASSENGERS RANK
LOS ANGELES, CALIFORNIA	-NEW YORK, NEW YORK	2,465	2,934,008	2.5	2.5	1	1,169	0.9	0.9	5
NEW YORK, N.Y./NEWARK, N.J.	-SAN FRANCISCO,CALIF.	2,576	2,163,244	1.8	4.3	2	822	0.6	1.5	8
MIAMI, FLORIDA	-NEW YORK, NEW YORK	1,091	1,597,851	1.3	5.6	3	1,448	1.1	2.7	4
CHICAGO, ILLINOIS	-LOS ANGELES, CALIF.	1,751	1,235,756	1.0	6.7	4	694	0.5	3.2	9
HONOLULU, OAHU, HAWAII	-LOS ANGELES, CALIF.	2,556	1,235,464	1.0	7.7	5	477	0.4	3.6	21
FORT LAUDERDALE, FLORIDA	-NEW YORK, NEW YORK	1,070	1,209,509	1.0	8.7	6	1,126	0.9	4.5	6
CHICAGO, ILLINOIS	-NEW YORK, NEW YORK	722	1,177,591	1.0	9.7	7	1,598	1.2	5.7	2
LOS ANGELES, CALIFORNIA	-WASHINGTON, D. C.	2,304	796,694	0.7	10.4	8	341	0.3	6.0	36
CHICAGO, ILLINOIS	-SAN FRANCISCO,CALIF.	1,855	754,605	0.6	11.0	9	397	0.3	6.3	26
BOSTON, MASSACHUSETTS	-LOS ANGELES, CALIF.	2,611	716,142	0.6	11.6	10	271	0.2	6.5	50
HONOLULU, OAHU, HAWAII	-SAN FRANCISCO,CALIF.	2,397	711,593	0.6	12.2	11	290	0.2	6.7	46
SAN FRANCISCO, CALIFORNIA	-WASHINGTON, D. C.	2,436	625,895	0.5	12.8	12	251	0.2	6.9	57
BOSTON, MASSACHUSETTS	-SAN FRANCISCO,CALIF.	2,704	550,281	0.5	13.2	13	200	0.2	7.1	83
HONOLULU, OAHU, HAWAII	-NEW YORK, NEW YORK	4,973	547,454	0.5	13.7	14	109	0.1	7.1	200
DALLAS&FT. WORTH, TEXAS	-NEW YORK, NEW YORK	1,379	544,793	0.5	14.2	15	384	0.3	7.4	28
LOS ANGELES, CALIFORNIA	-PHILADELPHIA, PENNA	2,407	516,708	0.4	14.6	16	212	0.2	7.6	77
LOS ANGELES, CALIFORNIA	-MIAMI, FLORIDA	2,342	502,552	0.4	15.0	17	207	0.2	7.8	78
DETROIT&ANN ARBOR, MICHIGAN	-LOS ANGELES, CALIF.	1,988	491,446	0.4	15.4	18	242	0.2	7.9	65
HOUSTON, TEXAS	-NEW YORK, NEW YORK	1,416	490,373	0.4	15.8	19	340	0.3	8.2	37
DENVER, COLORADO	-NEW YORK, NEW YORK	1,628	477,976	0.4	16.2	20	288	0.2	8.4	47
CHICAGO, ILLINOIS	-MIAMI, FLORIDA	1,187	465,873	0.4	16.6	21	385	0.3	8.7	27
NEW YORK, N.Y./NEWARK, N.J.	-TAMPA, FLORIDA	1,006	450,981	0.4	17.0	22	441	0.3	9.1	24
CHICAGO, ILLINOIS	-HONOLULU,OAHU,HAWAII	4,251	435,012	0.4	17.4	23	101	0.1	9.2	220
ATLANTA, GEORGIA	-NEW YORK, NEW YORK	755	434,563	0.4	17.7	24	552	0.4	9.6	15
DALLAS&FT. WORTH, TEXAS	-LOS ANGELES, CALIF.	1,241	410,836	0.3	18.1	25	326	0.3	9.8	42
LAS VEGAS, NEVADA	-NEW YORK, NEW YORK	2,238	409,643	0.3	18.4	26	178	0.1	10.0	96
CHICAGO, ILLINOIS	-LAS VEGAS, NEVADA	1,521	380,198	0.3	18.8	27	249	0.2	10.2	58
PHILADELPHIA, PA./CAMDEN, N.J.	-SAN FRANCISCO,CALIF.	2,526	376,691	0.3	19.1	28	146	0.1	10.3	138
LOS ANGELES, CALIFORNIA	-SEATTLE, WASHINGTON	956	368,065	0.3	19.4	29	382	0.3	10.6	29
HONOLULU, OAHU, HAWAII	-SEATTLE, WASHINGTON	2,678	367,548	0.3	19.7	30	134	0.1	10.7	151
LOS ANGELES, CALIFORNIA	-MINNEAPOLIS, MINN.	1,536	363,937	0.3	20.0	31	233	0.2	10.9	68
CHICAGO, ILLINOIS	-PHOENIX, ARIZONA	1,445	354,750	0.3	20.3	32	242	0.2	11.1	64
NEW YORK, N.Y./NEWARK, N.J.	-ORLANDO, FLORIDA	941	348,920	0.3	20.6	33	359	0.3	11.3	33
