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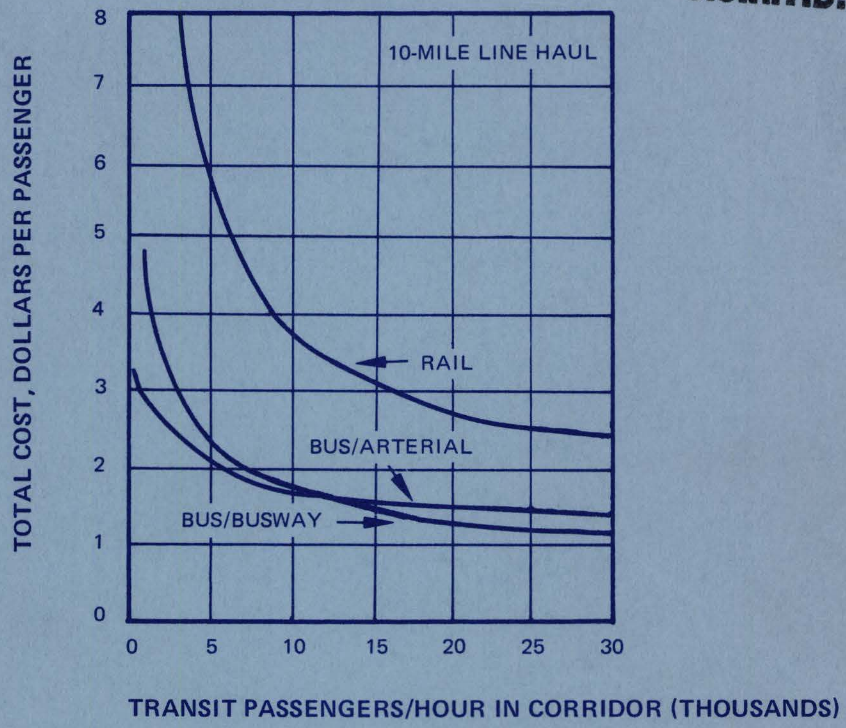
EVALUATION OF RAIL RAPID TRANSIT AND EXPRESS BUS SERVICE IN THE URBAN COMMUTER MARKET



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16. Abstract

This study analyzes and evaluates public transportation alternatives for serving the commuter market. The two main alternatives, rail rapid transit and integrated express bus service, are analyzed from the standpoint of full costs (both supplier and user time costs). User time costs of the two alternatives are roughly equal; however, the supplier costs of the integrated bus service are much lower than those of rail rapid transit.

Quantitative data on fuel consumption and emissions are presented, and the effects of political, regulatory, and institutional constraints are discussed.

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EVALUATION OF RAIL RAPID TRANSIT & EXPRESS BUS SERVICE IN THE URBAN COMMUTER MARKET

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FOREWORD

Under a previous contract, the Institute for Defense Analyses prepared for the Department of Transportation a study entitled "Economic Characteristics of the Urban Public Transportation Industry," which was published by the Government Printing Office in February 1972. Using that earlier work as a primary source of data, this study evaluates rail rapid transit and express bus service in the urban commuter market. Both studies were prepared under the cognizance of the Office of Transportation Planning Analysis in the Office of the Assistant Secretary for Policy, Plans and International Affairs.

We wish to thank Mr. Edward Weiner, Manager, Urban Analysis Program, Office of Transportation Planning Analysis, who served as the project monitor for this contract. Mr. Weiner's positive attitude regarding the project and his willingness to take the necessary time to provide frank and thorough evaluations of the effort are greatly appreciated.

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SCOPE OF THE ANALYSIS

An important part of the urban transportation problem is the movement of commuters from home to work and back. The congestion and pollution caused by the private automobiles of commuters and the diminishing service offered by conventional public transit despite ever-increasing public subsidy, are focii of public concern.

This study analyzes two main alternatives to serve the commuter market: (1) modern, highly automated rail rapid transit and (2) integrated express bus service. We compare various versions of the main alternatives on the basis of "full cost" (supplier cost plus user-time cost). Supplier costs include capital and operating costs for vehicles and way and structures; supplier costs would be equal to fares in cases where fares cover all operating and capital costs, including a normal return on investment. In recent years, fares have generally not covered supplier costs. User-time costs include access and egress walking-time costs, waiting-time costs, in-vehicle-time costs, and transfer-time costs. We also present quantitative data on fuel consumption and pollutant emissions of the alternatives.

The commuter trip may be divided into the elements of (1) residential collection, (2) line haul, and (3) central business district (CBD) distribution. Modern rail systems (for example, San Francisco's BART and the Washington Metro) consist of two-track lines which begin on one side of the urban area, proceed through the CBD, and end on the other side of the urban area. They provide line haul and, to a limited degree, CBD distribution services. Supplementary collection must be provided by rubber-tired vehicles. We analyze 5-passenger jitney, 8-passenger bus-wagon, 19-passenger minibus, and 50-passenger conventional buses for residential collection.

The integrated express bus circulates in the residential area collecting passengers, after which it proceeds with closed doors to the CBD, where it discharges passengers at curb-side stops. We analyze two basic variants of this alternative, where the bus either operates in express service on arterial streets or on exclusive busways for the line-haul portion of the trip.

CHARACTERISTICS OF VEHICLES ANALYZED

Table S-1 gives some basic characteristics of the types of vehicles analyzed. For residential collection, the smaller vehicles are faster because of their greater maneuverability and because they make fewer stops per vehicle-mile. Integrated buses operating on exclusive busways are faster than rail rapid transit, because of the latter's need to stop for passengers enroute. Most rail cars are

Table S-1. VEHICLE AND OPERATING CHARACTERISTICS

Mode	Seats per Vehicle	Average Overall Operating Speed (MPH)
Rail Rapid Transit		
Residential Collection		
Jitney	5	20
Bus-wagon	8	19
Minibus	19	17
Conventional Bus	50	15
Line Haul	79	35
CBD Distribution	79	18
Integrated Bus		
Residential Collection	50	15
Line Haul		
Exclusive Busway	50	45
Arterial Street	50	20
CBD Distribution	50	9

designed to carry proportionally more standees than buses; however, in this study the number of seats per unit of floor area has been equalized for both the bus and rail car, so that the standee capacity of both is the same percentage of the seated capacity. Under these assumptions, the capacity of an exclusive busway to handle seated passengers is greater than that of a two-track rapid rail transit system. However, the ability of the downtown street network to absorb buses from the busway limits the capacity of the bus system to approximately 30,000 seated passengers per hour per corridor, about the same as the capacity of the rail system.

SUPPLIER COSTS

Supplier costs have been projected to 1980 in constant 1972 dollars. The costs of different supplier elements have been increasing over time at different rates. For example, bus operating costs have been growing at 1.03 percent per annum over the last decade, including a 1.69 percent annual increase in driver's wages. Rail transit operating costs have increased at a 2.66 percent rate. The prices of new buses have declined at .38 percent per year, while rail transit cars have increased 6.4 percent per year.* All of these increases are in constant dollar terms.

Rail transit supplier costs are much higher than those of buses. Discounting at 10 percent per annum, the annual capital recovery cost for the way and structures portion of modern rail systems is estimated to be $2,500,000 per route-mile compared with $390,000 per route-mile for an exclusive busway. The annual capital cost for a rail transit car is $44,480 per year ($563 per seat) compared with $6,810 ($136 per seat) for expressway buses. Operating costs are approximately $1.97 per rail car-mile ($.025 per seat-mile) and $.51 per expressway bus-mile ($.010 per seat-mile), in line-haul service.

The costs of roads used by public transit vehicles were computed in two ways: (1) the long-run costs of land, capital, and road

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* In this study the rate of increase was assumed to slow to 4 percent in the future.

operations and maintenance were computed and allocated among transit and other vehicles; (2) the short-run costs of transit vehicle usage of roadways, due to the added congestion and delays to other traffic, were computed. Both methods necessitated the derivation of factors to convert bus use of road capacity to equivalent auto use. An express bus operating in mixed traffic on city streets is equivalent to two automobiles, while a local bus is equivalent to two to ten automobiles, depending on the proportion of green light time at critical intersections and the level of congestion on the street. The long-run allocated costs (which we use in the comparisons) are $.176 per bus-mile on arterial streets in express service, and $.878 per bus-mile in the CBD. The congestion cost estimates are somewhat higher, $.58 and $1.78, respectively. The ranking of rail and bus alternatives is not affected by the choice between the two methods of computing roadway costs for buses in mixed traffic.

Present transit operations pay low, if any, street user fees. Conventional local services operating along arterial streets into the CBD receive a substantial implicit subsidy in that they do not pay for the congestion costs of street capacity. A greater emphasis on express services (not to mention exclusive busways) would not only save user time costs and some supplier costs (due to faster speeds and less hourly costs per mile), but would economize as well on the use of scarce urban peak-hour street capacity.

Costs for rubber-tired vehicles and rail rapid transit were first developed for conventional operations on an average cost basis. Cost-estimating relationships were then developed from the average cost data. These estimating relationships allocate a greater-than-average amount of driver and capital costs to peak-hour service, and permit one to ascertain the effect of operating speed on cost per vehicle-mile. Total operating plus capital costs are shown in the last column of Table S-2 for typical peak hour operating conditions.

Table S-2. SUPPLIER COST SUMMARY
(1980 Costs in 1972 Dollars)

Type of Service	Type of Way	Vehicle Characteristics and Costs					Way and Structures Costs					Total Vehicle, Miscellaneous, and Way and Structures Cost ($/vehicle-mile)
		Vehicle Type	Capacity (Seats)	Speed (mph)	Utilization (hr/year)	Total Vehicle and Miscellaneous Costs ($/vehicle-mile)	Way Cost Basis	Road O&M	Road ROW	Construction	Total	
Residential Collection and Distribution (Peak Hour)	Residential Streets	Jitney	5	20	1000^a	.317	Vehicle-Mile				0^e	.317
		Bus-Wagon	8	19	1000^a	.345						.345
		Minibus	19	17	1000^b	.803						.803
		Conventional Bus	50	15	1000^b	1.24						1.24
		Expressway Bus	50	15	1000^c	1.31						1.31
Line Haul (Peak Hour)	Arterial Streets	Conventional Express Bus	50	20	1000^b	1.01	Vehicle-Mile	.001	.071	.104	.176	1.19
	Exclusive Busway	Expressway Bus	50	45	1000^c	.647	Route-Mile-Hour	2	70	203	275	2.02^g
	Rail Rapid Transit	Rail Rapid Transit	79	35	1000^d	3.05	Route-Mile-Hour	$-^f$	-	-	$1,785	11.97^h
CBD Distribution and Collection (Peak Hour)	CBD Street	Conventional Bus	50	9	1000^b	1.85	Vehicle-Mile	.006	.352	.520	.878	2.73
	CBD Street	Expressway Bus	50	9	1000^c	1.96	Vehicle-Mile	.006	.352	.520	.878	2.84
	Rail Rapid Transit	Rail Rapid Transit	79	18	1000^d	4.17	Route-Mile-Hour	$-^f$	-	-	$1,785	13.09^h

a. Jitney utilization in all services 40,000 miles (2,000 hours) per year.
b. Conventional bus utilization 29,400 miles per year in all services.
c. Integrated bus utilization 48,900 miles per year in all services.
d. Rail car utilization 48,900 miles per year in all services.
e. Way costs assumed included via fuel taxes in vehicle operating costs.
f. Rail way and structure O&M included in vehicle operating costs.
g. Based on 100 buses in each direction per hour.
h. Based on 100 cars in each direction per hour.

USER COSTS

User time costs depend both on travel time per trip and time valuation. Recent literature, based on statistical analysis of travel behavior and modal choice, indicates that travelers value time spent in urban transit vehicles at about 40 percent of their hourly average earnings. Out-of-vehicle time, such as walking and waiting, is valued at about hourly earnings, or two and one-half times in-vehicle time. In this study we have compared alternatives for commuter services assuming two values of time. The values we have used correspond to hourly earnings of $3.00 and $7.50 to represent the range of values that commuters place on their time. Surprisingly, the time value assumption has little effect on the ranking of alternatives established by our analysis.

FULL COSTS - RESIDENTIAL COLLECTION

Full costs for each of the alternatives and subalternatives were computed for patronage levels ranging from very low to very high. In each case, service frequency was optimized to minimize the sum of supplier and user time costs. At a given level of patronage, increasing frequency results in lower waiting-time cost but higher supplier cost per passenger. For the residential collection phase, 3-block and 6-block average route spacings were analyzed. The closer spacing reduces access walking-time costs, but increases (for a given level of passengers generated per square mile) waiting-time costs or supplier costs per passenger, or both.

Figure S-1 presents the supplier plus user time cost for residential collection for one set of assumptions. The 3-mile "feeder route perpendicular distance" refers to the depth of the residential area on each side of the line-haul corridor. "Two feeder routes" indicates that there are two feeder routes serving the residential area per mile of line-haul corridor. Figure S-1 presents full costs for the least-cost number of feeder routes for each mode, using a dashed line for two routes and a solid line for four routes.

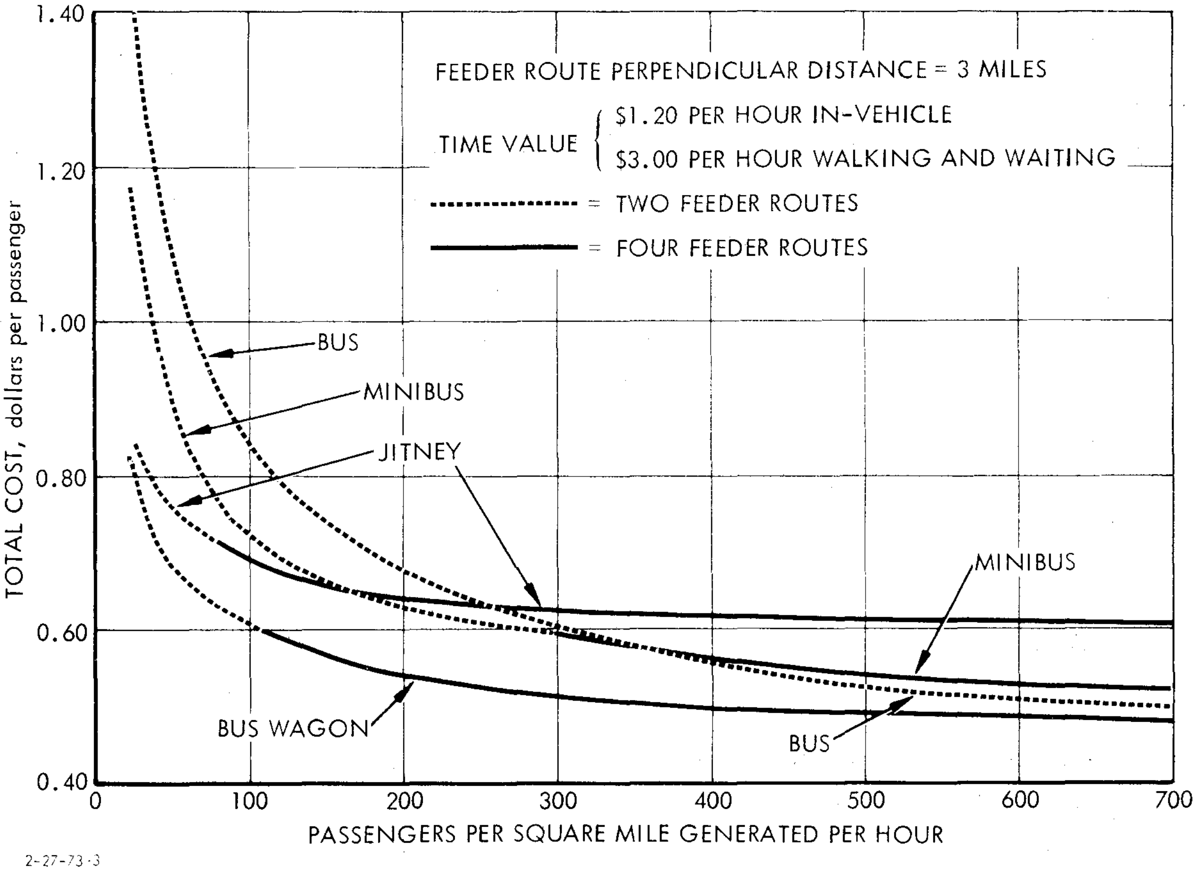

Figure S-1. RESIDENTIAL COLLECTION COST PER PASSENGER VERSUS PASSENGER DENSITY

Regardless of the mode, two perpendicular feeder routes per mile of corridor are more economical than four routes for low passenger-generation densities. Access-time costs are higher, but allocating more passengers to each route increases service frequency and thus reduces waiting time. In addition, vehicle occupancy may be higher, thus reducing per-passenger supplier costs. For higher densities, the savings in access costs outweigh the increases in waiting and supplier costs, so that four routes are optimal. Note that the left portions of the cost curves in Figure S-1 are dashed (two routes) and the right portions are solid (four routes). Greater passenger density is required to support the closer route spacing for larger vehicles.

Plots similar to Figure S-1 were made for other time values and feeder route perpendicular distances. These plots indicate that, for any time value, larger vehicles become relatively more economical than smaller vehicles on longer routes. Supplier costs (low seat-mile costs) become relatively more important than waiting costs (high service frequencies). Further, for routes of any length, the advantage of smaller vehicles over larger vehicles increases with time value. People who value time highly are willing to pay a higher fare, reflecting a higher seat-mile cost, for more frequent and faster service. The effect of frequency is more important to commuters than the effect of higher speeds, because in-vehicle-time values are lower and the difference in speeds among modes is relatively slight.

Figure S-1 and similar plots indicate that the 8-passenger bus-wagon is nearly always the most desirable low-cost alternative, even though conventional buses may have lower supplier costs at high densities. Conventional buses have lower full costs only for combinations of low time value, long routes, and high passenger density. By inference, bus-wagons operating as jitneys are likely to have lower full costs than bus transit for inner city circulation services (those bus operations within the city other than peak-hour CBD commutation).

FULL COSTS - COMPLETE COMMUTER TRIP

Table S-3 presents a sample full-cost comparison of the commuter service alternatives for "low" time value, 3-mile feeder route, 10-mile line-haul corridor, and 18,000 corridor passengers per hour (corresponding to 300 passengers per square mile per hour in the residential areas).

For the residential collection portion of the trip, note that the vehicle costs for the 50-passenger integrated bus alternatives are less than for the bus-wagon feeder to the rail line; however, the greater frequency of service of the bus-wagon results in lower user costs, so that the total residential collection costs are $.60 for the integrated bus and only $.51 for the bus-wagon.

Table S-3. COMPARATIVE COST PER PASSENGER OF INTEGRATED BUS AND RAIL WITH 8-PASSENGER BUS-WAGON FEEDER[a]

Type of Trip	Integrated Bus		Rail With 8-Passenger Bus-Wagon Feeder
	Arterial Street	Busway	
Residential Collection			
Vehicle Costs	$.17	$.17	$.29
Road Cost	0	0	0
User Time Cost	.43	.43	.22
Line Haul			
Vehicle Costs	.21	.14	.78
Road or Way Cost	.04	.15	.99
User Time Cost	.30	.13	.31
CBD Distribution			
Vehicle Costs	.04	.04	.05
Road or Way Cost	.02	.02	.05
User Time Cost	.32	.32	.28
Total Cost	1.53	1.40	2.97

a. Time Value { $1.20 Per Hour In-Vehicle; $3.00 Per Hour Walking and Waiting }
Feeder Route Perpendicular Distance = 3 miles
Corridor Distance = 10 miles
18,000 Passengers Per Hour on Corridor

For the line-haul portion of the trip, the vehicle and user costs for the bus on the busway are less than for the bus on an arterial street because of the higher speed possible on the busway (45 mph versus 20 mph); however, road costs are much higher for the busway operation. Note that rail supplier costs are higher than for the integrated bus alternatives. User costs are also higher for rail because they include the time required to transfer from the bus-wagon feeder to rail.