NEW YORK, N.Y./NEWARK, N.J.	-WEST PALM BEACH,FLA.	1,029	347,844	0.3	20.9	34	331	0.3	11.6	41
NEW YORK, N.Y./NEWARK, N.J.	-PHOENIX, ARIZONA	2,144	344,360	0.3	21.2	35	158	0.1	11.7	117
HOUSTON, TEXAS	-LOS ANGELES, CALIF.	1,384	341,072	0.3	21.5	36	244	0.2	11.9	63
NEW YORK, N.Y./NEWARK, N.J.	-WASHINGTON, D. C.	212	335,913	0.3	21.7	37	1,569	1.2	13.1	3
NEW YORK, N.Y./NEWARK, N.J.	-SAN DIEGO,CALIFORNIA	2,436	330,481	0.3	22.0	38	133	0.1	13.2	153
DETROIT&ANN ARBOR, MICHIGAN	-NEW YORK, NEW YORK	491	330,208	0.3	22.3	39	655	0.5	13.7	10
BOSTON, MASSACHUSETTS	-CHICAGO, ILLINOIS	860	322,875	0.3	22.6	40	369	0.3	14.0	31
BOSTON, MASSACHUSETTS	-NEW YORK, NEW YORK	191	319,002	0.3	22.8	41	1,685	1.3	15.3	1
DENVER, COLORADO	-LOS ANGELES, CALIF.	849	316,686	0.3	23.1	42	368	0.3	15.6	32
LOS ANGELES, CALIFORNIA	-SAN FRANCISCO,CALIF.	347	316,668	0.3	23.4	43	919	0.7	16.3	7
CLEVELAND, OHIO	-LOS ANGELES, CALIF.	2,057	310,614	0.3	23.6	44	149	0.1	16.4	133
CHICAGO, ILLINOIS	-DENVER, COLORADO	908	306,143	0.3	23.9	45	334	0.3	16.7	40
CHICAGO, ILLINOIS	-FORT LAUDERDALE,FLA.	1,172	303,514	0.3	24.2	46	256	0.2	16.9	55
MIAMI, FLORIDA	-SAN FRANCISCO,CALIF.	2,590	300,300	0.3	24.4	47	111	0.1	17.0	196
NEW YORK, N.Y./NEWARK, N.J.	-SEATTLE, WASHINGTON	2,410	298,873	0.3	24.7	48	120	0.1	17.1	179
NEW ORLEANS, LOUISIANA	-NEW YORK, NEW YORK	1,177	298,464	0.3	24.9	49	247	0.2	17.3	60
BOSTON, MASSACHUSETTS	-MIAMI, FLORIDA	1,258	295,617	0.2	25.2	50	233	0.2	17.5	70
LOS ANGELES, CALIFORNIA	-ST. LOUIS, MISSOURI	1,592	294,230	0.2	25.4	51	182	0.1	17.6	93
CHICAGO, ILLINOIS	-WASHINGTON, D. C.	595	292,227	0.2	25.7	52	472	0.4	18.0	22
DETROIT&ANN ARBOR, MICHIGAN	-SAN FRANCISCO,CALIF.	2,087	288,100	0.2	25.9	53	135	0.1	18.1	148
NEW YORK, N.Y./NEWARK, N.J.	-ST. LOUIS, MISSOURI	883	278,948	0.2	26.1	54	310	0.2	18.3	44
CHICAGO, ILLINOIS	-TAMPA, FLORIDA	1,008	265,346	0.2	26.4	55	261	0.2	18.5	54
CHICAGO, ILLINOIS	-SAN DIEGO,CALIFORNIA	1,729	260,712	0.2	26.6	56	147	0.1	18.6	134
MINNEAPOLIS/ST. PAUL,MINNESOTA	-NEW YORK, NEW YORK	1,018	260,303	0.2	26.8	57	252	0.2	18.8	56
KAHULUI, MAUI, HAWAII	-LOS ANGELES, CALIF.	2,486	255,312	0.2	27.0	58	95	0.1	18.9	230
LOS ANGELES, CALIFORNIA	-PITTSBURGH, PENNA.	2,144	252,641	0.2	27.2	59	117	0.1	19.0	186
ATLANTA, GEORGIA	-LOS ANGELES, CALIF.	1,946	251,921	0.2	27.4	60	124	0.1	19.1	171
MINNEAPOLIS/ST. PAUL,MINNESOTA	-SAN FRANCISCO,CALIF.	1,588	250,533	0.2	27.6	61	155	0.1	19.2	124
MIAMI, FLORIDA	-PHILADELPHIA, PENNA	1,021	248,413	0.2	27.9	62	241	0.2	19.4	66
DALLAS&FT. WORTH, TEXAS	-SAN FRANCISCO,CALIF.	1,475	245,206	0.2	28.1	63	164	0.1	19.5	110
CHICAGO, ILLINOIS	-DALLAS&FT.WORTH, TEX	800	241,721	0.2	28.3	64	293	0.2	19.7	45
SAN FRANCISCO, CALIFORNIA	-SEATTLE, WASHINGTON	672	233,967	0.2	28.5	65	342	0.3	20.0	35

Table C.3. (Cont'd)

CITY PAIR IN BOTH DIRECTIONS (IN ORDER OF PASSENGER-MILE RANK)		INTER-CITY DISTANCE (MILES)	PASSENGER-MILES NUMBER (1000)	PASSENGER-MILES PERCENT SIMPLE	PASSENGER-MILES PERCENT CUMU-LA-TIVE	PASSENGER-MILES RANK	PASSENGERS NUMBER (1000)	PASSENGERS PERCENT SIMPLE	PASSENGERS PERCENT CUMU-LA-TIVE	PASSENGERS RANK
CHICAGO, ILLINOIS	-PHILADELPHIA, PENNA.	673	233,165	0.2	28.7	66	339	0.3	20.3	38
ANCHORAGE, ALASKA	-SEATTLE, WASHINGTON	1,446	231,751	0.2	28.8	67	159	0.1	20.4	115
BOSTON, MASSACHUSETTS	-WASHINGTON, D. C.	403	224,683	0.2	29.0	68	559	0.4	20.8	14
BOSTON, MASSACHUSETTS	-FORT LAUDERDALE,FLA.	1,237	222,493	0.2	29.2	69	179	0.1	21.0	95
HOUSTON, TEXAS	-SAN FRANCISCO,CALIF.	1,647	215,673	0.2	29.4	70	130	0.1	21.1	161
CLEVELAND, OHIO	-NEW YORK, NEW YORK	411	213,921	0.2	29.6	71	509	0.4	21.5	18
LIHUE, KAUAI, HAWAII	-LOS ANGELES, CALIF.	2,628	212,994	0.2	29.8	72	79	0.1	21.5	286
MIAMI, FLORIDA	-WASHINGTON, D. C.	920	210,538	0.2	29.9	73	225	0.2	21.7	73
CHICAGO, ILLINOIS	-HOUSTON, TEXAS	932	208,415	0.2	30.1	74	217	0.2	21.9	74
CHICAGO, ILLINOIS	-SEATTLE, WASHINGTON	1,730	207,234	0.2	30.3	75	117	0.1	22.0	185
CHICAGO, ILLINOIS	-MINNEAPOLIS, MINN.	1,300	203,764	0.2	30.5	76	155	0.1	22.1	120
LAS VEGAS, NEVADA	-LOS ANGELES, CALIF.	1,365	203,397	0.2	30.6	77	147	0.1	22.2	136
KANSAS CITY, MISSOURI	-WASHINGTON, D. C.	1,480	200,759	0.2	30.8	78	132	0.1	22.3	154
DENVER, COLORADO	-SAN FRANCISCO,CALIF.	957	199,459	0.2	31.0	79	204	0.2	22.4	80
DENVER, COLORADO	-NEW ORLEANS, LA.	1,071	197,441	0.2	31.1	80	116	0.1	22.5	188
LOS ANGELES, CALIFORNIA	-SAN FRANCISCO,CALIF.	2,458	197,021	0.2	31.3	81	79	0.1	22.6	290
BALTIMORE, MARYLAND	-MIAMI, FLORIDA	1,150	195,613	0.2	31.5	82	169	0.1	22.7	106
DETROIT/WAYNE ARPORTS, MICHIGAN	-PITTSBURGH, PENNA.	323	192,323	0.2	31.6	83	577	0.4	23.2	12
NEW YORK, N.Y./NEWARK, N.J.	-SAN FRANCISCO,CALIF.	1,737	190,745	0.2	31.8	84	[illegible]	0.1	23.3	204
ST. LOUIS, MISSOURI	-WASHINGTON, D. C.	1,181	190,261	0.2	32.0	85	157	0.1	23.4	118
DALLAS/FT. WORTH, TEXAS	-SAN FRANCISCO,CALIF.	2,142	189,069	0.2	32.1	86	65	0.1	23.4	265
ATLANTA, GEORGIA	-MINNEAPOLIS, MINN.	345	187,320	0.2	32.3	87	544	0.4	23.9	16
CHICAGO, ILLINOIS	-TAMPA, FLORIDA	994	185,737	0.2	32.4	88	168	0.1	24.0	88
DETROIT/WAYNE ARPORTS, MICHIGAN	-LOS ANGELES, CALIF.	2,528	185,561	0.2	32.6	89	73	0.1	24.1	327
HARTFORD/SPRINGFIELD/WESTFLD,CONN	-ORLANDO, FLORIDA	991	182,929	0.2	32.7	90	179	0.1	24.2	94
CHICAGO, ILLINOIS	-WASHINGTON, D. C.	2,269	181,949	0.2	32.9	91	79	0.1	24.3	284
SAN DIEGO, CALIFORNIA	-NEW YORK, NEW YORK	1,201	181,598	0.2	33.0	92	161	0.1	24.4	113
KANSAS CITY, MISSOURI	-WASHINGTON, D. C.	2,321	179,803	0.2	33.2	93	75	0.1	24.5	309
SEATTLE, WASHINGTON	-WASHINGTON, D. C.	4,835	177,399	0.1	33.3	94	36	*	24.5	669
HONOLULU, OAHU, HAWAII	-PHILADELPHIA, PENNA	996	173,671	0.1	33.5	95	173	0.1	24.6	100
FORT LAUDERDALE, FLORIDA	-PORTLAND, OREGON	834	167,507	0.1	33.6	96	199	0.2	24.8	84
LOS ANGELES, CALIFORNIA	-HONOLULU,OAHU,HAWAII	5,095	167,155	0.1	33.8	97	32	*	24.8	738
BOSTON, MASSACHUSETTS	-SAN FRANCISCO,CALIF.	2,166	165,697	0.1	33.9	98	74	0.1	24.9	317
CLEVELAND, OHIO	-SAN DIEGO,CALIFORNIA	2,614	165,295	0.1	34.1	99	62	*	24.9	374
HONOLULU, OAHU, HAWAII	-SAN FRANCISCO,CALIF.	2,263	162,712	0.1	34.2	100	71	0.1	25.0	334
PITTSBURGH, PENNSYLVANIA										
TOP 100 CITY PAIR (RANKED IN ORDER OF PASGR-MILES).		XXX	40,591,440	34.2	34.2	XXX	32,147	25.0	25.0	XXX
ALL CITY PAIRS		XXX	118,720,034	100.0	100.0	XXX	128,739	100.0	100.0	XXX