Both buses operate in mixed traffic in the CBD and their costs are the same; rail costs are closer to those of bus in the CBD because of the relative operating speeds (9 mph for bus versus 18 mph for rail).

Total user costs are about equal for rail and bus. However, the line haul supplier costs are much greater for rail. As a result, total trip costs are approximately twice as great for rail as for bus.

Figure S-2 shows total cost per passenger versus transit passengers per hour in corridor for 3-mile feeder route perpendicular distance, 10-mile line haul, and "low" value of time. Similar plots are included in the study for other time values and feeder-route and line-haul distances. Note that, for the conditions described by Figure S-2, the bus operating on a busway is the least costly at passenger flows above 10,000 passengers per hour, while the bus operating on arterial streets is the least costly at lower passenger flows. In all cases, total cost for rail is markedly greater than for integrated bus. The rail disadvantage increases with line-haul distance, but decreases with number of transit passengers in corridor. The difference between rail and bus costs ranges from about $1 per passenger at high passenger volumes and 6-mile line haul to about $5 per passenger at low passenger volumes and 14-mile line haul. Rail's much higher supplier cost buys service virtually identical to that of integrated bus, measured by user time costs.

An analysis of standees equal to 50 percent of seated passengers indicated that the total costs for the alternative systems remained nearly the same in both relative and absolute terms. For example, for the conditions of Table S-3 (18,000 passengers per hour on Figure S-2), total costs per passenger were reduced from $1.53 to $1.45 for integrated buses operating on arterial streets, $1.40 to $1.35 for integrated buses operating on exclusive busways, and $2.97 to $2.70 for rail with 8-passenger bus-wagon feeders. The reason for these surprisingly small decreases is due mainly to the fact that, although vehicle costs per passenger are reduced, user-time costs are increased because of lower vehicle frequency. Further, the busway and rail way costs per passenger remain the same, since those costs must still be allocated to the same total number of passengers.

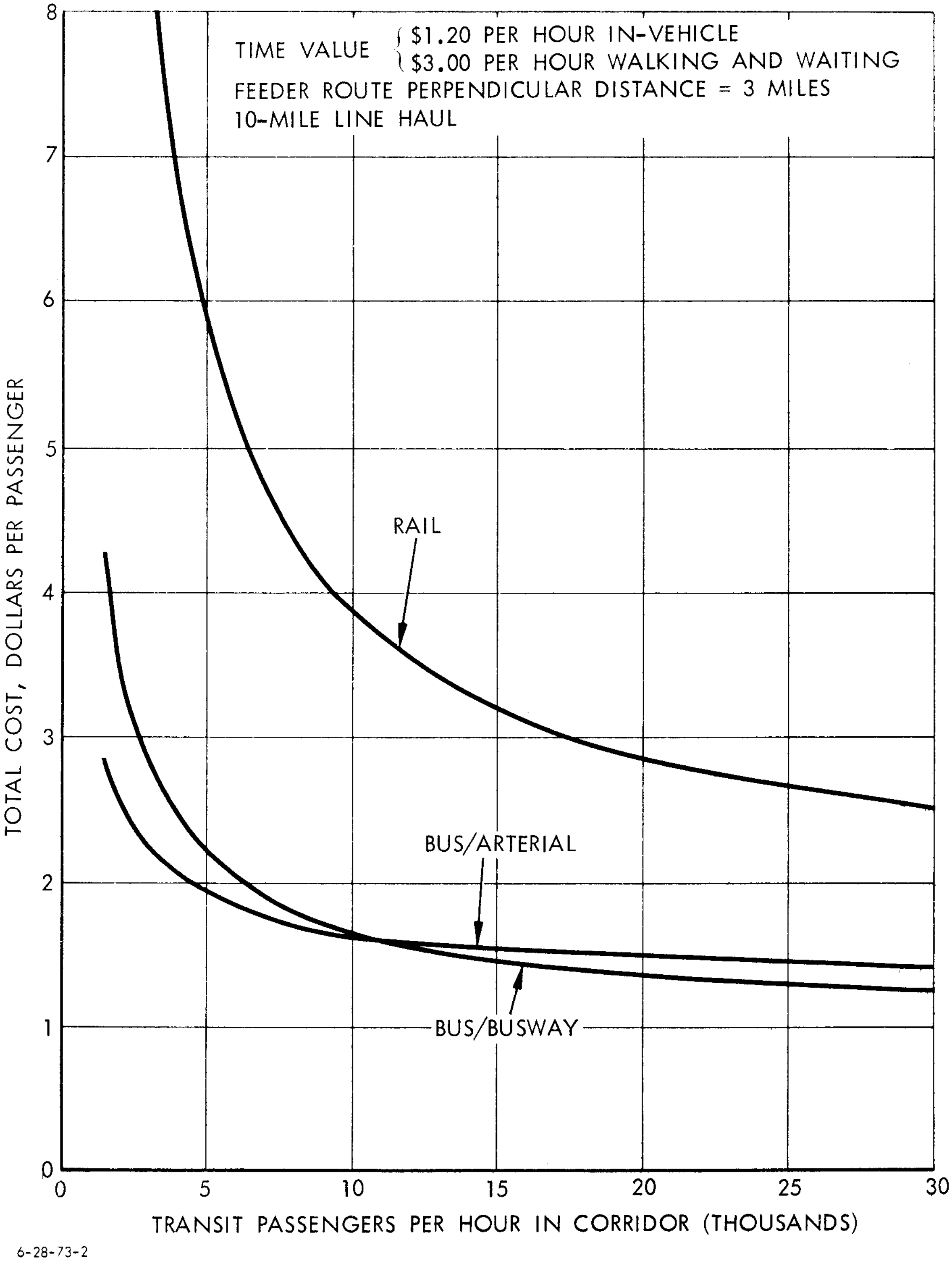

Figure S-2. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER

FUEL CONSUMPTION AND EMISSIONS

Table S-4 compares fuel consumption and emissions per passenger-trip for integrated bus on exclusive busway versus rail rapid transit with bus-wagon feeder. The exclusive busway is the cheapest full-cost integrated bus option for larger volumes, while the bus-wagon is the most economical feeder vehicle to rail rapid transit for nearly all time values and passenger densities considered. A 10-mile line-haul route with a 3-mile feeder has been assumed in Table S-4.

It is difficult to compare the fuel consumption of the two systems because different types of fuel are used. However, a rough comparison can be made by comparing the gallons of diesel fuel used by the integrated bus with the combined sum of the gallons of gasoline used by the bus-wagon and the heating oil used by rail transit. Three times as many gallons are used by the bus-wagon/rail combination as by the integrated bus. This ratio applies to both the residential collection and the line-haul/CBD portions of the trip.

For the total trip, all three emissions are higher for the bus-wagon/rail alternative: seven times as high for CO, almost twice as high for NO_x, and eight times as high for HC. The bulk of the CO and HC comes from the bus-wagon feeder, while most of the NO_x comes from electrical generating plants for the rail system. The fuel used for electric generation hardly affects the comparison between the alternatives. These figures by themselves indicate that the integrated bus is clearly superior on pollution grounds to the bus-wagon/rail alternative. However, it would be possible to eliminate the CO and HC disadvantage of the bus-wagon by substitution of a diesel-powered residential collector. If a 50-passenger diesel bus is used as a residential collector for the rail system, the pollutants emitted during residential collection would be approximately the same as in the integrated bus case. For the complete commuter trip using the 50-passenger bus plus rail, total CO emissions would be about one-half, NO_x emissions about double, and HC emissions about the same as those for the integrated bus. Further, if the electric generating

Table S-4. COMPARISON OF FUEL CONSUMPTION AND EMISSIONS, INTEGRATED BUS VERSUS RAIL RAPID TRANSIT WITH BUS-WAGON RESIDENTIAL COLLECTION

Part of Trip	Type of Fuel	Fuel Consumption Per Passenger	Pollutants Emitted (One-Thousandth Pound Per Passenger)		
			CO	NO_x	HC
		INTEGRATED BUS, EXCLUSIVE BUSWAY			
Residential Collection	Diesel Fuel	0.0288 gallon	1.126	2.957	0.122
Line Haul	Diesel Fuel	0.031 gallon	1.220	3.220	0.130
CBD	Diesel Fuel	0.0045 gallon	0.176	0.462	0.019
TOTAL	Diesel Fuel	0.064 gallon	2.52	6.64	0.27
		BUS-WAGON PLUS RAIL			
Residential Collection	Gasoline	0.091 gallon	17.880	0.975	1.950
Line Haul and CBD	Coal	1.090 pounds	0.273	10.899	0.109
	Natural Gas	14.1 cubic feet	Negligible	5.586	Negligible
	Heating Oil	0.101 gallon	Negligible	10.374	0.315
TOTAL	Gasoline and Coal	0.091 gallon 1.090 pounds	18.15	11.87	2.06
	Gasoline and Natural Gas	0.091 gallon 14.1 cubic feet	17.88	6.56	1.95
	Gasoline and Heating Oil	0.192 gallon	17.88	11.35	2.27

ASSUMTIONS:

1. All seats filled.
2. Assumes 3-mile residential collection, 10-mile line-haul route.
3. Two feeder route configuration, $D_f = 6.4$ vehicle-miles per trip.
4. Four feeder route configuration, $D_f = 6.5$ vehicle-miles per trip.
5. Average line-haul distances are 10 miles for bus (5 inbound plus 5 outbound) and 20 miles for rail (10 inbound plus 10 outbound).
6. Bus and rail CBD distances are 1 vehicle-mile per trip.

plant is remotely located from populated areas, the higher level of NO_x production associated with rail transit might not be any worse than that produced by integrated bus, insofar as the effect on population is concerned.

INSTITUTIONAL AND REGULATORY ENVIRONMENT

The institutional and regulatory structure of the urban transit industry is largely responsible for the exclusion of low full-cost alternatives such as the jitney and the encouragement of high-cost alternatives such as new rail rapid transit systems. DOT's Urban Mass Transportation Capital Grant Program, which sharply reduces the capital costs of new rail systems which must be financed at the local or State level, seems to have contributed to the rebirth in popularity of this alternative.

Public transit is organized as a franchised monopoly. Bus companies and rail systems, whether privately or publicly owned, possess exclusive franchises to transport passengers in certain areas. Taxicabs are licensed and usually limited in number. Both mass transit and taxicabs are subject to fare and service regulation. Economic regulation of entry, fare, and service tends to create monopoly earnings for the benefit of franchise holders and certain classes of customers who enjoy services at below-market prices. Innovative services such as the jitney are excluded.

Many small- and medium-sized cities do not now have organized bus service. It may be possible to encourage a jitney service in one or more of these locales under the UMTA Demonstration Grant Program, since no local bus company would stand to lose earnings as a result of new jitney operations in these cities. Direct subsidies to jitney operators would not be necessary, although a legal framework for their operation would have to be devised. Insurance innovations would be desirable, as would safety and traffic regulations to promote safe operation. It may be politically desirable to compensate existing taxi licensees for loss in franchise values due to the opening of free entry and the elimination of fare and service controls.

1. INTRODUCTION

1.1 SCOPE OF STUDY

This project is designed to analyze capital alternatives for urban public transportation. Capital alternatives require major physical changes in one or more of the existing modes of urban transportation, including automobile, bus, taxicab, rail transit, or any combination of these modes. We have limited our analyses to existing technology, whether rubber-tired or rail systems.

In contrast, noncapital alternatives--with little or no additional capital investment--serve to influence the travel behavior of individuals in an urban area. Examples include peak-hour tolls to smooth traffic flow, taxes or restrictions on downtown parking, direct controls on auto travel in certain sections of the city during certain hours, or innovative transit pricing to bring trip prices closer to marginal costs.

The focus of this study is on <u>public</u> transportation. The supply of private automobiles and the facilities for their use are taken as given in this study. In our analyses, we assume that the demand for travel is given exogenously, and we analyze the alternatives for different levels of patronage. We do not analyze the effect of improved service or lower fares on the number of trips that are taken. Nor do we analyze the distribution of these trips (1) between modes, (2) between different origins and destinations, and (3) by time of day.

1.2 OUTLINE OF BASIC APPROACH

Our first task is to identify relevant capital alternatives for urban transit and to devise an appropriate evaluation methodology for comparing the costs and benefits of these alternatives. We have adopted an analytic framework that includes both supplier and user costs. Supplier costs are those costs of transit services associated with vehicles and their operation, roadways, and other fixed facilities. User costs are the time costs borne by users of the transit system. Chapter 2 explains the evaluation methodology in greater detail, and relates it to other evaluation methodologies often employed in the cost-benefit literature.

Urban transportation is not a single market but many different markets. Alternatives good for one kind of urban transportation may not be suitable for another kind of urban transportation, and pressing social and policy concerns may be different as well. We have chosen for analysis the commuter market. Suburban and outer city to central business district (CBD) commuting is characterized by peaked temporal flows, morning and evening. The major social concern raised by commuter travel is the congestion caused by private automobiles competing for limited street and road space and unrestrained by a price mechanism. Public transit is thought to be more economical of scarce urban space during peak hours and to have the potential to reduce peak-hour congestion. Further, many people who are young, old, poor, or physically handicapped do not have ready access to private automobile travel, and the plight of these persons is a major social and policy concern.

For CBD peak-hour trips from the outer city and suburbs, alternatives such as commuter railroad, rail rapid transit, express buses, and express buses operating on exclusive rights-of-way are the types of alternatives which are being operated today. Chapter 2 develops the basic analytic methodology, including the square-root rule relating optimal service frequency to amount and costs of travel, and derives the basic relationships used in the subsequent analyses.

Basic supplier cost information, which is the foundation for the subsequent analysis, is presented in Chapter 3 and Appendix A. Extensive use has been made of the IDA transportation data bank. The data bank is based on reports from members of the American Transit Association and the International Taxicab Association and is supplemented by other data. In addition, published and unpublished sources have been extensively mined to assemble a comprehensive picture of the investment and operating costs of urban transportation systems.

This basic information is used to develop cost functions which allow one to compute supplier costs under alternative specifications of system parameters, such as level of patronage, operating speed, and the like. Appendix B contains a discussion of the allocation of capital costs between peak and off-peak services.

Chapter 4 reviews the empirical literature on value of travel time, the most important aspect of user costs. We base our selection of typical time values for evaluating alternative modes on this empirical evidence. Data on important effects such as air pollution are also presented, although we have not attempted to assign dollar values to these costs in our evaluations.

Chapter 4 also presents (with Appendix C) an analysis of the congestion cost imposed on other traffic by the operation of transit buses. Congestion cost is an important element of the cost of operating buses in mixed traffic, and the elimination of congestion cost is one of the benefits of operating transit vehicles over exclusive ways. We develop numerical estimates for these congestion costs, expressed as dollars per bus-mile, for buses operating on expressways, buses operating in express service on arterial streets, and local buses operating on city streets.

Chapter 5 evaluates transit capital alternatives for the commuter market. The focus of Chapter 5 is the comparison of bus rapid transit with rail rapid transit for peak-hour, CBD commuter trips.

Urban public transit operates today subject to a variety of political, regulatory, and institutional constraints. We discuss some of these constraints in Chapter 6, and emphasize those which inhibit the development and introduction of better transit alternatives.

2. ALTERNATIVES AND METHODOLOGY FOR EVALUATION

2.1 A TAXONOMY OF TRANSIT ALTERNATIVES

Before alternatives are considered, it will be useful to consider a taxonomy of transit systems. The basic distinction is between fixed-route and variable-route systems. Under the present organization of the industry, almost all public transit is operated on fixed-route systems, with the notable exception of taxicabs, which operate on variable routes. Private automobiles, which represent the dominant urban transportation mode, also operate on variable routes.

The following can operate as fixed-route systems:

1. Rubber-tired, chauffeur-driven vehicles operating in mixed traffic (for example, jitneys,* minibuses, and transit buses).
2. Rubber-tired, chauffeur-driven vehicles operating on special ways (for example, transit buses on exclusive busways).
3. Guided vehicles (for example, streetcars, commuter railroads, rail rapid transit, and personal rapid transit systems).
4. Continuous inertial systems (for example, conveyor belts and escalators).

Variable-route systems include:

1. Demand-activated, rubber-tired, chauffeur-driven public transit vehicles (for example, taxis and dial-a-ride).
2. Private automobiles.

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* Jitneys are taxi-like automobiles operating along either fixed or semifixed routes.

3. Bicycles.
4. Pedestrians.

Even though rubber-tired, chauffeur-driven vehicles are capable of operating either as part of fixed-route systems or operating as part of variable-route systems, they are usually operated along fixed routes. To the transit patron, there is little difference between the travel characteristics of a bus and those of a streetcar. A reason for operating along fixed routes is that, to reduce costs, it is necessary for numbers of independent travelers to ride the same transit vehicle, even though they are not likely to leave a common origin or be going to a common destination. Taxis, of course, have greater flexibility of routing, but at higher fares.

Within each type of system listed in the taxonomy, many different specifications are possible. For example, operating speeds can be fast or slow, service can be frequent or infrequent, vehicles can be more or less luxurious, stations and terminals can be more or less elaborate, routes may be close together or widely spaced. An evaluation methodology should, therefore, be flexible enough to allow for different design specifications within each basic system type. The full-cost methodology, described below, possesses this flexibility.

2.2 THE CHOICE OF ALTERNATIVES FOR ANALYSIS

For commuter market, we sought to analyze alternatives that meet certain criteria. First of all, the alternatives analyzed in detail must have some *a priori* evidence that they might be suitable for the market. For example, rapid rail transit systems and exclusive busways are alternatives for commutation that are actually in use, or under discussion or construction in many places. Second, the technology involved in the alternatives must be related to existing transit to allow the use of available cost and performance data. This tends to rule out from consideration here futuristic transit systems, dual-mode vehicles, and the like, for which reliable cost and performance data are lacking. We have limited our analyses to existing vehicles, whether rubber-tired or rail, but not to existing operating modes.

The first alternative for this market is rail rapid transit. The technological prototypes for the system used in our comparative analysis are the San Francisco Bay Area Rapid Transit (BART), the Washington Metro, and the Lindenwold Line of the Delaware Port Authority. At this writing, the Lindenwold Line has been operating for several years, sections of BART have been completed and are in trial service, and the Washington Metro is under construction but several years away from initiating service.

These systems are high-speed, high-technology, grade-separated rail rapid transit. For each of these systems, CBD distribution is accomplished by subways. In the case of the Lindenwold Line, the subway was already in existence. Feeder service is provided by bus, private automobile (park and ride or kiss and ride), or walking. A patronage forecast for an earlier version of the Washington Metro predicted that two-thirds of the patrons would arrive by feeder bus, about 1.5 percent by taxi, with the remaining patronage about equally distributed between walking and private automobile [1]. The currently authorized 98-mile Metro system consists of many more lines stretching out from the District of Columbia into the suburbs, so, presumably, an even smaller percentage of patrons in the widely spaced outlying stations would walk to the train. Both the stations and the trains of these new systems are designed to be highly automated, with only one trainman aboard each train.

To model this market, we have selected a corridor with outlying stations served by feeder vehicles operating along ordinary streets, and with subway stations downtown from which patrons will walk to their CBD destinations. Feeder service is analyzed separately, with buses, minibuses, and jitneys the principal alternatives compared.

The second major alternative is an "integrated" bus on an exclusive busway. The operating concept of integrated buses has been described by the President and General Manager of the Atlanta Transit System as follows:

> Buses would collect passengers in outlying areas as nearly door-to-door as possible. Each collecting area would be as small as possible to keep collecting time as short as possible. A seat for every passenger would be the standard loading level. When the bus was filled, it would move over local streets to the nearest busway entrance. On a radio signal from the bus, the busway gate would open automatically, the bus would enter and proceed downtown nonstop [2].

Such systems are currently in operation in the Washington, D.C. metropolitan area, the New York metropolitan area, and in Seattle. Expressway lanes are reserved exclusively for buses, enabling them to avoid automobile congestion for the express portion of the trip. Distribution is accomplished on downtown city streets in Washington, D.C. and Seattle, and a bus terminal is used in New York.

In modeling the integrated bus system, we assumed that the patronage and geographic area served are identical to the rail alternative. Buses circulate in the residential area collecting passengers, enter the busway for a nonstop trip to the central business district, and use conventional streets with mixed traffic for downtown distribution.

Conventional transit service, the third alternative for this type of market, consists of express buses which operate in mixed traffic. These buses circulate in the neighborhood for pickup, then operate in closed-door service along arterial streets to the CBD, where they again circulate while discharging passengers. The model for analyzing this service is identical with the model for analyzing the integrated bus on exclusive way, but, of course, with different cost and performance parameters.

In general, the new rail systems under construction or in the planning stages are expected by their proponents to give faster and better service than any existing bus operation. The initial investment cost for these rail systems is high--on the order of $1,000 per area inhabitant for the Washington Metro System. Perhaps a rapid bus system operating on exclusive busways could lower the full cost of commuter travel, even though the system must incur investment costs not necessary for existing bus transit systems which operate along city streets already in place.

The commuter rail line must be supplemented by a residential collection and distribution system. The alternatives which we analyze for this system are buses, minibuses, bus-wagons, and jitneys operating along fixed routes. We have not attempted to model conventional taxicab services.

Small vehicle jitney services seem to be successful in other countries where they are allowed by law, even though typically outlawed in this country. Rosenbloom [3] reports that jitneys operate legally along several routes in Atlantic City and San Francisco, and in black neighborhoods in Baton Rouge and Miami. They also operate illegally in ghetto areas in Chicago and New York. A jitney service operating in St. Louis was legislated out of existence in 1965. Jitney services also operate successfully in foreign cities such as San Juan, Caracas, Buenos Aires, Santiago, Lima, Manila, Seoul, and Teheran [3 and 4].

As is well known, buses have higher vehicle-mile costs and lower seat-mile costs than taxis or jitneys. But, when the number of trips demanded is low, operating buses so as to fill them would result in excessive waiting time for passengers and would increase the time cost of travel. Operating buses more frequently to reduce waiting time would result in low occupancy and high bus cost per passenger. Jitneys would seem to have the potential for lowering the sum of waiting-time and vehicle costs for low-density markets. In addition, because they can accelerate and stop more rapidly, cope with traffic better, and make fewer stops per vehicle-mile, jitneys promise more rapid transportation. They also make less noise than large buses. Bus-wagons and minibuses, the intermediate size between automobiles and full-sized transit buses, may be used advantageously for some intermediate levels of patronage.

2.3 ALTERNATIVE LEVELS OF ANALYSIS

Several levels of analysis could be applied to the evaluation of alternative urban transportation systems, and undoubtedly each of these levels has been used at some time to analyze choices among alternative systems. The following eight analytical approaches are discussed in more detail in the subsections below:

1. Level-of-service characteristics.
2. Initial investment costs.
3. Total supplier cost (capital cost on an annual basis plus operating cost).
4. Total supplier cost, holding service standards constant.
5. Total supplier and user costs.
6. Total supplier, user, and external costs.
7. Total supplier, user, and external costs. Effects on various socioeconomic groups.
8. Total supplier, user, and external costs. Prediction of demand effects and consumer surplus changes. Effects on various socioeconomic groups.

2.3.1 Level-of-Service Characteristics

The service characteristics of alternative systems may be compared. For example, one system, such as a rail rapid transit system, may offer fast comfortable rides in pleasant air-conditioned surroundings from one station to another, while a second system, such as conventional bus transit operating on city streets, may offer somewhat slower and less luxurious service.

2.3.2 Initial Investment Cost

Alternative systems may be compared in terms of initial investment cost. Rail systems typically have much higher initial investment costs than do comparable bus systems, particularly if the buses operate on city streets and the streets are not counted as part of the initial investment cost.

2.3.3 Total Supplier Cost (Annualized Capital Cost Plus Operating Cost)

At the third level of analysis, operating costs incurred in supplying transit services may be added to annualized capital costs to yield total (supplier) costs per year. Alternatively, the present discounted value of operating and maintenance costs over the life of the system can be added to the initial capital cost to yield the present value of total (supplier) costs.

2.3.4 Total Supplier Cost, Holding Service Standards Constant

The now-classic study of Meyer, Kain, and Wohl [5] compared the total supplier costs of several alternative transit systems designed to serve commuters during peak hours from suburban and outer city areas to the CBD. The alternative systems were designed to offer approximately the same level of service with respect to such important parameters as overall travel time. The Meyer, Kain, and Wohl study goes beyond a simple comparison of costs of alternative systems with unspecified comparative qualities of service. Nevertheless, these authors were not able to adhere strictly to their plan for such important elements of the trip as residential collection and distribution, because the technological characteristics of the various modes make it virtually impossible to maintain equal service standards for residential collection and distribution.

2.3.5 Total Supplier and User Costs

A fifth level of analysis--that adopted as the primary focus of this study--analyzes not only supplier costs but user costs as well. User costs, which will be discussed in more detail later, consist of those costs borne by the traveler, primarily the time that it takes him to make a trip. The total of supplier and user costs are defined in this study as "full costs."

2.3.6 Total Supplier, User, and External Costs

A sixth level of analysis includes not only supplier and user costs, but also external costs. External costs, such as congestion, noise, and air pollution are imposed by the transit system on outsiders. In principle, full costs ought to include these external costs. In fact, the problem of expressing external costs in meaningful dollar terms is extremely difficult. We have adopted the intermediate strategy of expressing such effects as pollution in quantitative, nondollar terms.

2.3.7 Total Supplier, User, and External Costs: Effects on Various Socioeconomic Groups.

The seventh level of analysis includes not only costs broadly defined, but also the effects of these costs on various socioeconomic groups. For example, one transit system, such as a commuter railroad, may reduce costs for suburban commuters, while another alternative system, such as an inner city jitney service, may reduce costs for dwellers of urban ghettos.

2.3.8 Total Supplier, User, and External Costs. Prediction of Demand Effects and Consumer Surplus Changes. Effects on Various Socioeconomic Groups.

An eighth level of analysis would include not only full costs but would also predict the effects of changes in transit systems on the number of trips demanded. An economic theory of travel demand would be necessary, one which hypothesizes that people in urban areas arrange their travel patterns as a part of the overall process of consumer choice. Travel is merely one of many alternative ways of spending time and money. An improvement in transit service which reduces user costs or money fares will cause people in urban areas to rearrange their travel behavior to consume more transit trips. The lowering of trip prices and consequent expansion of number of trips results in benefits to travelers, measured by consumer surplus gains. Quantitative information about the relevant elasticities and cross-elasticities of demand is largely lacking, as most so-called urban travel "demand" models simply assume certain levels of travel, independent of price. A notable exception is a recent study by Charles River Associates [6].

2.4 SUPPLIER AND USER COST FRAMEWORK

The plan of this study is to evaluate the supplier and user costs of serving various levels of demand with alternative transit systems. These costs include the following elements:

1. Supplier costs. These are costs incurred by the suppliers of the transit service. They include costs of buying, maintaining, and operating the stock of vehicles; other operating labor costs; costs of right-of-way and roadway (including public-provided to private operators); track construction and maintenance; stations; and administrative support and other overhead costs. Thus, supplier costs are those that one usually thinks of when transit system costs are mentioned. The supplier costs used in this study are documented in Chapter 3.
2. User time costs. These costs are borne by the user of the transit system. They include time to journey from the place where the trip begins to the spot where the vehicle is boarded (access time costs), the time spent waiting for the transit vehicle to arrive (waiting-time costs), time spent traveling on the transit vehicle (in-vehicle-time costs), time spent transferring from one vehicle or route to another (transfer time costs), and time from the place of the last transit stop to the destination point of the journey (egress time costs). Crowding costs could also be included as a user cost, in the form of a higher value in dollars per passenger-hour of time spent in vehicles; however, no attempt has been made to include crowding costs in this study. As we define them, user time costs do not include the fare or charges paid for riding the transit system. The fare represents a reimbursement to the supplier for all or part of the supplier costs, and is included in the method of analysis of this study under supplier costs.

We do not attempt to estimate the costs of the noise, air pollution and similar externalities of alternative urban transportation systems. However, in Chapter 4 we estimate the congestion costs that buses and other transit vehicles impose on other traffic. These costs are the short-run opportunity costs of using existing street and expressway capacity for transit service in mixed traffic. The capital recovery charges for right-of-way and road construction, estimated in Chapter 3, are the long-run costs of this capacity and are included in the supplier costs for alternative systems.

In Chapter 4 we have included data on the physical quantities of pollutants generated by the alternative systems. The energy requirements of the various systems are also shown. The cost of energy is included in the supplier cost, but the quantities of fuel required may also be of interest to policymakers who must decide which type of system should be supported.

2.5 SOME BASIC ANALYTICAL RELATIONSHIPS

The commuter market analysis of Chapter 5 makes use of a few simple relationships which we will now develop. Let the type of service, length of transit route, and level of patronage be given. The basic cost parameter α measures the round trip cost of a vehicle on the route. This parameter depends on both distance traveled and time spent per round trip, as explained in Chapter 3. If there are F round trips per hour, then total supplier costs, C, per hour are

$$C = \alpha F. \tag{1}$$

If the route generates Q passengers per hour, then the supplier cost per passenger is

$$c = \alpha F/Q. \tag{2}$$

Throughout this subsection, we use capital letters (C, A, W, H, T) to represent total costs for all passengers in dollars per hour, and lower case letters (c, a, w, h, t) for average cost in dollars per passenger. The definitions of these variables are shown in Figure 1 and are explained below.

α = round-trip cost of a vehicle on the route (dollars per vehicle round trip)

A = total access and egress costs per hour for all passengers (dollars per hour). "Access" involves walk from origin to transit boarding point; "egress" involves walk from transit deboarding point to destination.

a = average access and egress cost per passenger (dollars per passenger). "Access" involves walk from origin to transit boarding point; "egress" involves walk from transit deboarding point to destination.

C = total supplier costs per hour (dollars per hour)

c = average supplier costs per passenger (dollars per passenger)

F = vehicle round trips per hour

H = total in-vehicle-time costs for all passengers (dollars per hour)

h = average in-vehicle-time cost per passenger (dollars per passenger)

K = vehicle capacity (passengers)

L = feeder route length (miles)

P = maximum number of passengers per vehicle without limitation to actual vehicle capacity

Q = passengers per hour generated on route

S = overall vehicle speed along route (miles per hour)

T = full costs (supplier + user time) per hour for all passengers (dollars per hour)

t = average full cost (supplier + user time) per passenger (dollars per passenger)

v_1 = average value passengers place on in-vehicle time (dollars per passenger-hour)

v_2 = average value passengers place on time spent waiting (dollars per passenger-hour)

W = total waiting costs per hour for all passengers (dollars per hour)

w = average waiting cost per passenger (dollars per passenger)

Figure 1. DEFINITIONS OF VARIABLES USED IN ANALYTICAL RELATIONSHIPS

Access and egress costs depend on the value of time spent walking, walking speed, and average distances from trip origins or destinations to transit boarding points. For now, we assume that average access and egress cost, a, is given, although in the case study below, access and egress distances are a function of route and stop spacing. Thus, total access and egress cost per hour is

$$A = aQ. \tag{3}$$

Average waiting costs, w, depend on the frequency of service. Throughout this paper we assume uniform arrival rates of both passengers and vehicles at transit boarding points, so that the average wait is one-half the interval between vehicles.* Average waiting costs per passenger are

$$w = v_2/2F, \tag{4}$$

where v_2 is the average value passengers place on time spent waiting. Total waiting costs per hour are

$$W = v_2Q/2F. \tag{5}$$

The average time spent on board the transit vehicle depends on the overall vehicle speed, S, and the average distance traveled. For example, if the service being analyzed is a feeder route of length L, which picks up passengers distributed uniformly along it and deposits them at a terminal, then the average distance traveled is L/2, and in-vehicle-time costs are

$$h = v_1 \; L/2S, \text{ and} \tag{6}$$

$$H = v_1 \; LQ/2S, \tag{7}$$

---

* Waiting time can be less, particularly at low frequencies, if vehicles run on a schedule known to the passenger.

where v_1 is the average value passengers place on in-vehicle time.

Full cost per hour, T, and average full cost per passenger, t, for this illustrative example are the sum of supplier costs and all user time costs:

$$T = C + A + W + H \tag{8a}$$

$$T = \alpha F + Q\left(a + v_2/2F + v_1 L/2S\right) \tag{8b}$$

$$t = c + a + w + h \tag{9a}$$

$$t = \alpha F/Q + a + v_2/2F + v_1 L/2S. \tag{9b}$$

2.5.1 Optimal Service Frequency and the Square-Root Rule

Only supplier and waiting costs are affected by frequency of service. Differentiating equation (8b) with respect to F, setting the result equal to zero and solving for F yields the following expression for full-cost minimizing frequency, F^*:

$$F^* = \sqrt{Qv_2/2\alpha}. \tag{10}$$

Optimal frequency is proportional to the square root of quantity and waiting-time value, and inversely proportional to the square root of supplier cost per round trip.*

Substituting (10) into (8b) yields the minimum total full cost, T^* as a function of Q:

$$T^* = \sqrt{2Qv_2\alpha} + Q\left(a + v_1 L/2S\right). \tag{11}$$

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* A similar square-root rule for optimal frequency is derived by Mohring [7, p. 595].

The first term on the right of equation (11) is the sum of supplier and waiting costs, each of which is equal to $\sqrt{Qv_2\alpha/2}$ and, thus, proportional to the square root of patronage, waiting-time value, and per-vehicle round trip supplier cost. Dividing by Q yields average minimum full cost per passenger

$$t^* = \sqrt{2v_2\alpha/Q} + a + v_1L/2S. \tag{12}$$

2.5.2 Capacity-Load Threshold

The capacity load, P, for each vehicle occurs between the last pickup point and the terminal in the above example, and is given by

$$P = Q/F. \tag{13}$$

If Q is large enough, the square-root rule for service frequency may imply that P is greater than vehicle capacity, K. In this case, minimum full cost feasible frequency is given by

$$F^{**} = Q/K, \tag{14}$$

and minimum feasible total and average full costs are, respectively,

$$T^{**} = \alpha Q/K + v_2K/2 + Q\left(a + v_1L/2S\right), \text{ and} \tag{15}$$

$$t^{**} = \alpha/K + v_2K/2Q + a + v_1L/2S. \tag{16}$$

Note that now the total waiting costs, $v_2K/2$, are independent of Q, and supplier costs, $\alpha Q/K$, are proportional to Q [7, p. 593].

The capacity-load threshold quantity, $\bar{Q}$, is that Q for which the square-root rule just fills up the vehicle. The vehicle is full when P = K and, therefore, $K = \bar{Q}/F$ and $\bar{F} = \bar{Q}/K$. Setting $\bar{Q}/K$ equal to the right side of equation (10) and solving for $\bar{Q}$ yields

$$\overline{Q} = v_2K^2/2\alpha. \tag{17}$$

$\overline{Q}$ is the capacity-load threshold quantity. At the capacity-load threshold, total and average full costs are given by the following expressions, found by substituting (17) into (15) and (16), or into (11) and (12):

$$\overline{T} = v_2K + v_2K^2\left(a + v_1L/2S\right)\Big/2\alpha \tag{18}$$

$$\overline{t} = 2\alpha/K + a + v_1L/2S. \tag{19}$$

At the threshold, total supplier costs and total waiting-time costs are each one half the first term in equation (18), or, $v_2K/2$, while average supplier costs and average waiting-time costs are each α/K.

2.5.3 An Illustrative Example: Bus Versus Jitney

Suppose there are two alternatives, a 50-passenger bus and a 5-passenger jitney. As explained in Chapter 3, we estimate that conventional buses in residential collection peak-hour service cost \$1.24 per mile to operate, while jitneys cost \$.32 per mile (see Table 9). If the route length, L, is 5 miles, or 10 miles round trip, α would be \$12.40 for bus and \$3.20 for jitney. Operating speeds are, respectively, 15 and 20 miles per hour. Assume that passengers value waiting time at \$3.00 per hour and in-vehicle time at \$1.20 per hour. Average in-vehicle-time costs are, from equation (6), \$.15 for jitney and \$.20 for the slower bus. Capacity-load thresholds are 11.7 passengers per hour for jitneys and 302 passengers per hour for buses, from equation (17). The two panels of Figure 2 plot average waiting, in-vehicle, and supplier costs for both jitney and bus. Figure 3 presents full-cost curves for both bus and jitney for purposes of comparison.