* LESS THAN .5 PERCENT.

NOTES.
DOMESTIC OPERATIONS ARE THOSE WITHIN THE 50 U.S. STATES, WITH PURELY INTRA-ALASKA TRAFFIC EXCLUDED.
(PRIOR TO 1968 DOMESTIC INCLUDED ONLY THE 48 CONTIGUOUS U.S. STATES.)
PASSENGER AMOUNTS ARE THE SUM OF PASSENGER JOURNEYS MOVING IN BOTH DIRECTIONS BETWEEN THE CITY PAIRS, ON A DIRECTIONAL ORIGIN-DESTINATION BASIS, REGARDLESS OF THE NUMBER OF TRANSFER POINTS OF AIRLINES USED, WITH ROUND TRIPS AND OTHER ITINERARIES INVOLVING MOVEMENT IN TWO DIRECTIONS TREATED AS TWO ONE-WAY JOURNEYS.
DOMESTIC PORTIONS OF DOMESTIC-INTERNATIONAL/TERRITORIAL ITINERARIES ARE INCLUDED IN THIS TABLE.
PASSENGER-MILES ARE THE SUMMATION OF THE NUMBER OF PASSENGERS MULTIPLIED BY THE GREAT-CIRCLE AIRPORT-TO-AIRPORT MILEAGE FOR EACH AIR CARRIER FLIGHT-COUPON STAGE IN THE INDIVIDUAL ITINERARIES MOVING BETWEEN THE CITY PAIRS.

SOURCE.
DERIVED FROM CIVIL AERONAUTICS BOARD, DOMESTIC ORIGIN-DESTINATION SURVEY OF AIRLINE PASSENGER TRAFFIC, VOLUME VIII-4-1, FOURTH QUARTER 1975, TABLES 1, 7, AND 8, RESPECTIVELY (PUBLISHED BY THE AIR TRANSPORT ASSOCIATION OF AMERICA).

Source: Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement*, Washington, D.C., December 1977.

Appendix D: CONVERSION FACTORS

Table D.1

Energy Use and Production-Related Conversions

Heat Values of Fuels	
Coal	
Anthracite	25.4×10^6 Btu/short ton = 29.7 MJ/kg
Bituminous	26.2×10^6 Btu/short ton = 30.6 MJ/kg
Lignite	12.4×10^6 Btu/short ton = 14.5 MJ/kg
Bituminous and lignite	
Production av	23.5×10^6 Btu/short ton = 27.5 MJ/kg
Consumption av	22.8×10^6 Btu/short ton = 26.7 MJ/kg
Natural gas	
Wet	1,095 Btu/ft^3 = 40.79 MJ/kg
Dry	1,021 Btu/ft^3 = 38.04 MJ/kg
Liquid	95,800 Btu/gal = 3569 MJ/kg
Crude petroleum	138,100 Btu/gal = 5145 MJ/kg
Fuel oils	
Residual	149,700 Btu/gal = 41.73 MJ/liter
Distillate	138,700 Btu/gal = 38.66 MJ/liter
Automotive gasoline	125,000 Btu/gal = 34.84 MJ/liter
AVGAS	124,000 Btu/gal = 34.56 MJ/liter
Jet fuel (naphtha)	127,500 Btu/gal = 35.54 MJ/liter
Jet fuel (kerosene)	135,000 Btu/gal = 37.63 MJ/liter
Lubricants	144,400 Btu/gal = 40.25 MJ/liter
Waxes	131,800 Btu/gal = 36.74 MJ/liter
Asphalt and road oil	158,000 Btu/gal = 44.04 MJ/liter
Petroleum coke	143,400 Btu/gal = 39.97 MJ/liter