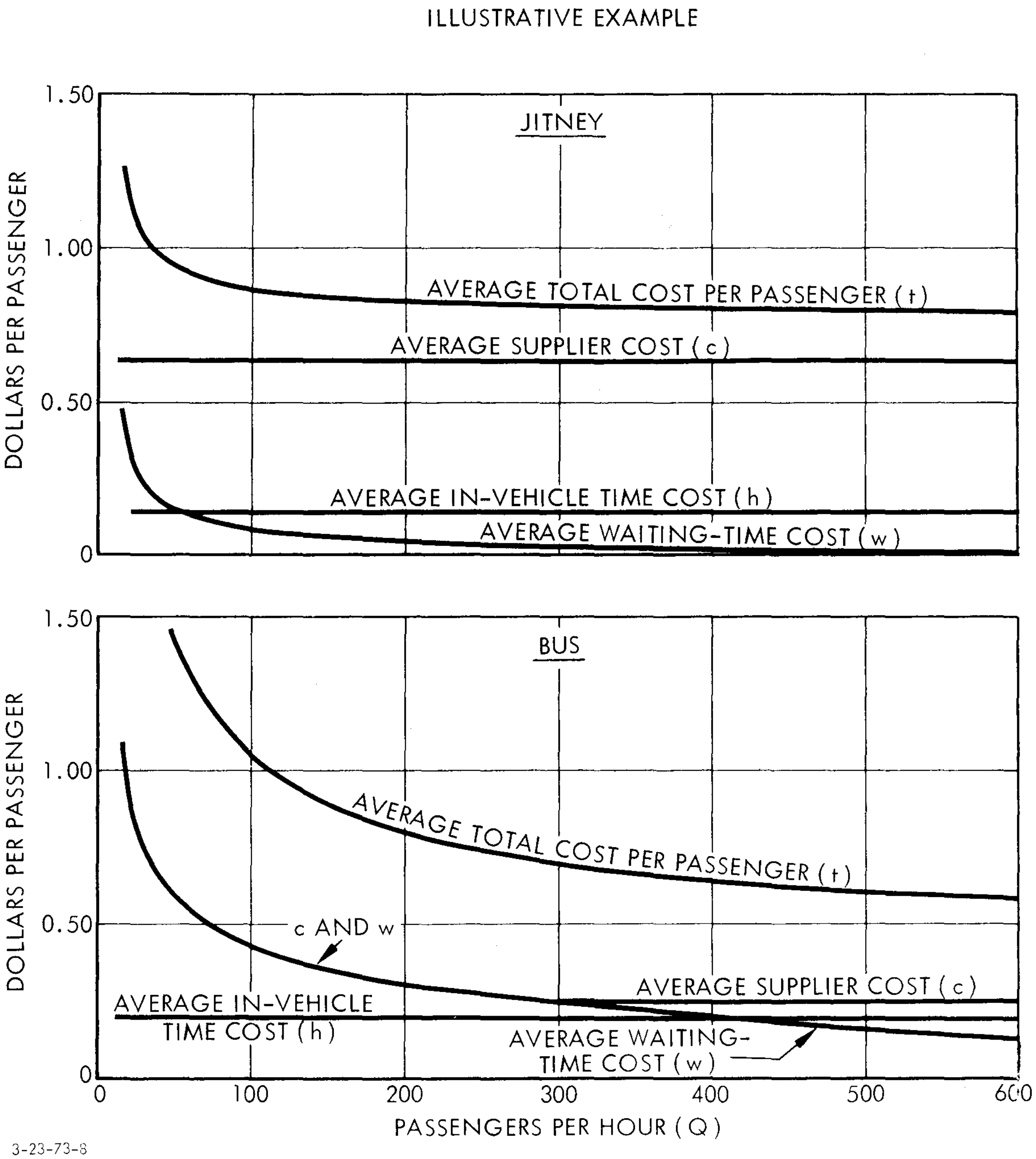

Figure 2. AVERAGE WAITING-TIME COST, IN-VEHICLE-TIME COST, AND SUPPLIER COSTS FOR BUS AND JITNEY

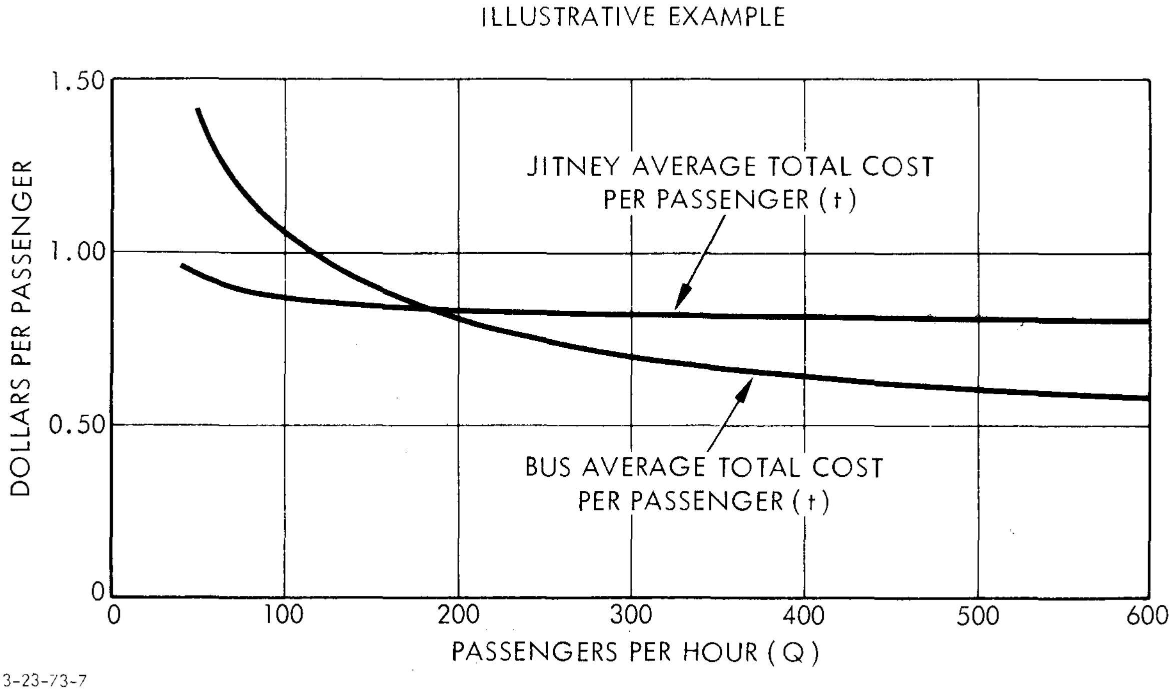

Figure 3. COMPARATIVE FULL COST (WAITING TIME, IN-VEHICLE TIME, AND SUPPLIER) FOR BUS AND JITNEY

Suppose there are 100 passengers per hour along the route, or 20 per mile. Then 20 jitneys per hour, or one every three minutes, would be required. Supplier cost would be \$.64 per passenger, and waiting-time costs \$.08. Jitney full cost would, therefore, be \$.87, including waiting-time cost, in-vehicle-time cost, and supplier cost (\$.08 + \$.15 + \$.64). Buses would operate under the square-root rule 3.48 times per hour, (every 17 minutes) and carry 29 passengers per trip. Supplier and waiting-time costs would each be \$.43, for a full cost of \$1.06 (\$.20 + \$.43 + \$.43). The bus costs 23 percent more than the jitney for this number of passengers. In fact, Figure 3 indicates that bus costs are greater than those for jitney up to almost 200 passengers per hour, as may be verified using equation (16).

3. COSTS OF SUPPLYING URBAN PUBLIC TRANSPORTATION

3.1 INTRODUCTION

In order to derive supplier costs per passenger, it is necessary to develop operating and capital costs for the vehicles and operating conditions listed in Table S-1 of the Summary. These costs include the following elements:

- Vehicle operating costs
- Vehicle capital costs
- Miscellaneous capital costs
- Roadway/railway operating and maintenance costs
- Roadway/railway capital costs (right-of-way plus construction).

The derivation of these costs is presented in Appendix A. In Sections A.3 and A.4 of Appendix A, costs for rubber-tired vehicles and rail rapid transit, respectively, are presented for conventional operations on an average cost basis. In Section A.7, cost-estimating relationships are developed from the average cost data of Sections A.3 and A.6. These estimating relationships allocate a greater-than-average amount of driver and capital costs to peak-hour service, and permit one to ascertain the effect of operating speed on cost per vehicle-mile.

In Appendix A, average cost data are presented for past years in terms of the actual dollar value for the year of the data (current dollars). Based on trends in the cost of each element, costs are projected to 1972, 1980, and 1990, all expressed in 1972 dollars. In comparing competing systems, one should ideally project the annual costs of each system over its lifetime and then discount the stream of costs to a present value for each system. Such a calculation requires a detailed time phasing of the planning, procurement, construction, and operating costs of each system. For simplicity, 1980 costs (expressed in 1972 dollars) have been used for all elements of all systems. This is a representative period for the operation of competitive systems being evaluated now.

Some costs, such as fuel costs or bus purchase costs, are fairly constant for different operations in different cities. Other costs, particularly site-specific capital costs such as roadway or guideway right-of-way and construction costs, can vary considerably from these typical values. In all cases, the methodology and data are presented in sufficient detail to allow the reader to adjust the results for locales with substantially differing costs for land and other specific inputs.

3.2 AVERAGE COSTS FOR RUBBER-TIRED VEHICLES

Average costs for rubber-tired vehicles are based primarily on data for conventional bus and taxi operations. The costs for bus-wagon jitneys and 19-passenger minibuses are derived by interpolation of the bus and taxi costs.

3.2.1 Rubber-Tired Vehicle Operating Costs

Local transit bus costs for conventional services operating along arterial streets in mixed traffic may be estimated directly from the IDA Data Base [8]. Table 1 presents bus operating costs, using the American Transit Association cost categories [9]. The third and fourth columns present typical costs in current dollars for 1960 and 1970. The next column shows the annual rate of growth in real terms from 1960 to 1970. The final three columns show projected costs for 1972, 1980, and 1990, assuming that the rate of growth of cost in real terms from 1960 to 1970 continues from 1970 to 1990. The total operating cost has been increasing about one percent per year in real terms.

A jitney is basically an automobile that operates on fixed routes. It is essentially a small (5-passenger) bus operation. We have been unable to obtain actual cost data on jitney operations, most of which are illegal in this country. However, since jitneys

Table 1. BUS OPERATING COSTS[a], BY CATEGORY

Category Number	Category Name	Costs Per Vehicle Mile					
		Current Dollars		Annual Growth Rate (%)	Constant 1972 Dollars		
		1960	1970		1972	1980	1990
4	Equipment, Maintenance, and Garage	.102	.140	.46	.152	.158	.165
7	Transportation[b]	.269	.404	1.37	.447	.499	.571
8	Drivers', Helpers' Wages, etc.	.216	.335	1.69	.373	.427	.505
9-12	Fuel and Oil	.027	.028	-2.32	.029	.024	.019
13	Station	.001	.001	-2.67	.001	.001	.001
14	Traffic, Advertising, etc.	.004	.005	-.48	.005	.005	.005
15	Insurance and Safety	.023	.033	.91	.036	.039	.043
17	Administrative and General	.055	.088	2.01	.099	.116	.141
20	Operating Taxes and Licenses	.047	.054	-1.31	.057	.051	.045
21	Operating Rents - Net	.004	.007	2.93	.008	.010	.013
	TOTAL OPERATING COST	.504	.732	1.03	.805	.874[c]	.968[c]

a. Excludes depreciation and amortization chargeable to operations.
b. Transportation includes other items in addition to the two listed here.
c. Elements do not add to total because of change in relative weights over time.

Source: Averages for 38 bus properties for 1960 and 1970 from IDA Computerized Data Bank on Urban Transportation.

and taxis are similar vehicles, their costs per mile should be about the same; accordingly, taxi costs were used as a basis for estimating jitney costs for use in this study.

Taxi operating costs are presented in Table 2. We have assumed that the corresponding cost categories (excepting fuel costs) will increase over time at about the same rate as bus costs. Automotive antipollution regulation will probably affect taxi gasoline engines to a greater degree than bus diesel engines, and cause much poorer fuel economy. In the absence of better information, we have assumed a zero rate of growth in vehicle operation costs (which are largely gasoline costs) as a more reasonable choice than the -2.32 percent found for bus fuel costs. Projected costs for 1972, 1980, and 1990, all in 1972 dollars, are given in Table 2.

Table 2. TAXI OPERATING COSTS

Category Name	Assumed Growth Rate (%)	Dollars per Vehicle Mile			
		1970 (Current Dollars)	Constant 1972 Dollars		
			1972	1980	1990
Driver Cost	1.69	.156	.174	.199	.235
Vehicle Operation	None	.025	.027	.027	.027
Tires		.003			
Gasoline		.022			
Maintenance	.46	.020	.022	.023	.024
Labor		.011			
Parts		.009			
Public Liability Insurance	.91	.016	.018	.019	.021
Other (General and Administrative, Garage)	2.01	.049	.055	.065	.080
TOTAL		.266	.296	.333	.387

Source: Wells, John D., et al, Economic Characteristics of the Urban Public Transportation Industry, Institute for Defense Analyses for U.S. Department of Transportation, February 1972.

3.2.2 Rubber-Tired Vehicle Capital Costs

3.2.2.1 Vehicle Capital Costs. Table 3 presents the basis for calculation of rubber-tired vehicle capital costs. These factors are used first to calculate a yearly capital-recovery cost which is then converted to a cost per vehicle-mile by dividing the recovery cost by the annual miles traveled by the vehicle.

Table 3. RUBBER-TIRED VEHICLE CAPITAL COST FACTORS

Vehicle Type	1972 Initial Cost (Dollars)	Annual Growth Rate of Initial Cost (Percent)	Life (Years)	Residual Value (Dollars)	Vehicle-Miles per Year
Automobile Jitney	3,000	0	3	300	40,000
Bus-Wagon Jitney	4,200	0	3	420	40,000
19-Passenger Minibus	14,000	-.38	8	0	29,400
50-Passenger Bus					
Conventional	43,000	-.38	15	0	29,400
Busway	48,000	-.38	12	0	48,900

3.2.2.2 Right-of-Way (ROW) Land Costs. The most convenient way to account for the location effect on land price is to express the price as a function of population density. Obviously, there are many determinants of land price, but population density is probably the most important and the relationship of land price and population density is fairly constant for all cities.

The results of two other studies dealing with road ROW costs are shown in Figure 4, expressed in 1972 dollars. Both studies relate ROW cost to population density. The two bottom curves are based on the method used by Meyer, Kain, and Wohl (MK&W) who give equations as a function of number of lanes. The top MK&W curve depicts their costs for a four-lane road; this type of road was

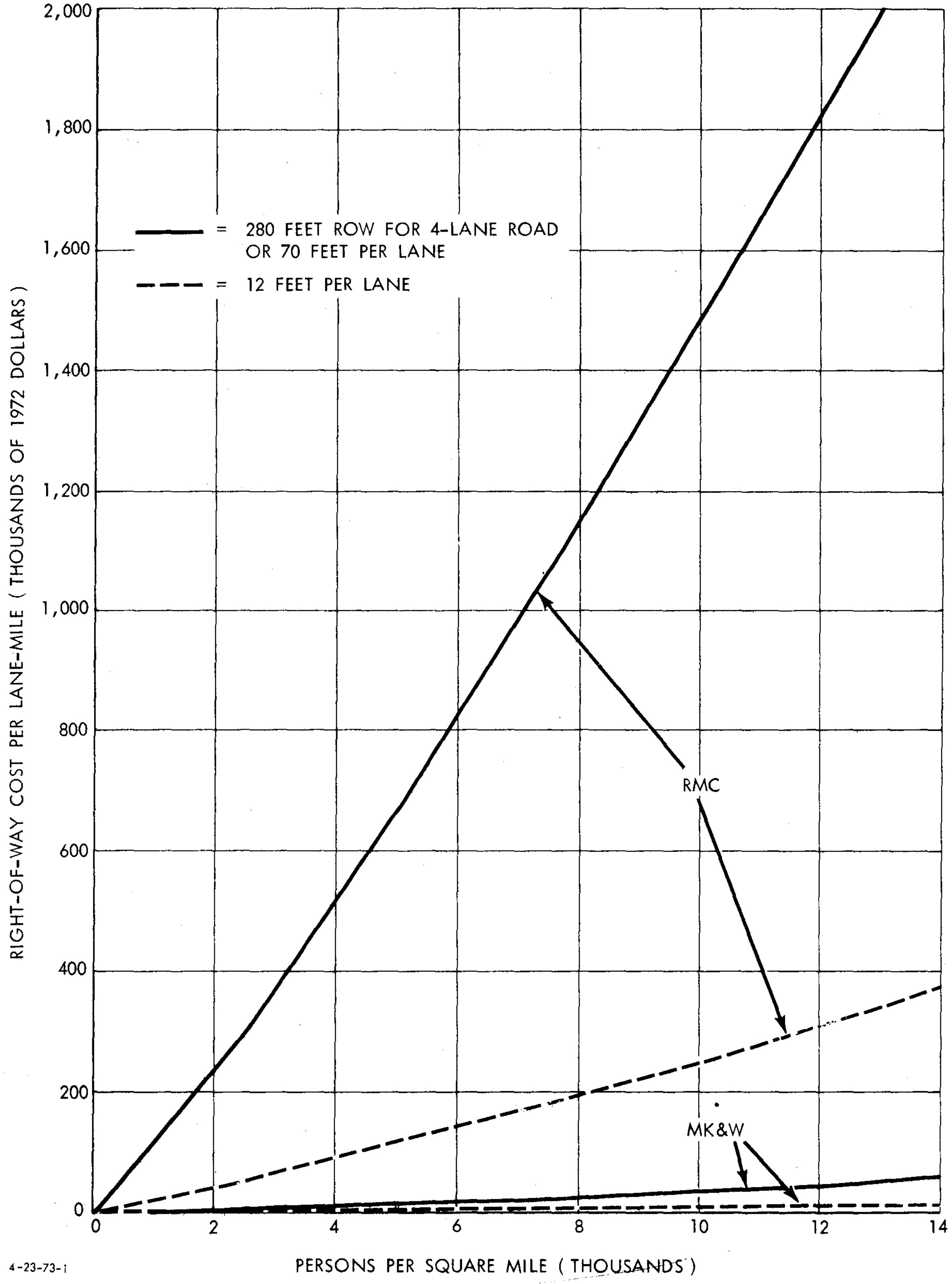

Figure 4. RIGHT-OF-WAY COST PER LANE-MILE VERSUS POPULATION DENSITY

selected as being representative of the type used by buses in conventional line-haul service. For this road they specify a total ROW width of 280 feet, or an average of 70 feet per lane. For an urban street, it seems more correct to charge the vehicles for only the actual lane width. The sidewalks, planting areas, etc., on both sides of the actual vehicle lanes would be needed for pedestrians and aesthetic reasons, even if the road carried no vehicle traffic. Four-lane major city streets have an average lane width of about 12 feet [12, p. 24]. Accordingly, in the bottom dotted line of Figure 4, we have reduced the MK&W right-of-way cost to 12/70 of the solid line to reflect the cost of the actual lane width.

Resource Management Corporation (RMC) has developed equations which relate land costs in urban areas to population density [11, Chapter 5]. The top two curves of Figure 4 show ROW costs based on the RMC equation for average urban land prices. The top solid line shows the per-lane cost corresponding to the solid MK&W line (280 feet ROW for a four-lane road, or 70 feet per lane); the bottom dotted line corresponds to the MK&W dotted line (12-foot lane width only).

The MK&W method appears to be based on figures which reflect only out-of-pocket payments for ROW. If a street is rebuilt or a new street is constructed over ROW already owned by the municipality, no ROW cost is included. Actually, the land does have opportunity cost (the municipality could sell it) and this should be reflected in the true cost of the roadway. However, it seems more correct to charge only for the lane width--not for sidewalks, planting areas, etc.--so that the lower RMC curve of Figure 4 seems the most correct representation of true ROW cost; it is used in the calculation of ROW costs.

3.2.2.3 Exclusive Busways. Table 4 presents the construction costs of busways. The average cost of $1,400,000 per lane-mile is about double the cost used in this study for a four-lane urban road. The limited-access features of the busway may account for the difference. The entire construction cost of the busway must be allocated to the bus operation.

Table 4. CONSTRUCTION COSTS OF BUSWAYS

Facility	Description	Number of Lanes	Distance (Miles)	Construction Costs (Millions of Dollars)			
				Total Cost	Cost Per Lane-Mile	Construction Date	
						Start	Complete
Shirley Highway, Va.	In highway median; 11 to 18 feet wide	1	9.0	5.5[a]	0.6[b] 1.3[c]	1969	1971
East PAT-ways, Pittsburgh	Abandoned railroad ROW	2	8.0	21.4	1.3	1973	late 1974
South PAT-ways, Pittsburgh	Difficult terrain; three new bridges and rehabilitation of existing trolley tunnel	2	4.0	16.8	2.1	1972	late 1973
San Bernadino Busway, California	Parallels San Bernadino Freeway; partly in median and partly to one side	2	11.0	39.0	1.8	1972	1973
Crosstown Busway, Chicago	Partly in Expressway median and partly to one side	2	20.0	97.2	2.4	Proposed in 1971	
Dallas Busway	Mainly elevated	2	10.0	32.2	1.6	Proposed	
Dayton Busway	Abandoned railroad ROW	2 1	4.8 2.7	4.8	0.4	Proposed	
Kansas City Transitway	Includes new bridge across Missouri River	2	19.0	29.5[d]	0.8	Proposed	
Milwaukee Transitway	Parallel to East-West Freeway	2	8.0	40.2[e]	2.5	Proposed	
New Haven Busway	Paving over railroad tracks at track level; Buses operate from 6 AM to 1 AM and freight trains operate from 1 AM to 6 AM	2	13.3	15.0	0.5	Proposed in 1971	
AVERAGE					1.4		

a. Temporary construction cost. Permanent lanes being incorporated in Shirley Highway reconstruction to Interstate Standards.

b. Based on 9-Mile Section.

c. Based on 4-Mile Section.

d. 1969 prices.

e. 1970 prices.