Table D.2

Alternative Fuel Equivalents

1 million bbl/day crude oil	= 0.3650 billion bbl/year crude oil
	= 5.800 trillion Btu/day
	= 2.117 quadrillion Btu/year
	= 246.1 thousand short tons coal/day
	= 90.09 million short tons coal/year
	= 5.681 billion ft^3 natural gas/day
	= 2.074 trillion ft^3 natural gas/year
1 billion bbl/year crude oil	= 2.740 million bbl/day crude oil
	= 15.89 trillion Btu/day
	= 5.800 quadrillion Btu/year
	= 676.2 thousand short tons coal/day
	= 246.8 million short ton coal/year
	= 15.56 billion ft^3/day natural gas/day
	= 5.68 trillion ft^3/year natural gas/day
1 trillion Btu/day	= 172.4 thousand bbl/day crude oil
	= 62.93 million bbl/year crude oil
	= 0.3650 quadrillion Btu/year
	= 42.55 thousand short tons coal/day
	= 15.53 million short tons coal/year
	= 979.4 thousand ft^3 natural gas/day
	= 357.5 billion ft^3 natural gas/year
1 quadrillion Btu/year	= 0.4724 million bbl/day crude oil
	= 172.4 million bbl/year crude oil
	= 2.740 trillion Btu/day
	= 116.6 thousand short tons coal/day
	= 42.55 million short tons coal/year
	= 2.683 billion ft^3 natural gas/day
	= 979.4 billion ft^3 natural gas/year
1 million short tons coal/day	= 4.052 million bbl/day crude oil
	= 1.479 billion bbl/year crude oil
	= 23.50 trillion Btu/day
	= 8.578 quadrillion Btu/year
	= 365.0 million short tons coal/year
	= 23.02 billion ft^3 natural gas/day
	= 8.401 trillion ft^3 natural gas/year
1 trillion short tons coal/year	= 11.10 million bbl/day crude oil
	= 4.052 billion bbl/year crude oil
	= 64.38 trillion Btu/day
	= 23.50 quadrillion Btu/year
	= 2.734 million short tons coal/day
	= 63.06 billion ft^3 natural gas/day
	= 23.02 trillion ft^3 natural gas/year
1 billion ft^3 natural gas/day	= 0.1760 million bbl/day crude oil
	= 64.25 million bbl/year crude oil
	= 1.021 trillion Btu/day
	= 0.3727 quadrillion Btu/year
	= 43.45 thousand short tons coal/day
	= 15.86 million short tons coal/year
	= 365.0 billion ft^3 natural gas/year
1 trillion ft^3 natural gas/year	= 0.4823 million bbl/day crude oil
	= 0.1760 billion bbl/year crude oil
	= 2.797 trillion Btu/day
	= 1.021 quadrillion Btu/year
	= 119.0 thousand short tons coal/day
	= 43.45 million short tons coal/year
	= 2.740 billion ft^3 natural gas/day

Table D.3

Energy Unit Conversions

1 Btu = 778.2 ft-lb
= 107.6 kg-m
= 1055 J
= 39.30×10^{-5} hp-hr
= 39.85×10^{-5} metric hp-hr
= 29.31×10^{-5} kWhr

1 kWhr = 3412 Btu
= 2.655×10^{6} ft-lb
= 3.671×10^{5} kg-m
= 3.60×10^{6} J
= 1.341 hp-hr
= 1.360 metric hp-hr

1 kg-m = 92.95×10^{-4} Btu
= 7.233 ft-lb
= 9.806 J
= 36.53×10^{-7} hp-hr
= 37.04×10^{-7} metric hp-hr
- 27.24×10^{-7} kWhr

1 J = 94.78×10^{-5} Btu
= 0.7376 ft-lb
= 0.1020 kg-m
= 37.25×10^{-8} hp-hr
= 37.77×10^{-8} metric hp-hr
= 27.78×10^{-8} kWhr

1 hp-hr = 2544 Btu
= 1.98×10^{6} ft-lb
= 2.738×10^{6} kgm
= 2.685×10^{6} J
= 1.014 metric hp-hr
= 0.7475 kWhr

1 metric hp-hr = 2510 Btu
= 1.953×10^{6} ft-lb
= 27.00×10^{4} kg-m
= 2.648×10^{6} J
= 0.9863 hp-hr
= 0.7355 kWhr

Table D.4

Distance and Velocity Conversions

1 in. = 83.33×10^{-3} ft
= 27.78×10^{-3} yd
= 15.78×10^{-6} mile
= 25.40×10^{-3} m
= 0.2540×10^{-6} km

1 ft = 12.0 in.
= 0.333 yd
= 189.4×10^{-3} mile
= 0.3048 m
= 0.3048×10^{-3} km

1 mile = 63360 in.
= 5280 ft
= 1760 yd
= 1609 m
= 1.609 km

1 km = 39370 in.
= 3281 ft
= 1093.6 yd
= 0.6214 mile
= 1000 m

1 ft/sec = 0.3048 m/sec = 0.6818 mph = 1.0972 km/hr
1 m/sec = 3.281 ft/sec = 2.237 mph = 3.600 km/hr
1 km/hr = 0.9114 ft/sec = 0.2778 m/sec = 0.6214 mph
1 mph = 1.467 ft/sec = 0.4469 m/sec = 1.609 km/hr

Table D.5

Force Conversions

From \ To	Horsepower	Kilowatts	Metric horsepower	Ft-lb per sec	Kilocalories per sec	Btu per sec
Horsepower	1	0.7457	1.014	550	0.1781	0.7068
Kilowatts	1.341	1	1.360	102.0	737.6	0.9478
Metric horsepower	0.9863	0.7355	1	542.5	0.1757	0.6971
Ft-lb per sec	1.82×10^{-3}	1.356×10^{-3}	1.84×10^{-3}	1	0.3238×10^{-3}	1.285×10^{-3}
Kilocalories per sec	5.615	4.187	5.692	3088	1	3.968
Btu per sec	1.415	1.055	1.434	778.2	0.2520	1