Source: Interim Report to the National Cooperative Highway Research Program, Project 8-10, "Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities." Wilbur Smith and Associates, New Haven, Connecticut, March 1972.

3.2.3 Typical Total Costs For Conventional Rubber-Tired Services

Table 5 summarizes the costs per bus-mile for conventional operations on urban streets in mixed traffic. The table shows costs for 1972 and projections for 1980 and 1990, both expressed in 1972 dollars. The cost growth in real terms from 1972 to 1990 can be seen to be moderate and is due almost entirely to increases in bus operating costs and right-of-way costs.

Table 5. TYPICAL[a] COSTS PER VEHICLE-MILE FOR BUS OPERATION (1972 Dollars)

Cost	Annual Growth Rate (%)	Cost per Vehicle-Mile		
		1972	1980	1990
CONVENTIONAL OPERATION ON URBAN STREETS WITH OTHER TRAFFIC				
OPERATING COSTS		.811	.881	.976
Bus	1.03	.805	.874	.968
Road O&M	1.73	.006	.007	.008
CAPITAL COSTS		.592	.644	.748
Bus	-0.38	.192	.187	.180
Right-of-Way	5.00	.119	.176	.287
Roadway Construction	0	.260	.260	.260
Miscellaneous Capital	0	.021	.021	.021
TOTAL		1.40	1.53	1.72
EXCLUSIVE BUSWAY OPERATION				
OPERATING COSTS		.464	.504	.559
Bus	1.03	.460	.499	.554
Busway O&M	1.73	.004	.005	.005
CAPITAL COSTS		.605	.642	.715
Bus	-0.38	.144	.140	.134
Right-of-Way	5.00	.085	.126	.205
Busway Construction	0	.363	.363	.363
Miscellaneous Capital	0	.013	.013	.013
TOTAL		1.07	1.15	1.27

a. Capital costs depend on vehicle and roadway/busway utilization.

Table 5 also summarizes costs for busway operations. The same pattern of growth as before is observed Operating costs are lower than for conventional service, because of greater average speed. Bus capital costs are lower, since the effect of greater assumed annual mileage more than balances the higher initial costs and shorter life. Busway costs are estimated to be higher because, even though the limited access busway handles more bus-equivalent vehicles per hour in nonstop service than the arterial street handles in local service, it costs twice as much per lane-mile.

It should be emphasized that these are typical comparisons only. For example, the actual cost per bus-mile for busway right-of-way and construction would depend on the amount of bus traffic on the busway. The cost-estimating relationships developed below allow unit costs to vary with system parameters.

Table 6 presents comparable costs for three smaller vehicles, jitney, bus-wagon, and minibus. The jitney vehicle costs are based on taxi costs and the other jitney costs on scaled-down conventional bus costs. The 8-passenger bus-wagon costs include an allowance for somewhat higher vehicle operating and capital costs but are otherwise the same as jitney. The 19-passenger minibus costs, with the exception of vehicle capital costs, were constructed by averaging jitney (one-third weight) and bus (two-thirds weight) costs.

3.3 AVERAGE COSTS FOR RAIL RAPID TRANSIT

3.3.1 Rail Operating Costs

Rail transit operating costs are presented in Table 7. The cost categories are those reported by the American Transit Association [9]. The costs shown are average values for the eight U.S. properties in operation in 1960 and nine in 1970 (see Table A-14 of Appendix A). Since all properties did not report every item, the elements of Table 7 do not add exactly to the totals; the total figures are used as a basis for extrapolation into the future.

The third and fourth columns of Table 7 are average costs in current dollars for 1960 and 1970. The next column shows the annual

Table 6. TYPICAL[a] COSTS PER VEHICLE-MILE FOR JITNEY, BUS-WAGON, AND MINIBUS (1972 Dollars)

Cost	Annual Growth Rate (%)	Cost per Vehicle-Mile		
		1972	1980	1990
JITNEY				
Operating Costs		.297	.334	.386
Vehicle	1.50	.296	.333	.387
Road O&M	1.73	.001	.001	.001
Capital Costs		.104	.115	.137
Vehicle	.0	.028	.028	.028
Right-of-Way	5.0	.024	.035	.057
Roadway Construction	.0	.052	.052	.052
TOTAL		.40	.45	.52
8-PASSENGER BUS WAGON				
Operating Costs		.304	.341	.396
Vehicle	1.5	.303	.340	.395
Road O&M	1.73	.001	.001	.001
Capital Costs		.115	.126	.148
Vehicle	.0	.039	.039	.039
Right-of-Way	5.0	.024	.035	.057
Roadway Construction	.0	.052	.052	.052
TOTAL		.42	.47	.54
19-PASSENGER MINIBUS				
Operating Costs		.639	.699	.780
Vehicle	1.2	.635	.694	.774
Road O&M	1.73	.004	.005	.006
Capital Costs		.368	.405	.480
Vehicle	-.38	.089	.086	.083
Right-of-Way	5.0	.083	.123	.201
Roadway Construction	.0	.182	.182	.182
Miscellaneous Capital		.014	.014	.014
TOTAL		1.01	1.10	1.26

a. Capital costs depend on vehicle and roadway utilization.

Table 7. RAIL RAPID TRANSIT OPERATING COSTS[a], BY CATEGORY (Average Values, U.S. Properties Only)

Category Number	Category Name	Costs per Passenger Car-Mile					
		Current Dollars		Annual Growth Rate (%)	Constant 1972 Dollars		
		1960	1970		1972	1980	1990
4	Way and Structures	.128	.228	3.12	.261	.334	.454
5	Equipment	.074	.154	4.74	.182	.264	.419
6	Power-Maintenance	.012	.022	3.20	.025	.032	.045
7	Power (Purchased-Generated)	.086	.110	-0.28	.118	.115	.112
8	Conducting Transportation	.420	.772	3.42	.890	1.164	1.630
9	Wages of Trainmen	.143	.238	2.42	.269	.326	.414
10	General Miscellaneous	.151	.370	6.45	.452	.745	1.392
11	Injuries and Damages	.035	.092	7.17	.114	.198	.396
12	Traffic	.001	.003	11.61	.004	.010	.029
14	Operating Taxes	.073	.082	-1.55	.086	.076	.065
15-13	TOTAL OPERATING EXPENSES	.92[b]	1.57[b]	2.66	1.78[b]	2.20[b]	2.86[b]

a. Excludes depreciation and amortization chargeable to operations.

b. Elements do not add to total because all properties did not report every item and because of change in relative weights over time.

rate of growth in real terms from 1960 to 1970. The final three columns show projected costs for 1972, 1980, and 1990 based on the assumption that the rate of growth of cost in real terms from 1960 to 1970 will continue from 1970 to 1990.

3.3.2 Rail Car Capital Costs

In Figure 5, the price per rail car in 1972 dollars versus year ordered is plotted. The trend line through the data points of the figure indicates that car prices increased from 1950 to 1972 at an annual rate of about 6.43 percent in real terms.

Some of the price increase indicated in Figure 5 is associated with higher-quality cars. The comfort, aesthetics, and performance of today's cars are much improved over those of 20 years ago. It is not likely, however, that car quality will continue to increase at this rate.

We expect that the rate of increase in rail transit car prices should be somewhat lower in the future than it was from 1950 to 1972 because, (1) car quality will probably increase at a lower rate in the future, and (2) the opening of new rail transit systems and the extension of older systems should enlarge and stabalize the market for rail transit cars. The impact of these changes on the rate of increase in rail transit car prices is difficult to quantify; our estimate is that car prices will increase in the future at about 4 percent per year in real terms (versus 6.43 percent from 1950-1972).

3.3.3 Other Rail Transit Capital Costs

In this analysis we will aggregate all capital costs other than cars into a single "other capital cost" category, which we will then relate to route miles. These other costs include land, roadbed, supporting and enclosing structures, track, power supply, signal system, stations, shops and yards, offices, etc.--in short, all the capital facilities making up a rail transit system, other than cars.

Figure 6 presents data on the capital costs (excluding cars) of rail transit systems built in North America since World War II. Cost per route-mile versus mid-year of construction is plotted.

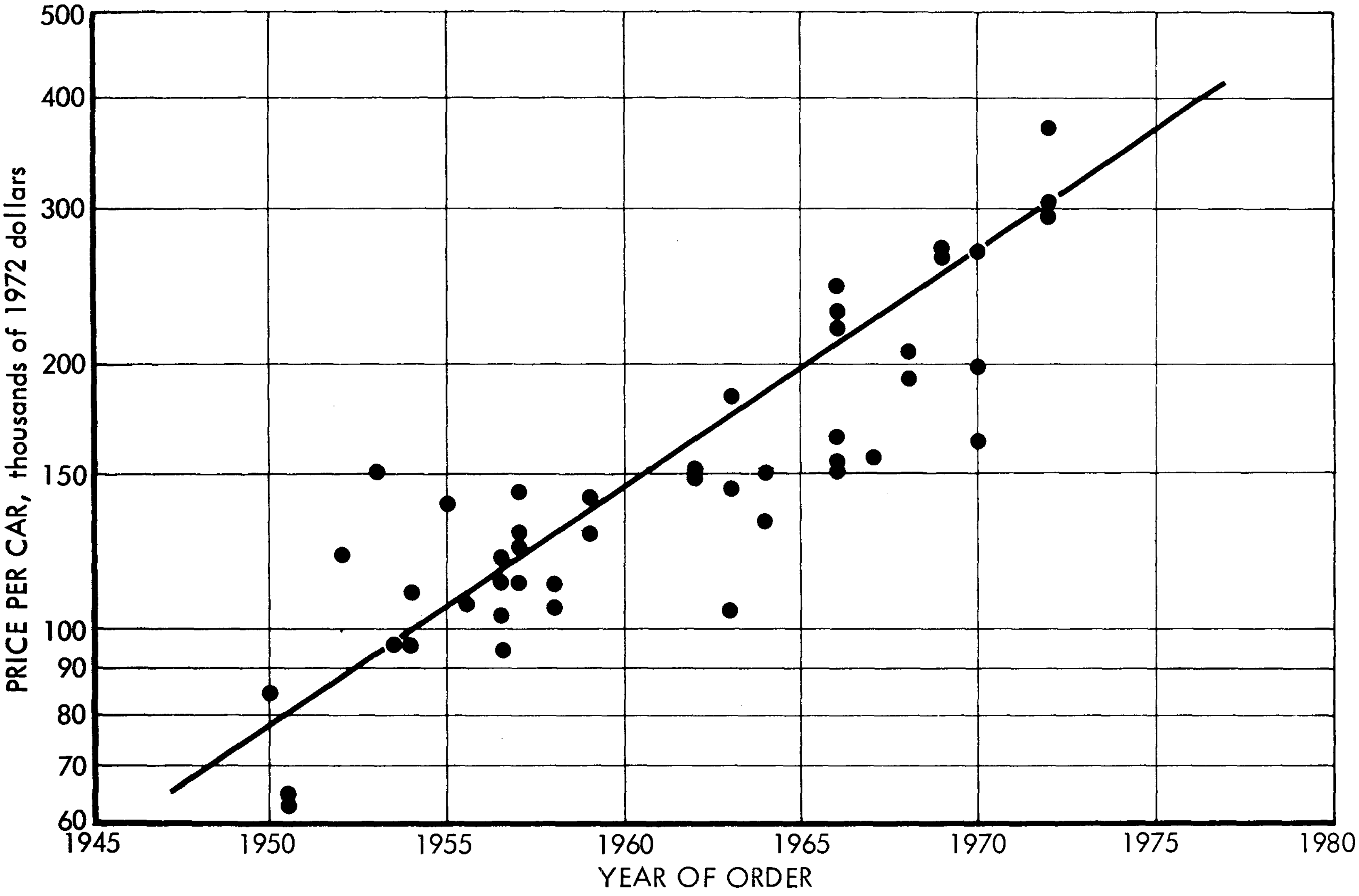

Figure 5. RAIL TRANSIT CAR PRICES VERSUS YEAR OF ORDER

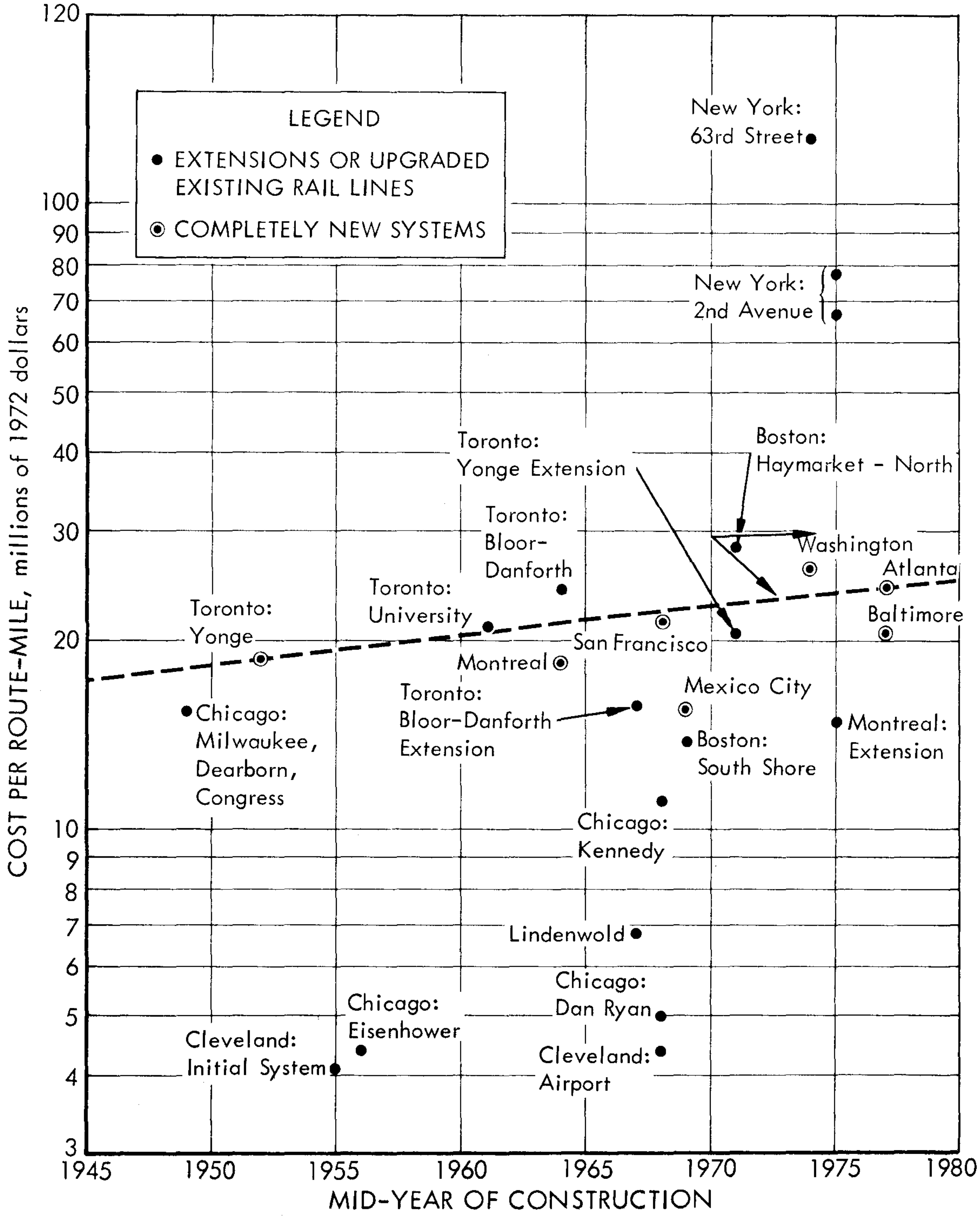

Figure 6. RAIL TRANSIT SYSTEM COSTS VERSUS MID-YEAR OF CONSTRUCTION

The cost per route-mile ranges from about $4 million to $113 million (in 1972 dollars). The higher points are generally for completely new systems or extensions involving new right-of-way acquisition and construction. The New York City points are much higher than any of the other points and reflect the unusual difficulty of subway construction in New York and the fact that part of the route has four tracks. Two of the five lowest points are for extensions in freeway medians (the Eisenhower and Dan Ryan freeway lines in Chicago). The other three low points are for upgraded existing rail lines (the Cleveland initial system and airport extension and the Lindenwold Line). Completely new systems are indicated by double circles (Toronto Yonge St. Line, which was the first part of the Toronto system; Montreal initial system; Mexico City; San Francisco; Washington; Baltimore; and Atlanta).

Any projection based on the data of Figure 6 will obviously be crude because the data points available involve three countries and each city's system involves different land prices, soil conditions, and system characteristics. With these caveats, we have projected a trend line for new system capital costs (other than cars) passing through the points for Atlanta and Toronto (Yonge Street). This trend line is representative of the cost of completely new systems (indicated by double circles). The resulting cost per route-mile in 1972 is $23.2 million and the annual cost increase is 1.09 percent in real terms.

3.3.4 Total Rail Transit Costs

Table 8 summarizes the costs per rail transit car-mile. The table shows costs for 1972 and projections for 1980 and 1990, all expressed in 1972 dollars. All cost elements are expected to increase in real terms; the increase in total costs is significant over this period of time.

3.4 PEAK-HOUR COST-ESTIMATING RELATIONSHIPS

The derivation of the cost-estimating relationships is presented in Section A.7 of Appendix A. They are summarized in Table 9

Table 8. TYPICAL COSTS PER RAIL TRANSIT CAR-MILE[a]
(1972 Dollars)

Cost	Annual Growth Rate (%)	Cost per Car-Mile (Dollars)		
		1972	1980	1990
Operating Costs	2.66	1.78	2.20	2.86
Capital Costs				
Cars	4.00	.89	1.21	1.80
ROW and Construction	1.09	5.11	5.58	6.21
TOTAL		7.78	8.99	10.87

a. Capital costs depend on car and track utilization.

and are used in the case studies reported in Chapter 5. The three types of service shown in Table 9 (residential collection and distribution, line-haul, and CBD distribution) comprise the elements of peak-hour commuter travel. Representative route speeds for each vehicle type in each operating environment are shown.

The theory of peak-load pricing was used to derive an allocation of vehicle capital costs between peak and base services (technical details are given in Appendix B), and differential labor cost estimates were constructed for peak and base services.

Note that in Table 9 the vehicle operating costs are divided into those elements primarily dependent on vehicle-hours, and those primarily dependent on vehicle-miles. This allocation of costs permits one to ascertain the effect of operating speed on cost per vehicle-mile.

In the case of the exclusive busway and rail rapid transit systems, the entire roadway (or track) cost was included in the system cost. In the case of rubber-tired vehicles operating on congested streets with other traffic, a portion of road operating and capital costs have been allocated to public transportation vehicles.

One can argue that residential streets are needed for other purposes, regardless of public transit service. Residential streets are, in general, not made more expensive due to their use by public transit vehicles. Further, they are generally uncongested so that public transit vehicles do not impose significant delay costs on other vehicles. For these reasons, it is felt that the capital costs of residential streets should not be allocated to public transit vehicles.