Table D.6

Energy Intensity and Efficiency Conversions

1000 Btu/mile = 621.5 Btu/km
= 66.86×10^3 kg-m/km
= 655.6 kJ/km
= 0.2931 kWhr/mile
= 0.1822 kWhr/km
= 125.0 mpg[a]
= 1.882 liter/100 km

1000 Btu/km = 1609 Btu/mile
= 107.6×10^6 kg-m/km
= 1055 kJ/km
= 0.4716 kWhr/mile
= 0.2931 kWhr/km
= 77.67 mpg[a]
= 3.028 liter/100 km

10 mpg[a] = 12,500 Btu/mile
= 7767 Btu/km
= 835.8×10^3 kg-m/km
= 8195 kJ/km
= 3.664 kWhr/mile
= 2.277 kWhr/km
= 23.52 liter/100 km[a]

10 liter/100 km[a] = 5315 Btu/mile
= 3302 Btu/km
= 355.4×10^3 kg-m/km
= 3484 kJ/km
= 1.558 kWhr/mile
= 0.9683 kWhr/km
= 23.52 mpg[a]

1000 kJ/km = 1525 Btu/mile
= 947.8 Btu/km
= 102.0×10^3 kg-m/km
= 0.4469 kWhr/mile
= 0.2778 kWhr/km
= 81.97 mpg[a]
= 2.869 liter/100 km[a]

1 kWhr/mile = 3412 Btu/mile
= 2120 Btu/km
= 228.1×10^3 kg-m/km
= 2237 kJ/km
= 0.6214 kWhr/km
= 36.64 mpg[a]
= 6.419 liter/100 km[a]

[a]Assuuming automotive gasoline at 125,000 Btu/gal.

Table D.7

Volumetric and Flow Rate Conversions

The conversions for flow rates are identical to those for volumetric measures, provided the time units are identical.

1 U.S. gal	= 231 in.^{3}	1 liter	= 61.02 in.^{3}
	= 0.1337 ft^3		= 3.531×10^{-2} ft^3
	= 3.785 liters		= 0.2624 U.S. gal
	= 0.8321 Imperial gal		= 0.2200 Imperial gal
	= 0.1781 bbl		= 6.29×10^{-3} bbl
	= 7.500 lb foreign crude[a]		= 1.982 lb foreign crude[a]
	= 7.034 lb domestic crude[a]		= 1.858 lb domestic crude[a]
1 Imperial gal	= 277.4 in.^{3}	1 bbl	= 9702 in.^{3}
	= 0.1606 ft^3		= 5.615 ft^3
	= 4.545 liters		= 158.97 liters
	= 1.201 U.S. gal		= 42 U.S. gal
	= 0.2139 bbl		= 34.97 Imperial gal
	= 9.007 lb foreign crude[a]		= 315.0 lb foreign crude[a]
	= 8.4472 lb domestic crude[a]		= 295.4 lb domestic crude[a]

1 U.S. gal/hr	= 3.209 ft^3/day	= 1171 ft^3/year
	= 90.84 liter/day	= 33157 liter/year
	= 19.97 Imperial gal/day	= 7289 Imperial gal/year
	= 4.274 bbl/day	= 1560 bbl/year
	= 216.2 lb foreign crude/day[a]	= 78901 lb foreign crude/day[a]
	For Imperial gallons, multiply above values by 1.201	
1 liter/hr	= 0.8474 ft^3/day	= 309.3 ft^3/year
	= 6.298 U.S. gal/day	= 2299 U.S. gal/year
	= 5.28 Imperial gal/day	= 1927 Imperial gal/year
	= 0.1510 bbl/day	= 55.10 bbl/year
	= 47.57 lb foreign crude/day[a]	= 17362 lb foreign crude/year[a]
	= 44.59 lb domestic crude/day[a]	= 16276 lb domestic crude/year[a]
1 bbl/hr	= 137.8 ft^3/day	= 49187 ft^3/year
	= 1008 U.S. gal/day	= 3.679×10^5 U.S. gal/year
	= 839.3 Imperial gal/day	= 3.063×10^5 Imperial gal/year
	= 3815 liter/day	= 1.393×10^6 liter/day
	foreign crude[a]	
	= 7560 lb/day	= 2.759×10^6 lb/year
	= 3.780 short tons/day	= 1380 short tons/year
	= 3.375 long tons/day	= 1232 long tons/year
	domestic crude[a]	
	= 7090 lb/day	= 2.588×10^6 lb/year
	= 3.545 short tons/day	= 1294 short tons/year
	= 3.165 long tons/day	= 1155 long tons/year

[a]Assuming representative specific gravities of 25.6 for foreign crude oil and 36.0 for domestic crude oil.

Table D.8

Nomenclature and Powers of Ten

	Value	Prefix	Symbol
One million million millionth	10^{-18}	atto	a
One thousand million millionth	10^{-15}	femto	f
One million millionth	10^{-12}	pico	p
One thousand millionth	10^{-9}	nano	n
One millionth	10^{-6}	micro	M
One thousandth	10^{-3}	milli	m
One hundredth	10^{-2}	centi	c
One tenth	10^{-1}	deci	d
UNITY	10^{0}		
Ten	10^{1}	deca	da
One hundred	10^{2}	hecto	h
One thousand	10^{3}	kilo	k
One million	10^{6}	mega	M
One billion[a]	10^{9}	giga	G
One trillion[a]	10^{12}	tera	T
One quadrillion[a]	10^{15}	peta	P
One quintillion[a]	10^{18}	exa	E

[a]Care should be exercised in the use of this nomenclature, especially in foreign correspondence, as it is either unknown or carries a different value in other countries. A "billion", for example signifies a value of 10^{12} in most other countries.