All capital costs include an interest charge of 10 percent. A greater proportion of vehicle and way and structures capital costs is allocated to peak-hour than to base-hour service.

The cost elements of Table 9 are used to calculate typical costs per vehicle-mile in Table 10. For example, the cost per mile for the bus operating on the exclusive busway is calculated as shown below.

> At a speed of 45 mph, the vehicle hourly costs (from Table 9) are converted to mileage costs as follows:

Driver:	\$7.27 ÷ 45 = \$.16 per mile
Other hourly costs:	\$1.78 ÷ 45 = \$.04 per mile
Vehicle capital cost:	\$5.79 ÷ 45 = \$.13 per mile

> Vehicle mileage costs are:

Vehicle operating costs	\$.30 per mile
Miscellaneous capital costs	\$.01 per mile

> Busway cost per route-mile-hour = \$275. Assuming 100 buses in each direction per hour, the cost per bus-mile of the busway is
>
> \$275 ÷ 200 = \$1.38 per mile
>
> The total of the above figures = \$2.02 per mile.

The final column of Table 10 shows that the cost per vehicle-mile for the rail transit system is much higher than for the 50-passenger bus systems. Even after accounting for the rail car's

Table 9. SUPPLIER COST RELATIONSHIPS
(1980 Costs in 1972 Dollars)

Type of Service	Type of Way	Vehicle Characteristics and Costs									Miscellaneous Capital Costs	Total Vehicle and Miscellaneous Costs		Way and Structures Costs				
		Vehicle Type	Capacity (Seats)	Speed (mph)	Utilization (hr/year)	Vehicle Operating Costs				Vehicle Capital Cost ($/hr)				Way Cost Basis	Road O&M	Road ROW	Construction	Total (Dollars)
						Driver ($/hr)	Other-Hr Basis ($/hr)	Mileage Basis ($/mi)	Total ($/mi)		($/vehicle-mile)	($/mile)	($/seat-mile)					
Residential Collection and Distribution (Peak Hour)	Residential Streets	Jitney	5	20	1000[a]	3.10	-	.134	.289	.558	0[g]	.317	.063	Vehicle-Mile				0[f]
		Bus-Wagon	8	19	1000[a]	3.10	-	.141	.304	.781	0[g]	.345	.043	Vehicle-Mile				0[f]
		Minibus	19	17	1000[b]	7.07		.247	.663	2.15	.014	.803	.042	Vehicle-Mile				0[f]
		Conventional Bus	50	15	1000[b]	7.27	1.78	.304	.907	4.64	.021	1.24	.025	Vehicle-Mile				0[f]
		Expressway Bus	50	15	1000[c]	7.27	1.78	.304	.907	5.79	.013	1.31	.026	Vehicle-Mile				0[f]
Line Haul (Peak Hour)	Arterial Streets	Conventional Express Bus	50	20	1000[b]	7.27	1.78	.304	.757	4.64	.021	1.01	.020	Vehicle-Mile	.001[i]	.071[i]	.104[i]	.176[i]
	Exclusive Busway	Expressway Bus	50	45	1000[c]	7.27	1.78	.304	.505	5.79	.013	.647	.013	Route-Mile-Hr	2	70	203	275
	Rail Rapid Transit	Rail Rapid Transit	79	35	1000[d]	3.64[e]	-	1.87	1.97	37.80	0[g]	3.05	.039	Route-Mile-Hr	-[h]	-	-	1,785
CBD Distribution and Collection (Peak Hour)	CBD Street	Conventional Bus	50	9	1000[b]	7.27	1.78	.304	1.310	4.64	.021	1.85	.037	Vehicle-Mile	.006[j]	.352[j]	.520[j]	.878[j]
	CBD Street	Expressway Bus	50	9	1000[c]	7.27	1.78	.304	1.310	5.69	.013	1.96	.039	Vehicle-Mile	.006[j]	.352[j]	.520[j]	.878[j]
	Rail Rapid Transit	Rail Rapid Transit	79	18	1000[d]	3.64[e]	-	1.87	2.07	37.80	0[g]	4.17	.053	Route-Mile-Hr	-[h]	-	-	1,785

a. Jitney utilization in all services 40,000 miles per year (2,000 hours per year).
b. Conventional bus utilization 29,400 miles per year in all services.
c. Integrated bus utilization 48,900 miles per year in all services.
d. Rail car utilization 48,900 miles per year in all services.
e. Assumes two-car train. For ten-car train, driver cost would be $.73 per car-hour.
f. Way costs assumed included via fuel taxes in vehicle operating costs.
g. Miscellaneous capital charges included in other costs.
h. Rail way and structure O&M included in vehicle operating costs.
i. For closed-door express service, bus uses road capacity of 2 automobiles.
j. For CBD distribution, bus uses road capacity of 10 automobiles.

Table 10. SUPPLIER COST SUMMARY
(1980 Costs in 1972 Dollars)

Type of Service	Type of Way	Vehicle Characteristics and Costs					Way and Structures Costs					Total Vehicle, Miscellaneous, and Way and Structures Cost ($/vehicle-mile)
		Vehicle Type	Capacity (Seats)	Speed (mph)	Utilization (hr/year)	Total Vehicle and Miscellaneous Costs ($/vehicle-mile)	Way Cost Basis	Road O&M	Road ROW	Construction	Total	
Residential Collection and Distribution (Peak Hour)	Residential Streets	Jitney	5	20	1000[a]	.317	Vehicle-Mile				0[e]	.317
		Bus-Wagon	8	19	1000[a]	.345						.345
		Minibus	19	17	1000[b]	.803						.803
		Conventional Bus	50	15	1000[b]	1.24						1.24
		Expressway Bus	50	15	1000[c]	1.31						1.31
Line Haul (Peak Hour)	Arterial Streets	Conventional Express Bus	50	20	1000[b]	1.01	Vehicle-Mile	.001	.071	.104	.176	1.19
	Exclusive Busway	Expressway Bus	50	45	1000[c]	.647	Route-Mile-Hour	2	70	203	275	2.02[g]
	Rail Rapid Transit	Rail Rapid Transit	79	35	1000[d]	3.05	Route-Mile-Hour	-[f]	-	-	1,785	11.97[h]
CBD Distribution and Collection (Peak Hour)	CBD Street	Conventional Bus	50	9	1000[b]	1.85	Vehicle-Mile	.006	.352	.520	.878	2.73
	CBD Street	Expressway Bus	50	9	1000[c]	1.96	Vehicle-Mile	.006	.352	.520	.878	2.84
	Rail Rapid Transit	Rail Rapid Transit	79	18	1000[d]	4.17	Route-Mile-Hour	-[f]	-	-	1,785	13.09[h]

a. Jitney utilization in all services 40,000 miles (2,000 hours) per year.
b. Conventional bus utilization 29,400 miles per year in all services.
c. Integrated bus utilization 48,900 miles per year in all services.
d. Rail car utilization 48,900 miles per year in all services.
e. Way costs assumed included via fuel taxes in vehicle operating costs.
f. Rail way and structure O&M included in vehicle operating costs.
g. Based on 100 buses in each direction per hour.
h. Based on 100 cars in each direction per hour.

higher seating capacity, its cost per seat-mile is still much higher than for the large bus systems. The high rail transit costs are due primarily to high capital costs.

4. TIME VALUE, POLLUTANT EMISSIONS, FUEL CONSUMPTION, AND CONGESTION COSTS

4.1 INTRODUCTION

This chapter presents quantitative information on three aspects often overlooked when comparing alternative urban transportation systems: (1) value of time spent traveling, (2) emissions of various pollutants and fuel consumption by alternative systems, and (3) congestion costs imposed by buses operating in mixed traffic.

Time valuation forms a key component of our full-cost comparison of alternatives. Some findings in the literature are summarized to ascertain the relation between travel time value and hourly earnings, and among in-vehicle, walking, and waiting time.

Dollar values on pollutant emissions are not yet available. We compare carbon monoxide, oxides of nitrogen, and hydrocarbon emissions for major alternatives, expressed as pounds per vehicle-mile and per passenger. Unfortunately, better economic information is needed to rank systems on the basis of emissions, as neither of the major alternative commuter systems was lowest on all three major pollutants.

Congestion costs were computed using information from [12], the Highway Capacity Manual, which allows bus-miles to be converted into equivalent auto-miles. The congestion cost per auto-mile is substantial, especially in peak hours, and the congestion cost per bus-mile depends crucially on the type of service--local or express.

4.2 TRAVEL TIME VALUE

4.2.1 The Recent Literature

The literature on time valuation and transportation is voluminous. Haney [13, pp. 18-19] lists 47 studies, up to 1961, in the transportation literature which used a value of time. Perhaps 15 of these studies derived a value of time using a methodology based on consumer behavior. Nelson [14] summarizes and criticizes some of the literature on time value. Boyd and Walton [15] summarize several estimates of travel time value for contemporary intercity travel. Research into the value travelers place on travel time has occupied many transportation specialists, because savings in travel time usually is one of the largest benefits of an investment in new or improved highways or other transportation facilities. In the language of this study, time costs are a significant part of the full costs of travel.

To have empirical validity, a numerical dollar value of travel time must be based on observations of travelers' behavior. Travelers often have choices between alternatives offering different combinations of time and money costs. Transit versus private automobile, toll versus free roads, and train versus airplane are examples of such choices. Statistical techniques including probit, logit, and discriminant analysis have been used to explain modal choice of individual travelers on the basis of money cost differences and time cost differences (among other factors) between alternative modes. Time valuation is inferred by the relative weights found for cost and time differences, which establishes a rate of exchange between dollars and hours. Explanations of these statistical techniques and their application to modal choice and travel time valuation are given in Warner [16], Lisco [17], and Quarmby [18].

Recent research into the valuation of urban commuters' travel time has shed light on two issues relevant to this study: (1) the relation of travel time value to the traveler's wage rate or average hourly earnings, and (2) the relation between the value of in-vehicle travel time and the value of walking and waiting time. There is no reliable information on the value travelers place on "comfort" or on the relation of the value of travel time to total time of the journey. Nevertheless, there is some evidence that comfort and total time may be important influences on travel time valuation.

4.2.2 Time Value and Hourly Earnings

There is substantial evidence that basic in-vehicle-time value is less than the traveler's wage rate. An early study by Beesley [19], using a crude comparison of money and time differences, found average time valuation about one-third average hourly wage for his sample. A large-scale study by Quarmby [18, pp. 296-297] replicated Beesley's result when only money and time differences were considered. Consideration of other variables such as walking and waiting time and whether the car was used for work resulted in an average in-vehicle travel time value of 20 to 25 percent of average wage rate. Stratified estimates showed this proportion to be roughly constant across income. Lave [20] incorporated a factor of proportionality between time value and hourly wage directly into his estimating relationship. Using this methodology, he found in-vehicle time valuation equal to 42 percent of hourly wage. Thomas and Thompson [21] found that in-vehicle time value increases $.40 per hour for every $1.00 per hour of hourly wage.

4.2.3 In-Vehicle, Walking, and Waiting Time

There is also some evidence that out-of-vehicle time is valued at a higher rate than in-vehicle time. Lisco found walking time values on the order of $7.20 per hour, based on the decline of parking lot charges with distance from the Chicago Loop. This compares with his estimate of about $2.60 for in-vehicle time, implying walking time valuation 2.8 times in-vehicle. Quarmby [18, p. 297] concludes that "walking and waiting time are worth between two and three times in-vehicle times." These findings are also consistent with other work [22] as quoted in [18, p. 292].

4.2.4 Other Factors Affecting Time Value

Travelers are apparently willing to pay a premium for the comfort of private auto over transit, even when money and time costs are equal (taking account also of the different weighting for in-vehicle time and walking and waiting time). There is, as yet, no empirical evidence on the relationship of this premium to transit or auto attributes. We conjecture that the crowding characteristic of conventional peak-hour transit may explain much of this premium, since the differential attributable to walking and waiting time has already been explicitly accounted for. We have assumed no standees in the comparisons in Chapter 5, a much higher level of comfort than is characteristic of conventional transit. This may remove some or all of the comfort premium valuation of auto over transit. We know of no evidence that passengers value other attributes which might be peculiar to one transit mode such as rail, bus, or taxi.

It may be that average travel time valuation is not independent of total time spent on the trip, as we have assumed. We know of no evidence on this point as it applies to urban travel. A study by IDA [23] found that transatlantic air passengers valued time at a higher proportion of their incomes than domestic passengers. This was determined on the basis of passenger willingness to pay jet surcharges. Thomas and Thompson [21 and 24] found nonlinearities in the value of travel time but they considered time value as a function of the difference in time between the two alternatives, rather than as a function of the total time. (There are also statistical grounds for suspicion of their estimates, as pointed out in the "Discussion" by Lisco of the Thomas and Thompson findings.)

4.2.5 Time Values for Full Cost Comparisons

The consensus of the studies discussed under Section 4.2.2 indicates an in-vehicle-time value of approximately 40 percent of the traveler's wage rate. Further, the studies discussed in Section 4.2.3 indicated that walking and waiting time are valued at approximately two and one-half times in-vehicle time. Hence, the value of walking and waiting time would be approximately equal to the traveler's wage rate.

We have computed the full cost of the alternatives (Chapter 5) using two sets of time values. The "low" set of time values is \$3.00 per hour for walking and waiting time and \$1.20 per hour (40 percent) for in-vehicle time. The "high" set of time values is \$7.50 and \$3.00, respectively. The "low" time value corresponds to a 1980 annual income of \$6,000 (2000 hours times \$3.00), and the "high" value to \$15,000, expressed in 1972 dollars. Real per-capita GNP rose 2.06 percent per year between 1950 and 1971. Assuming the same constant growth rate, the corresponding annual incomes in 1972 would be \$5,080 and \$12,710 (\$2.55 and \$6.40 walking and waiting-time values; \$1.00 and \$2.55 in-vehicle-time values in 1972).

These assumptions probably encompass the range of average time values likely to be encountered by transit lines. The "low" time value would represent a line in a very low-income area, with riders willing to incur extra time costs to economize on money expenditure. The "high" time value would represent a line in an affluent area, whose clientele would be willing to pay extra fare to save travel time. If the choice between alternatives is sensitive to the assumption about travel time valuation, calculations using both time values should highlight this sensitivity. As it happens, the choice among the basic alternatives we compare is not much affected by time valuation, although some of the design characteristics, such as frequency and route spacing, do depend on time value.

4.3 POLLUTANT EMISSIONS AND FUEL CONSUMPTION

There are, as yet, no satisfactory measures of the costs of pollution. That is to say, we know little of people's willingness to pay for different levels of environmental quality. It is precisely this degradation of environmental quality that is the cost of the emissions from transportation and other sources. Nonetheless, quantitative information of a physical nature can be useful in at least two instances:

- If the quantities of pollutants per passenger are the same or reasonably "close" for two alternatives, then the choice between them on the basis of full cost (user time costs plus supplier costs) can be made with greater confidence.
- If the full costs are equal or close, then substantial differences in emissions may be the deciding factor in the choice.

If full costs and pollutant emissions point to different transportation systems, further research is needed to establish dollar valuations for emissions before a choice can be indicated.

Fuel costs are, of course, included as part of the operating costs under supplier costs. It may, nevertheless, be useful to know something about the fuel consumption of the various alternatives, and in any event, fuel consumption is necessary to estimate pollutant emissions. Therefore, we have also included fuel consumption information.

4.3.1 Fuel and Emissions Estimates by Vehicle Type

Table 11 summarizes the fuel consumption and pollutant characteristics for different types of vehicles. A recent publication by the U.S. Department of Transportation (DOT) [25] contains data on three types of pollutants produced by vehicles using fossil fuels: carbon monoxide (CO), oxides of nitrogen (NO_x), and hydrocarbons (HC). The derivation of fuel consumption and pollutant figures by vehicle type is explained below.

Jitney

The International Taxicab Association [26] indicates that taxicabs average 10.8 miles per gallon of gasoline, or .093 gallon per mile. It is assumed for our purposes that this figure would be typical of jitney operations also.

Table III-1 of the DOT publication shows emission factors for autos in pounds per vehicle-mile. Figures are given as a function of speed and model year. The 1975-1990 model-year category and the

Table 11. VEHICLE FUEL REQUIREMENTS AND POLLUTANTS

Vehicle	Type of Fuel	Fuel Consumption per Vehicle-Mile	Pounds of Pollutants per Vehicle-Mile		
			Carbon Monoxide (CO)	Oxides of Nitrogen (NO_x)	Hydro-carbons (HC)
Jitney (5-passenger)	Gasoline	.093 gallon	.018	.00096	.0020
Bus-Wagon (8-passenger)	Gasoline	.111 gallon	.022	.0012	.0024
Bus (19-passenger)	Gasoline	.154 gallon	.030	.0016	.0033
Bus (50-passenger)					
Mixed traffic	Diesel Fuel	.226 gallon	.0088	.0231	.00094
Exclusive busway	Diesel Fuel	.157 gallon	.0061	.0161	.00065
Rail car	Coal	4.08 pounds	.001	.041	.00041
	Natural Gas	53 cubic feet	Negligible	.021	Negligible
	Heating Oil	.38 gallon	.000015	.039	.0012

12.5 to 15 mph speed were selected as being most relevant for future jitney operations. Table III-3 of that same publication gives factors to correct emission levels for vehicle age and indicates that vehicles three years old emit about 20 percent more pollutants than new vehicles. Hence, the figures of Table III-1 that apply to new vehicles were increased by 20 percent to correct for the average age of jitneys in service. The pounds of pollutants per jitney-mile derived from these tables are

CO .015 x 1.2 = .018 pound per vehicle-mile
NO_x .0008 x 1.2 = .00096 pound per vehicle-mile
HC .0017 x 1.2 = .0020 pound per vehicle-mile.

Bus-Wagons

Bus-wagons are approximately 20 percent heavier and more powerful than 5-passenger automobiles. It is assumed that the fuel consumption will be about 20 percent greater: 1.2 times .093 or .111 gallon per mile.

It is also assumed that the pounds of pollutants emitted per bus-wagon-mile will be about 20 percent greater than for 5-passenger automobiles, or,

CO .018 x 1.2 = .022 pound per vehicle-mile
NO_x .00096 x 1.2 = .0012 pound per vehicle-mile
HC .0020 x 1.2 = .0024 pound per vehicle-mile.

Minibus (19-Passenger)

Except for Mercedes, which accounts for about one percent of the total inventory [27], all minibuses in the United States are gasoline-powered. Figures released by the Flxible Co., [28] indicate that the gasoline-powered type averages about 6.5 miles per gallon or .154 gallon per mile.

Since both the minibus and jitney are gasoline-powered, the pollutants emitted by the minibus are assumed to be greater than those of the jitney by the ratio of their respective fuel consumptions:

$$\text{CO} \quad .018 \times \frac{.154}{.093} = .030 \text{ pound per vehicle-mile}$$

$$\text{NO}_x \quad .00096 \times \frac{.154}{.093} = .0016 \text{ pound per vehicle-mile}$$

$$\text{HC} \quad .0020 \times \frac{.154}{.093} = .0033 \text{ pound per vehicle-mile.}$$

50-Passenger Bus

Conventional Operation in Mixed Traffic. Fifty-passenger buses are almost always diesel-powered. In conventional urban bus service in mixed traffic, this type of bus averages 4.4 miles per gallon of diesel fuel, or .226 gallon per mile [8].

Page III-27 of the DOT publication [25] presents the following pollution rates for "controlled" diesel engines with which most buses manufactured in the future will be equipped:

CO .0088 pound per vehicle-mile
NO_x .0231* pound per vehicle-mile
HC .00094* pound per vehicle-mile.

Exclusive Busway Operation. Figures available from the Interstate Commerce Commission [29, pp. 102 and 110] give the diesel fuel expense and corresponding bus-miles for Class I carriers of passengers engaged in intercity service. The average diesel fuel cost is $.124 per gallon [8]. These figures indicate an average of 6.4 miles per gallon of diesel fuel or .157 gallon per mile for buses in intercity service. This figure of .157 should be representative of buses operating on exclusive busways also.

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* NO_x and HC figures were interchanged in reference [25].

It is assumed that the pollutants emitted by the bus in exclusive busway operation will be less than those of the bus in conventional operation in mixed traffic by the ratio of their respective fuel consumptions:

$$\text{CO} \quad .0088 \times \frac{.157}{.226} = .0061 \text{ pound per vehicle-mile}$$

$$\text{NO}_x \quad .0231 \times \frac{.157}{.226} = .0161 \text{ pound per vehicle-mile}$$

$$\text{HC} \quad .00094 \times \frac{.157}{.226} = .00065 \text{ pound per vehicle-mile.}$$

Rail Transit

Energy for the operation of rail transit systems is supplied by generating stations using either fossil fuel, nuclear fuel, or water power as a primary energy source. In this study, only fossil fuel energy sources are considered, since they can be compared more directly with the fuels used by rubber-tired vehicles. There are three types of fossil fuel used: coal, natural gas, and oil. Data on rail transit fuel requirements are presented in [25, pp. III-29 through III-31]. Generating plants require an average of 10,000 BTUs to produce a kilowatt-hour of electricity, and the average power consumption of rail transit cars is 5.3 kilowatt-hours per car-mile. Hence, 53,000 BTUs per car-mile are required. Based on these figures, the fuel requirements for the three types of fossil fuel are as follows:

- Coal contains 26 million BTUs per ton. Hence, coal consumption per car-mile is 4.08 pounds or .00204 ton per car-mile.
- Natural gas contains 1000 BTUs per cubic foot. Hence, natural gas consumption is 53 cubic feet per car-mile or .053 thousand cubic foot per car-mile.
- Oil contains 140,000 BTUs per gallon. Hence, oil consumption is .38 gallon per car-mile.

The rail car pollutants listed in Table 11 for each of the three types of fossil fuel are taken directly from the DOT publication [25, Table III-5]. In many cases, the pollution resulting from electrical power generation occurs in locations other than where the transit system operates and is thus less objectionable to the population served by the transit system than comparable pollution produced directly by transit vehicles themselves.

4.3.2 Fuel Consumption and Emissions Per Seat-Mile and Per Passenger

Table 12 displays fuel consumption and emissions per seat-mile, calculated from the Table 11 figures. In residential collection service, fuel consumption and CO and HC emissions are smaller per seat-mile in larger vehicles, while NO_x emissions are higher for the diesel-powered bus. In line-haul service, buses operating in mixed traffic on arterial streets have higher fuel consumption and emissions in all categories than buses operating on exclusive busways. Compared to bus, rail has slightly higher oil consumption per seat-mile, much lower CO, and about the same NO_x and HC per seat-mile, whether on the line-haul or CBD distribution parts of the journey.

Table 13 compares fuel consumption and emissions per passenger-trip for integrated bus on exclusive busway versus rail rapid transit with bus-wagon feeder. The exclusive busway is the cheapest full-cost integrated bus option for larger volumes, while the bus-wagon is the most economical feeder vehicle to rail rapid transit for nearly all time values and passenger densities considered. The minimum feasible full-cost service frequency almost always resulted in the vehicles operating at capacity, greatly simplifying the calculations of pollutants per passenger trip (see Chapter 5 for details). We have assumed a 10-mile line-haul route with a 3-mile feeder in Table 13.

It is difficult to compare the fuel consumption of the two systems because different types of fuel are used. However, a rough comparison can be obtained by comparing the gallons of diesel fuel used by the integrated bus with the combined sum of the gallons of

Table 12. FUEL CONSUMPTION AND POLLUTANT EMISSIONS PER SEAT-MILE

Part of Trip	Type of Fuel	Fuel Consumption per Seat-Mile	Pollutants Emitted (One-Thousandth Pound Per Seat-Mile)		
			Carbon Monoxide (CO)	Oxides of Nitrogen (NO_x)	Hydrocarbons (HC)
Residential Collection					
Jitney (5-passenger)	Gasoline	.019 gallon	3.600	.192	.400
Bus-Wagon (8-passenger)	Gasoline	.014 gallon	2.750	.150	.300
Minibus (19-passenger)	Gasoline	.0081 gallon	1.579	.084	.174
Bus (50-passenger)	Diesel Fuel	.0045 gallon	.176	.462	.019
Line Haul					
Bus on arterial street, mixed traffic (50-passenger)	(Same as residential collection)				
Bus on exclusive busway (50-passenger)	Diesel Fuel	.0031 gallon	.122	.322	.013
Rail (79-passenger)	Coal	.052 pound	.013	.519	.0052
	Natural Gas	.67 cubic foot	Negligible	.266	Negligible
	Heating Oil	.0048 gallon	Negligible	.494	.015
CBD Distribution					
Bus	(Same as residential collection)				
Rail	(Same as line haul)				

Table 13. COMPARISON OF FUEL CONSUMPTION AND EMISSIONS INTEGRATED BUS VERSUS RAIL RAPID TRANSIT WITH BUS-WAGON RESIDENTIAL COLLECTION

Part of Trip	Type of Fuel	Fuel Consumption Per Passenger	Pollutants Emitted (One-Thousandth Pound Per Passenger)		
			CO	NO_x	HC
INTEGRATED BUS, EXCLUSIVE BUSWAY					
Residential Collection	Diesel Fuel	0.0288 gallon	1.126	2.957	0.122
Line Haul	Diesel Fuel	0.031 gallon	1.220	3.220	0.130
CBD	Diesel Fuel	0.0045 gallon	0.176	0.462	0.019
TOTAL	Diesel Fuel	0.064 gallon	2.52	6.64	0.27
BUS-WAGON PLUS RAIL					
Residential Collection	Gasoline	0.091 gallon	17.880	0.975	1.950
Line Haul and CBD	Coal	1.090 pounds	0.273	10.899	0.109
	Natural Gas	14.1 cubic feet	Negligible	5.586	Negligible
	Heating Oil	0.101 gallon	Negligible	10.374	0.315
TOTAL	Gasoline and Coal	0.091 gallon 1.090 pounds	18.15	11.87	2.06
	Gasoline and Natural Gas	0.091 gallon 14.1 cubic feet	17.88	6.56	1.95
	Gasoline and Heating Oil	0.192 gallon	17.38	11.35	2.27

ASSUMTIONS:

1. All seats filled.
2. Assumes 3-mile residential collection, 10-mile line-haul route.
3. Two feeder route configuration, D_f = 6.4 vehicle-miles per trip.
4. Four feeder route configuration, D_f = 6.5 vehicle-miles per trip.
5. Average line-haul distances are 10 miles for bus (5 inbound plus 5 outbound) and 20 miles for rail (10 inbound plus 10 outbound).
6. Bus and rail CBD distances are 1 vehicle-mile per trip.

gasoline used by the bus-wagon and the heating oil used by rail transit. The total gallons used by the bus-wagon and rail transit are three times the number used by the integrated bus. This ratio applies to both the residential collection and the line-haul and CBD portions of the trip.

For the total trip, all three emissions are higher for the bus-wagon/rail alternative: seven times as high for CO, almost twice as high for NO_x, and eight times as high for HC. The bulk of the CO and HC comes from the bus-wagon feeder, while most of the NO_x comes from electrical generating plants for the rail system. The fuel used for electric generation hardly affects the comparison between the alternatives. These figures by themselves indicate that the integrated bus is clearly superior on pollution grounds to the bus-wagon/rail alternative. However, it would be possible to eliminate the CO and HC disadvantage of the bus-wagon by substitution of a diesel-powered residential collector. If a 50-passenger diesel bus is used as a residential collector for the rail system, the pollutants emitted during residential collection would be approximately the same as in the integrated bus case. For the complete commuter trip using the 50-passenger bus plus rail, total CO emissions would be about one-half, NO_x emissions about double, and HC emissions about the same as those for the integrated bus. Further, if the electric generating plant is remotely located from populated areas, the higher level of NO_x production associated with rail transit might not be any worse than that produced by integrated bus, insofar as the effect on population is concerned.

4.4 CONGESTION COSTS OF OPERATING TRANSIT VEHICLES IN MIXED TRAFFIC

The costs of street and road capacity and an allocation to transit vehicles operating in mixed traffic were derived in Chapter 3 and Appendixes A and B. In this chapter, we present estimates of the short-run congestion costs of using the capacity of streets and roads for transit services. Details of the calculations are presented in Appendix C. The congestion cost of adding a transit vehicle to the traffic stream is the cost of delays caused to the other vehicles on the road. Equivalently, the congestion cost of capacity used by any vehicle in the stream is the savings in time and operating costs that will be enjoyed by the other vehicles if the vehicle in question is removed from the stream. Thus, adding a vehicle lowers average speed of the other vehicles, imposing a cost on them. It is this cost which we wish to estimate with respect to the delay caused by transit vehicles on other vehicles using the roads.

The method of analysis involves the following steps:

1. A typical traffic flow (vehicles per hour) and corresponding speed is selected.
2. A bus is added to this traffic flow.
3. The reduction in traffic speed due to the introduction of the bus is estimated.
4. The cost of this reduction in speed is estimated from the increased travel time imposed on the initial traffic flow and a cost per vehicle-hour.
5. The cost of (4) above is the "congestion cost" due to the introduction of the bus; it is related to bus mileage and expressed in dollars per bus-mile.

In order to make these calculations, it is first necessary to estimate the amount of street capacity used by buses relative to autos (the "auto equivalency factor for buses).

The Highway Capacity Manual, [12], describes three different situations for conventional buses, depending on their utilization of street capacity relative to private automobiles:

1. Buses operating nonstop on expressways and freeways, which we shall call expressway buses.
2. Through buses operating in express service without passenger stops on streets in mixed traffic.
3. Local transit buses operating on streets in mixed traffic and stopping to pick up and discharge passengers.

Expressway buses use capacity equivalent to 1.6 automobiles. This applies both to mixed traffic and exclusive busway operations [12, pp. 342-345].

Auto equivalency factors for through buses (and trucks, which have the same effect on traffic flow) depend on the proportion of trucks and through buses to total traffic, including autos, and the ratio of actual traffic flow to street capacity.

For representative peak-hour mixtures of through buses and auto traffic on urban arterial streets, the auto equivalency of a through bus ranges from 1.9 to 2.2. We have used an auto equivalency factor of 2.0 autos per through bus for all computations in this chapter and in Chapter 3.

The auto equivalency factor of local transit buses is more complicated. It depends on the following factors:

1. The proportion of trucks and through buses to total traffic, including autos.
2. The ratio of actual traffic flow to street capacity.
3. Location within the city (CBD versus fringe and outlying).
4. One- or two-way street.
5. Parking conditions on street.
6. Number and width of lanes.
7. Location and spacing of bus stops (near-side, far-side, every block, every other block, etc.).
8. Percent green time of stop lights in direction of flow.

Depending on the above factors, auto equivalency factors for local transit buses can vary from about two to ten.

Table 14 presents the results of our computations of bus costs, based on the auto equivalencies discussed above. We have assumed two types of street, an arterial street with long green light times, and a CBD street with roughly equal green and red times. For base services, local buses on an arterial street cause congestion costs of \$.39 per bus-mile while express buses cost only \$.14 per mile. The differential widens in the peak to \$2.90 versus \$.58. In the CBD, base-hour costs are \$.28 per bus-mile and peak-hour costs are \$1.74.

These costs are two to three times the costs obtained in Chapter 3, which were derived by allocating road capital costs to the using vehicles. The \$.58 arterial street cost and the \$1.74 CBD street cost of Table 14 compare to Chapter 3 costs of \$.18 and \$.88, respectively. The costs of Chapter 3 are used in the commuter

Table 14. CONGESTION COSTS OF STREETS USED BY BUSES IN MIXED TRAFFIC (Dollars per Bus-Mile)

Conditions	Local Bus			Through Bus (Express)	
	Auto Cost per Mile (Dollars)	Auto Equivalents per Bus	Bus Cost per Mile (Dollars)	Auto Equivalents per Bus	Bus Cost per Mile (Dollars)
Arterial Street					
(G = .80, L = 3)					
Base-Hour (R = .5)	.07	5.5	.39	2	.14
Peak-Hour (R = .9)	.29	10	2.90	2	.58
CBD Street					
(G = .55, L = 3)					
Base-Hour (R = .5)	.07	4	.28		
Peak-Hour (R = .9)	.29	6	1.74		

G = proportion of green light time
L = lanes in each direction
R = volume/capacity ratio

travel case study of Chapter 5 because it is felt that they are more representative of the true costs of road usage by buses. The ranking of rail and bus alternatives is not affected by the choice between the two methods of computing roadway costs for buses in mixed traffic.

Present auto road-user charges, consisting primarily of gasoline taxes, are less than $.015 per mile. This is far below the real cost of using the road in both peak ($.29) and base ($.07) periods. It is even lower than the $.088 figure for peak capacity which results from the costing of Chapter 3 (this figure is obtained from the bus cost of $.88 times the auto to bus equivalency factor of 1/10 used in Chapter 3). Clearly, peak-hour private auto travel is heavily subsidized. Charges sufficient to cover the true costs of auto travel in urban areas would surely cause a major restructuring of travel behavior and urban form.

Present transit operations pay low, if any, street user fees. Table 14 suggests that conventional local services operating along arterial streets into the CBD receive a substantial implicit subsidy in that they do not pay for the congestion costs of street capacity. There is even a substantial subsidy on the basis of allocated costs of Chapter 3. A greater emphasis on express services (not to mention exclusive busways) would not only reduce user time costs and some supplier costs (due to higher speeds and lower hourly costs per mile), but would economize as well on the use of scarce urban peak-hour street capacity.

5. ANALYSIS OF PEAK-HOUR COMMUTING, SUBURB AND OUTER CITY TO DOWNTOWN

5.1 INTRODUCTION

The supplier cost-estimating relationships and time values derived in Chapters 3 and 4 form the basis for a full-cost evaluation of alternative transit systems. In the following analysis, rail and bus systems are compared for peak-hour commuting service to the CBD. The comparisons are made for projected 1980 cost conditions, expressed in 1972 dollars.

First, a full-cost model for residential collection and distribution is presented, and costs for the four rubber-tired vehicles (jitney, bus-wagon, minibus, and conventional bus) are presented. Next, a rail transit system in a corridor is modeled and full costs are computed. The sum of collection costs (by the least-cost rubber-tired vehicle) and rail transit costs for the line-haul and CBD distribution are the costs of this major alternative.

Costs are then computed for two integrated bus systems, one in which the line-haul portion is operated on conventional streets, and the other in which it is operated on an exclusive busway. In both cases, a single vehicle performs the residential, line-haul and CBD phases of the journey. The costs of the residential-collection phase are computed for the same conditions as for the rail alternative. The line-haul portion of the model assumes express service on both conventional streets and exclusive busways. CBD distribution is via surface streets in mixed traffic.

The final section of this chapter compares full costs of the rail and bus systems. All computations are performed for "low" and "high" time values.

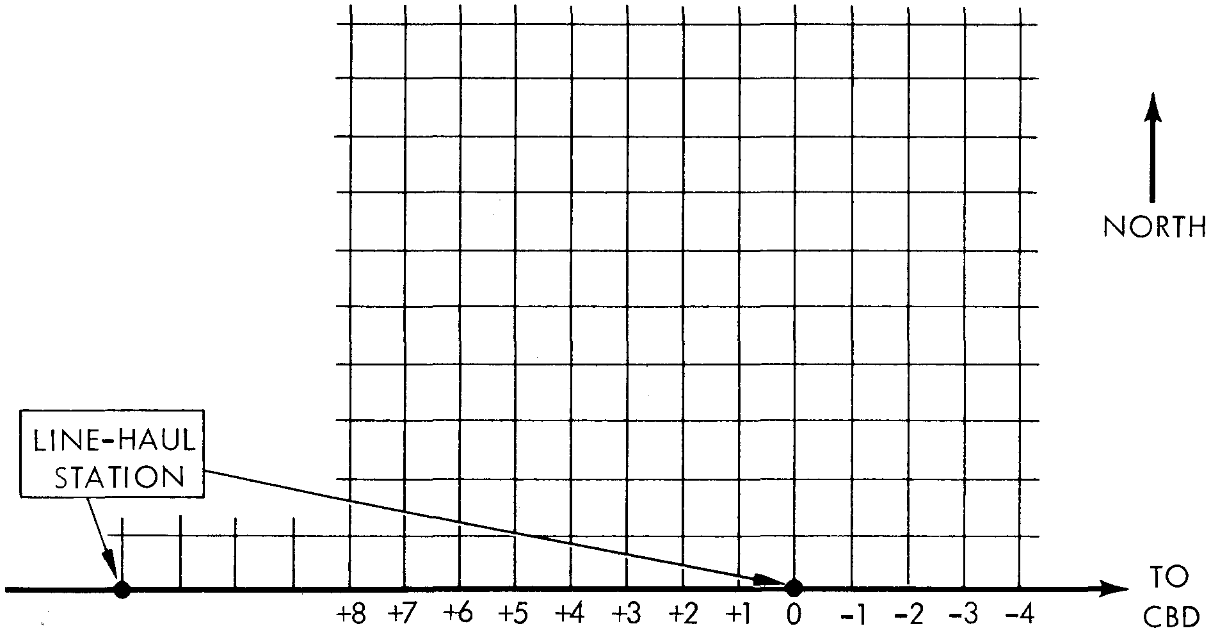
5.2 RESIDENTIAL COLLECTION AND DISTRIBUTION

Any line-haul facility, such as a rail rapid transit system, commuter railroad, or bus expressway, requires a feeder system of some sort to collect passengers from low- and medium-density residential areas. It would be far too expensive to build and operate a subway with a stop within walking distance of everyone's house or a bus expressway with an entrance near everyone's house.

5.2.1 Geometry of Residential Collection

Meyer, Kain, and Wohl [5] modelled bus and rail line-haul routes serving corridors, and having stations (or entrances, in the case of bus expressways) spaced one mile apart. Figure 7 describes such a model. In this model, it is assumed that there are 12 blocks to the mile. The line-haul route runs from west to east toward the central business district. Line-haul stations are located at the heavy dots. The streets are numbered -1 through -4 going toward the CBD and +1 through +7 going away from the CBD. This one-third--two-thirds service area split is roughly optimal if the feeder speed is one-third of the line-haul speed; for example, a feeder speed of 15 mph and a line-haul speed of 45 mph. The grid of streets is partially indicated north of the line-haul route, and a similar grid would, of course, be present south of the route. Feeder vehicles move along one of the perpendicular streets to the line-haul route, and then parallel the line-haul route to the station.