BIBLIOGRAPHY

Adams, R. J. "Aircraft/Air Carrier Energy Conservation Measures, Status and Operational Constraints to Additional Improvements," paper presented at 5th National Conference on the Effects of Energy Constraints on Transportation Systems. August 1978.

The Aerospace Corporation, *Mode Shift Strategies to Effect Energy Savings in Intercity Transportation,* El Segundo, CA, April 1977.

American Automobile Association, Road Maps and Intercity Mileage Guides, 1978 Revisions.

American Bus Association, *America's Number 1 Passenger Transportation Service,* Washington, D.C., 1977.

American Public Transit Association, *Transit Fact Book,* 1976-78 Editions, Washington, D.C.

American Public Transit Association, *Transit Operating Report for Calendar/Fiscal Year 1975,* Washington, D.C., 1976.

Association of American Railroads, *Statistics of Railroads of Class I, Years 1967 to 1977,* Washington, D.C., September 1978.

Association of American Railroads, *Yearbook of Railroad Facts, 1978 Edition,* Washington, D.C., 1978.

Austin, T. C., and K. H. Hellman, *Passenger Car Fuel Economy Trends and Influencing Factors,* SAE Paper 730790, Warrendale, PA, 1973.

Auto-Train Corporation, *Annual Report to the Interstate Commerce Commission,* Washington, D.C., 1972-77.

Bayler, T., L. Eder, *Impacts of Diagnostic Inspection on Automotive Fuel Economy and Emissions,* SAE Paper 780028, Warrendale, PA, 1978.

Blackmore, D. R., and A. Thomas, *Fuel Economy of the Gasoline Engine,* New York, John Wiley, 1977.

Boeing Commercial Airplane Company, *Intercity Passenger Transportation Data,* Renton, Washington, 1975.

Chang, Man-Feng and R. Herman, *An Attempt to Characterize Traffic in Metropolitan Areas,* Publication GHR-2401, General Motors Research Laboratories, Warren, MI, 1977.

Chang, Man-Feng et al., *Gasoline Consumption in Urban Traffic,* Transportation Research Record 599, Transportation Research Board, Washington, D.C., 1976.

Chomitz, K., and C. A. Lave, *A Survey and Analysis of Energy Intensity Estimates for Urban Transportation Modes,* Irvine, CA, 1978. (Available through ORNL.)

Civil Aeronautics Board, *Handbook of Airline Statistics, Supplement,* Washington, D.C., December 1977.

Crain Automotive Group, *Automotive News, Market Data Book Issues,* Editions 1971-1978, Detroit, MI.

Dogget, R. M. et al, *The Transportation Energy Conservation Network (TECNET), Volume 1: A Presentation of Findings,* Draft, McLean, VA, June 1977.

Evans, L., and R. Herman, "Automotive Fuel Economy on Fixed Urban Driving Schedules," *Transportation Science,* 12 (No. 2) 137-52, May 1978.

Evans, L., R. Herman, and T. N. Lam, *Gasoline Consumption in Urban Traffic,* SAE Paper 760048, Warrendale, PA, 1976.

Fels, M. F., *Driving Cycles for Fuel Economy Testing,* Princeton, N.J., August 1977. Unpublished study performed for Oak Ridge National Laboratory.

Greyhound Lines Inc., *Greyhound Lines System Timetable,* April 30, 1978.

Hurter, D. A., and W. D. Lee, *A Study of Technological Improvements in Automobile Fuel Consumption,* SAE Paper 750005, Warrenndale, PA, 1975.

Iura, T., W. U. Roessler, and H. M. White, *Research Plan for Achieving Reduced Automotive Energy Consumption,* Aerospace Report No. ATR-76(7467)-1, National Science Foundation, Washington, D.C., 1975.

Janssen, L. J., and H. J. Emmelmann, *Aerodynamic Improvements — A Great Potential for Better Fuel Economy,* SAE Paper 780265, Warrendale, PA, 1978.

La Pointe, L. *Potential for Automotive Fuel Economy Improvement,* presented at the Fourth National Conference on Effects of Energy Constraints on Transportation Systems, Schenectady, N.Y., August 1977.

McNutt, B. D., et al., *A Comparison of Fuel Economy Results from EPA Tests and Actual In-Use Experience, 1974-1977 Model Year Cars,* U.S. Department of Energy, Washington, D.C., February 1978.

Mittal, R. K., *Energy Intensity of Intercity Passenger Rail,* Office of University Research, U.S. Department of Transportation, Washington, D.C., December 1977.

Mittal, R. K., *Energy Intensity of Various Transportation Modes,* Schenectady, N.Y., 1977. (Available through ORNL.)

Murrel, J. D., *Light Duty Automotive Fuel Economy...Trends Through 1978*, SAE Paper 780036, Warrendale, PA, 1978.

Murrel, J. D., et al., *Light Duty Automotive Fuel Economy...Trends Through 1977*, SAE Paper 76095, Warrendale, PA, 1977.

Murrel, J. D., *Factors Affecting Fuel Economy of Conventional Autos*, Washington, D.C., 1975.

National Archives and Records Service, Machine Readable Archives Division, *CAB Form 41 Schedule T-2*, Washington, D.C., 1970-77.

National Railroad Passenger Corporation, *Annual Report to the Interstate Commerce Commission*, Washington, D.C., 1972-77.

National Railway Publications Co., *Official Railway Guide, North American Passenger Travel Edition*, May 1978.

Rand McNally & Company, *Standard Highway Mileage Guide*, New York, N.Y.

Sherman, D., "New Cars '79: Technical Highlights," *Car and Driver* 24(No. 4): 49, October 1978.

Shonka, D. B., et al., *Transportation Energy Conservation Data Book, Edition 2*, ORNL 5320, Oak Ridge National Laboratory, Oak Ridge, TN, October 1977.

Society of Automotive Engineers, *Automotive Fuel Economy*, Report PT-15, Warrendale, PA, 1976.

Stanford Research Institute, *Energy Study of Rail Passenger Transportation, Volume 2*, Oakland, CA, August 1977.

Sturm, J. C., and W. F., Harriet, *Automotive Fuel Economy Discrepancy Study for NHTSA, Appendix B*, U.S. Department of Transportation, Cambridge, MA.

TERA Inc., and D. L., Greene, *VMT Statistics, Lifetime VMT, and Current State Methods of Estimating VMT*, ORNL/TM-6327, Oak Ridge National Laboratory, Oak Ridge, TN, 1978.

U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States 1976*, Washington, D.C., 1978.

U.S. Department of Commerce, Bureau of the Census, *1972 Census of Transportation Vol. I, National Transportation Survey*, Washington, D.C., 1974.

U.S. Department of the Interior, Bureau of Mines, *Petroleum Statement Annual*, Washington, D.C., 1970-76.

U.S. Department of the Interior, U.S. Geological Survey, *The National Atlas of the United States of America,* Washington, D.C., 1970.

U.S. Department of Transportation, *DOT/SAE Truck and Bus Fuel Economy Measurement Study Report.* P59-A, Cambridge, MA, October 1976.

U.S. Department of Transportation, *1974 National Transportation Report, Urban Data Supplement,* GPO Stock No. 050-000-0014-8 Washington, D.C., 1976.

U.S. Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation, Calendar Year 1976,* Washington, D.C., 1976.

U.S. Department of Transportation, *DOT/SAE Truck and Bus Fuel Economy Measurement Study Report,* Cambridge, MA, 1976.

U.S. Department of Transportation, Federal Highway Administration, *Table VM-1,* 1970-76.

U.S. Department of Transportation, *Effect of Variation of Speed Limits on Intercity Bus Fuel Consumption, Coach and Driver Utilization, and Corporate Profitability,* Boston, MA, November 1975.

U.S. Travel Data Center, *1976 National Transportation Survey, Full Year Report,* Washington, D.C., 1977.

U.S. Urban Mass Transportation Administration, *Urban Mass Transportation Industry Uniform System of Accounts and Records and Reporting System, Volume I: General Description,* Report No. UMTA-IT-06-0094-77-1, 1977.

U.S. Environmental Protection Agency, *1976 Gas Mileage Guide for New Car Buyers,* Washington, D.C., 1976.

Walker, D. L. et al., *How Passenger Car Maintenance Affects Fuel Economy and Emissions, A Nationwide Survey,* SAE Paper 780032, Warrendale, PA, 1978.

Williams, L. J., NASA Ames Research Center, *Air Transportation Energy Efficiency,* paper presented at the Fourth National Conference on the Effects of Energy Constraints on Transportation Systems, Schenectady, N.Y., August 1-5, 1977.

INTERNAL DISTRIBUTION

1. J. T. Arehart
2. S. E. Beal
3. F. D. Boercker
4. D. J. Bjornstad
5. R. S. Carlsmith
6. M. J. Collins
7. R. M. Davis
8-10. Energy and Environmental Response Center
11. W. Fulkerson
12. D. L. Greene
13. R. F. Hibbs
14. E. A. Hirst
15. D. Jared
16. G. E. Liepins
17-26. A. S. Loebl
27. J. D. Mason
28. H. Postma
29. C. R. Richmond
30. B. R. Rogers
31-55. A. B. Rose
56. M. W. Rosenthal
57. T. H. Row
58. M. A. Smith
59. R. L. Spore
60. T. J. Wilbanks
62-63. Central Research Library
64. Document Reference Section
65-67. Laboratory Records
68. Laboratory Records (RC)
69. ORNL Patent Office
70-72. Technical Publications Department

EXTERNAL DISTRIBUTION

73. Assistant Manager, Office of Energy Research and Development, DOE-ORO
74. D. B. Shonka, c/o Joe Shonka, Safety and Environmental Protection Division, Building 535, Brookhaven National Laboratory, Upton, L.I., N.Y. 11973
75. Fred Westbrook, TERA, Suite 888, 1901 N. Ft. Myer Drive, Arlington, Va. 22209
76-240. Regional and Urban Studies Distribution, Energy Division
241-290. Philip D. Patterson, Chief, Data Analysis Branch, Division of Transportation Energy Conservation, United States Department of Energy
291-397. Data Management and Analysis Group, Energy Division, Transportation Energy Conservation Distribution
398-424. Technical Information Center, Box 62, Oak Ridge, Tenn. 37830

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979-748-189/362