The asterisks in the bottom panel of Figure 7 indicate various combinations of perpendicular streets that might have line-haul service. For example, if there are six routes serving this line-haul station (from the north), spaced every two blocks, the asterisks indicate that line-haul service would be provided on a street zero (the street intersecting the main line at the station), streets -2 and -4 toward the CBD, and streets +2, +4, and +6 away from the CBD. A system of four routes would operate on street zero, street -3 toward the CBD, and streets +3 and +6 away from the CBD. For a two-route system, feeder vehicles would operate either on streets zero



NO. OF ROUTES	ROUTE SPACING (BLOCKS)	FEEDER STREETS								
6	2	*		*		*	*	*		*
4	3	*			*		*		*	
3	4			*			*			*
2	6	*					*			
2	5,7		*				*			

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Figure 7. RESIDENTIAL COLLECTION ROUTE SPACING

and +6 for six-block spacing, or on streets zero and +5 for five- and seven-block spacing. As shown below, the five- and seven-block spacing results in slightly lower access costs, as well as slightly lower parallel travel distance.

The model adopted by Meyer, Kain, and Wohl contemplated a circular service area around each feeder bus stop [5, p. 257]. This pattern of service does not minimize costs. Adding stations or stops along a residential collection (feeder) line is much cheaper than adding lines. For example, if one wishes to double the number of stops while holding frequency of service constant, doubling the number of lines with the same stop spacing would double the costs. However, doubling the number of stops along the line would increase supplier costs only slightly for the same frequency of service, as the vehicle would now take somewhat longer to make a round trip. Therefore, we assume that the feeder vehicle makes a stop at every cross-street. Figure 8 illustrates the service area for a feeder vehicle stop assuming both three- and four-block feeder-route spacing. The feeder vehicle operates along Arterial Street. The boundary of the service area of stop J is indicated by dashed lines. It is assumed that passengers are uniformly distributed along each

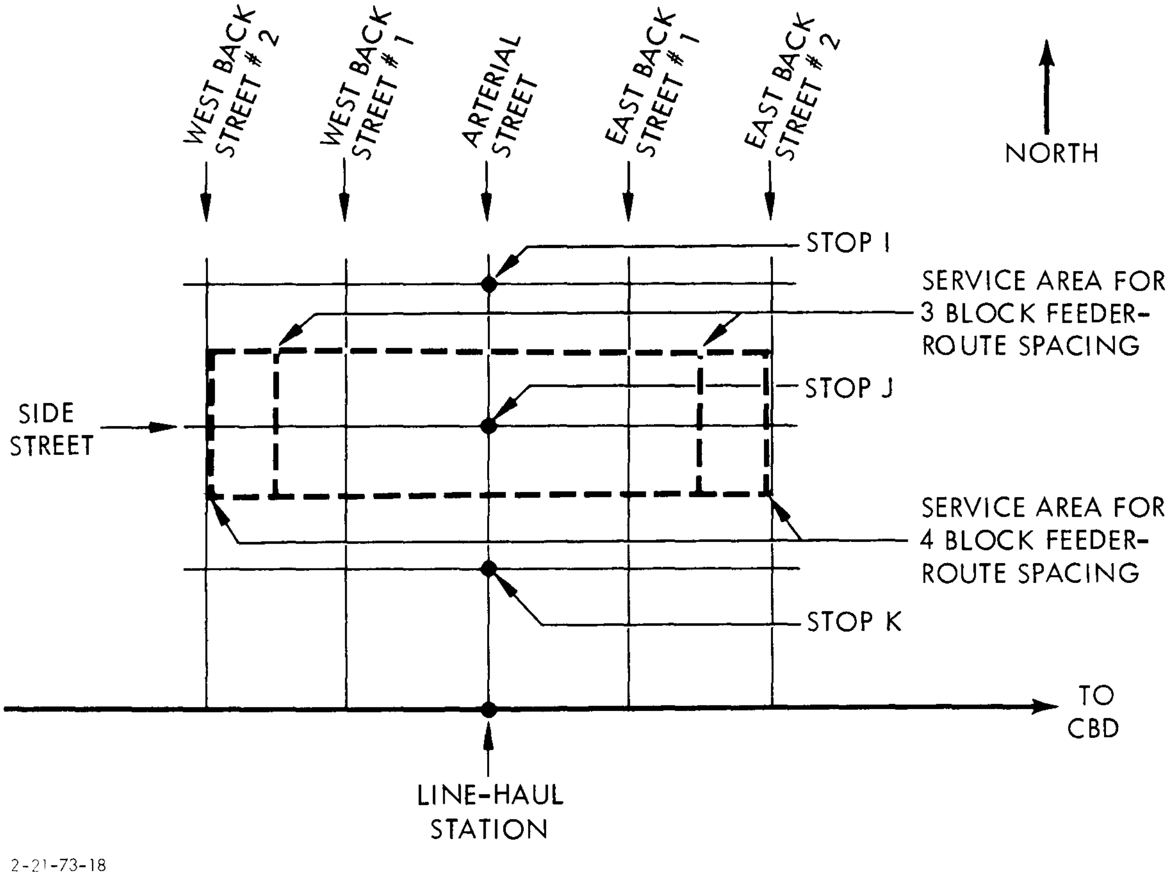

Figure 8. SERVICE AREA FOR FEEDER VEHICLE STOP

street, and that they walk along streets to get to the bus stop. Thus, with three-block feeder-route spacing, passengers walk a maximum east-west distance of one and one-half blocks; with four-block spacing, the maximum east-west distance is two blocks. In addition, passengers living along one of the north-south streets also walk a maximum north-south distance of one-half block.

The calculation of average access distance is illustrated in Table 15 for both three-block and four-block feeder-route spacing. Each linear block is assumed to generate ρ passengers. For persons living along the arterial street, access distance ranges from zero to one-half block, for an average distance of one-fourth block. There is one linear block involved, which generates ρ passengers,

Table 15. AVERAGE ACCESS DISTANCE CALCULATION THREE- AND FOUR-BLOCK FEEDER-ROUTE SPACING
(ρ Passengers Per Linear Block)

Street	Average Distance	Number of Blocks	Passengers	Passenger-Blocks
THREE-BLOCK ROUTE SPACING				
Arterial	¼	1	ρ	¼ρ
Side (1st blocks)	½	2	2ρ	ρ
Side (2nd blocks)	1¼	1	ρ	1¼ρ
Back	1¼	2	2ρ	2½ρ
			6ρ	5ρ
Average Distance = 5ρ/6ρ = .833 blocks				
FOUR-BLOCK ROUTE SPACING				
Arterial	¼	1	ρ	¼ρ
Side	1	4	4ρ	4ρ
Back 1	1¼	2	2ρ	2½ρ
Back 2	2¼	1	ρ	2¼ρ
			8ρ	9ρ
Average Distance = 9ρ/8ρ = 1.125 blocks				

and since the average distance is one-fourth block, there are a total of one-fourth ρ passenger-blocks walked by persons along Arterial Street. Similarly, for the first blocks of the side street (that is, the blocks stretching from Arterial Street to East Back Street 1 and West Back Street 1), the average distance is one-half block. Since there are two of these blocks, 2ρ passengers generate a total of ρ passenger-blocks of walking. Performing similar exercises for the second blocks of the side streets and the back street yields the other numbers in the top panel of Table 15. A total of six linear blocks in the service area of stop J generate a total of 6ρ passengers and 5ρ passenger-blocks. Dividing passenger-blocks by passengers, we find that average access distance is .833 block.

The calculation for the four-block spacing, also shown on Table 15, is similar. West Back Street 2 and East Back Street 2 now split their passengers between the feeder line running on Arterial Street and other feeder lines whose service areas abut the feeder line in question. The average access distance is 1.125 blocks.

Table 16 reports the results of these and similar calculations for feeder-route spacings ranging from one to seven blocks. Note that moving from an odd number of blocks to an even number of blocks, the increment in average distance is somewhat larger than when moving from an even number of blocks to the next higher odd number of blocks. Note also, that the average distance for six-block route spacing is 19.5/12 or 1.625 blocks, while for five- and seven-block spacing the access distances are, respectively, 13.5/10 or 1.35 blocks, and 26/14 or 1.857 blocks. The average access distance for five- and seven-block route spacing is (13.5 + 19.5)/(10 + 12), or 1.5 blocks. The average access distance for the six-block route spacing is thus 8.3 percent higher than for the five- and seven-block spacing.

Table 16. AVERAGE ACCESS DISTANCE

Feeder-Route Spacing (blocks)	Average Access Distance (blocks)
1	.250
2	.625
3	.833
4	1.125
5	1.350
6	1.625
7	1.857
5 and 7	1.500

5.2.2 Algebraic Relationships

Service Area and Passenger Generation

The area served by each line-haul station is given by

$$A = 2L_f D_s . \tag{1}$$

where L_f is the perpendicular distance from the main line to the end of the feeder service area measured in miles, D_s is the station spacing, also measured in miles, and A is service area measured in square miles. Since station spacing is assumed to be one mile, service area is

$$A = 2L_f . \tag{2}$$

If p is passenger-generation density in passengers per square mile per hour, then total passengers arriving at the station per hour is given by

$$P = pA. \tag{3}$$

Supplier Costs

We have computed residential collection costs for two sets of route spacing: four routes, three blocks apart, serving each line-haul station; and two routes, five and seven blocks apart, serving each station. Supplier costs per passenger for the four-route and two-route cases are

$$\text{4 routes:} \quad c = 4\beta F\left(4L_f + 1\right)/P \tag{4a}$$

$$\text{2 routes:} \quad c = 4\beta F\left(2L_f + 5/12\right)/P. \tag{4b}$$

β is the cost of operating the vehicle type in feeder service in dollars per vehicle-mile, F is the frequency of service on each route in vehicles per hour, and c is the supplier cost in dollars per passenger. The initial coefficient 4 is derived from the fact that there are two one-way trips per round trip for each vehicle, and two sides, north and south, to the line-haul route. The term $4L_f$ in parentheses in equation (4a) is the total perpendicular distance per one-way trip. The parallel distance from the route on the arterial street intersecting the main line at the station is zero. There are two routes which are 3/12 mile from the station, and one route which is 6/12 mile from the station, for a total parallel distance on all four routes of one mile. Thus, the term in parentheses in equation (4a) is the total distance traveled on all four routes per one-way trip per side per vehicle per hour. The supplier cost for the two-route case is calculated in a similar manner, and here the parallel distance from the one route which does not intersect the main line at the station is 5/12 mile. For six-block spacing, this term would be 6/12 instead of 5/12.

Access and Egress Cost

Access cost from residence to feeder vehicle is calculated, based on the model discussed above. Egress cost for the trip homeward is the same as the access cost for the outbound trip, which is given by

$$4 \text{ routes:} \quad a = v_3/18S_a \tag{5a}$$

$$2 \text{ routes:} \quad a = v_3/8S_a. \tag{5b}$$

where a is average access cost in dollars per passenger, v_3 is the value of time (in dollars per passenger-hour) spent walking to the transit stop, and S_a is walking speed in miles per hour. The average access distance is .833 block for the four-route case, which is equal to .0693 mile, while the average access distance for the two-route case is 1.5 blocks divided by 12, or 1/8 mile.

Waiting Costs

The average waiting cost per passenger is

$$w = v_2/2F \tag{6}$$

where v_2 is the value of time spent waiting, in dollars per passenger-hour.

In-Vehicle-Time Cost

The average in-vehicle-time cost per passenger for the feeder trip, in dollars, is given by

$$4 \text{ routes:} \quad h = v_1\left(L_f/2 + 1/4\right)/S \tag{7a}$$

$$2 \text{ routes:} \quad h = v_1\left(L_f/2 + 5/24\right)/S, \tag{7b}$$

where v_1 is the value of in-vehicle time, in dollars per passenger-hour. The average perpendicular distance of all passengers is $L_f/2$, and the average parallel distance is the total parallel distance as derived in the discussion of supplier costs (equations 4a and 4b), divided by the number of routes, or 1/4 and 5/24 for the four- and two-route cases, respectively. (6/24 for six-block spacing.) S is overall travel speed of the vehicle in feeder service.

Vehicle Occupancy and Optimal Service Frequency

The number of buses arriving from the 2n feeder routes at the station per hour is given by

$$\text{Vehicles per hour} = 2nF. \qquad (8)$$

Since P total passengers arrive at the station per hour, the number of passengers per vehicle is given by

$$\text{Passengers per vehicle} = P/2nF. \qquad (9)$$

It is convenient to define the average supplier cost of a round trip on one of the collection routes

$$\alpha = 2D_f\beta,$$

where the one-way distance D_f is $(L_f + 1/4)$ for the four-route collection system and $(L_f + 5/24)$ for the two-route system, and β is the vehicle-mile cost. Then, supplier costs per passenger for the $(2L_f \times 1)$ mile area serving the station (equations 4a and 4b) can be expressed alternatively as

$$c = 2n\alpha F/P.$$

The only component of user time cost which varies with service frequency is waiting-time cost, $w = 1/2F$. Adding c to w, differentiating the sum with respect to F, setting the result equal to zero, and solving for F gives the optimal service frequency

$$F^* = \sqrt{v_2 P/4n\alpha}. \qquad (10)$$

Frequency is proportional to the square root of waiting-time value, v_2, and total passengers, P, and inversely proportional to the number of feeder routes, n, serving each side of the line-haul station and the cost of a vehicle round trip, α. Thus, optimal service frequency is lower for vehicles with higher vehicle-mile costs and for longer routes, since α would be higher.

It may be, however, that equation (10) gives a service frequency low enough to overload the vehicles. If K is the vehicle seating capacity, substituting K for passengers per vehicle in equation (9) and solving for F gives

$$F^{**} = P/2nK. \tag{11}$$

The optimal feasible service frequency is the greater of F^* or F^{**}.

5.2.3 Passenger-Generation Densities

Meyer, Kain, and Wohl [5] computed costs for trip-origin densities per block per hour ranging from 1 to 37.5, and present some evidence that these densities are within the range experienced by transit systems in large cities. This corresponds to trip origins in the range of 144 to 5,400 per square mile per hour. Their line-haul analysis considered trips per transit station ranging from 333 to 5,000 passengers per hour. Given the assumption of symmetrical rectangular service areas adopted by both their study and our study, it is possible to calculate the service distance resulting from the combinations of station passengers and trip-origin density considered by Meyer, Kain, and Wohl. Table 17 presents the results of these computations. The service distance (L_f) ranges from .03 mile to 17.36 miles. Computations for 1,000 and 3,000 passengers per station per hour and densities from 1 to 10 per block-hour were reported in [5, p. 267]. The lengths of the service areas resulting from these parameter combinations are indicated with superscript "a" in Table 17. These range from something less than one-half mile on either side of the line-haul station to over 10 miles.

We have decided instead to specify the passenger generation density and the length of the service area, and to let the number of

Table 17. FEEDER SERVICE DISTANCES IN MILES, RESULTING FROM MEYER, KAIN, AND WOHL PARAMETER VALUES (Line-Haul Station Spacing = One Mile)

Passenger Origins Per Hour		Line-Haul Station Passengers Per Hour	Feeder Service Distance L_f (Miles)
Per Block	Per Square Mile		
1	144	333	1.16
		1,000	3.47[a]
		3,000	10.42[a]
		5,000	17.36
2	288	333	.58
		1,000	1.74[a]
		3,000	5.21[a]
		5,000	8.68
5	720	333	.23
		1,000	.69[a]
		3,000	2.08[a]
		5,000	3.47
10	1,440	333	.12
		1,000	.35[a]
		3,000	1.04[a]
		5,000	1.74
12	1,728	333	.10
		1,000	.29
		3,000	.87
		5,000	1.45
37.5	5,400	333	.03
		1,000	.09
		3,000	.28
		5,000	.46

a. Combinations of trip origin and station passengers for which cost computations were reported in MK&W text [5, p. 267].

passengers arriving at the line-haul station be the dependent variable. We analyze costs for service areas of two different sizes, 3 miles and 5 miles. The Massachusetts Institute of Technology Dial-a-Ride Project claims that dial-a-ride equals the cost of conventional transit at approximately 35 trips per square mile per hour [30, p. 3-20]. We have, therefore, computed the costs of feeder service at lower trip-generation densities than envisioned by Meyer, Kain, and Wohl, starting at 25 trips per square mile per hour. The higher densities seem improbable, except for limited areas. We have assumed an upper limit of 700 passengers per square mile per hour. These limits imply a range of passengers arriving at the station of 150 (3 miles x 1 mile x 2 sides x 25) to 4,200 per hour for a 3-mile feeder, and 250 to 7,000 per hour for a 5-mile feeder. A line-haul route with ten stations would thus carry 2,500 to 70,000 passengers per hour, assuming uniform passenger-generation densities in the ranges considered in our computations.

5.2.4 Comparative Costs: Residential Collection and Distribution

Computations for two time values are reported: "low" ($3.00 per passenger hour for walking and waiting time, $1.20 for in-vehicle time) and "high" ($7.50 and $3.00, respectively). The in-vehicle-time value is assumed to be 40 percent of waiting and walking time. As explained in Chapter 4, these time values represent the extremes of averages for clientele likely to use a modern transit system. It may also be that different time values (for example, in low-income areas versus high-income areas of a city) lead to different optimal system configurations.

A sample calculation of residential feeder costs for one set of parameter values is presented below.

Parameter Values

"Low" time value: v_1 = \$1.20, v_2 = \$3.00, v_3 = \$3.00

Feeder routes $n = 4$

Feeder distance L_f = 3 miles

300 passengers per square mile per hour

8-passenger bus-wagon

Supplier Costs

Per vehicle-mile: β = mileage cost + 1.083* hour costs/S

$= .141 + 1.083 \times 3.88/19 = \$.362$

Per round trip: $\alpha = 2\left(L_f + .25\right)\beta$

$= 2(3 + .25)\ .362 = \$2.35$

Time per round trip: $T = 1.083^* \times 2(3.25)/19 = .37$ hour

= 22 minutes

Total passengers: $P = 300 \times 2 \times L_f$

$= 300 \times 2 \times 3 = 1{,}800$ passengers per hour, all routes

Optimal service frequency: $F^* = \sqrt{v_2 P/4n\alpha}$

$= \sqrt{3.00 \times 1800/(4 \times 4 \times 2.35)}$

= 12 vehicles per hour (each route)

Check vehicle load: $P/(2nF) = 2{,}400/(2 \times 4 \times 12) = 25 > 8$

Vehicle load: Eight passengers

Minimum feasible frequency: $F^{**} = P/2nK$

$= 1800/(2 \times 4 \times 8) = 28.1$ vehicles per hour

---

[*] Accounts for five minutes per hour layover time.

Supplier cost: $c = \alpha/\text{Load}$

$= \$2.35/8 = \$.29$ per passenger

User Time Costs

Access time cost: $a = v_3/18S_a$

$= \$3.00/(18 \times 3) = \$.06$ per passenger

Waiting-time cost: $w = v_2/2F$

$= \$3.00/(2 \times 28.1) = \$.05$ per passenger

In-vehicle-time cost: $h = v_1\left(L_f/2 + .25\right)/S$

$= \$1.20\ (1.75)/19 = \$.11$ per passenger

User time cost: $u = a + w + h$

$= .06 + .05 + .11 = \$.22$ per passenger

Total Full Cost

$t = c + u$

$= .29 + .22 = \$.51$ per passenger

Figures 9 through 12 and Tables D-1 through D-8 of Appendix D present the complete results of the computations. All cost figures are expressed in dollars per passenger. Figures 9 through 12 summarize full cost for four sets of parameter values: "low" and "high" time value combined with 3- and 5-mile feeder lengths. In addition, two- and four-route configurations were considered, as explained above. Figures 9 through 12 present full costs for the least-cost number of feeder routes for each mode, using a dashed line for two routes and a solid line for four routes.

Regardless of the mode, two routes are more economic than four routes for low passenger-generation densities. Access time costs are higher, but allocating more passengers to each route

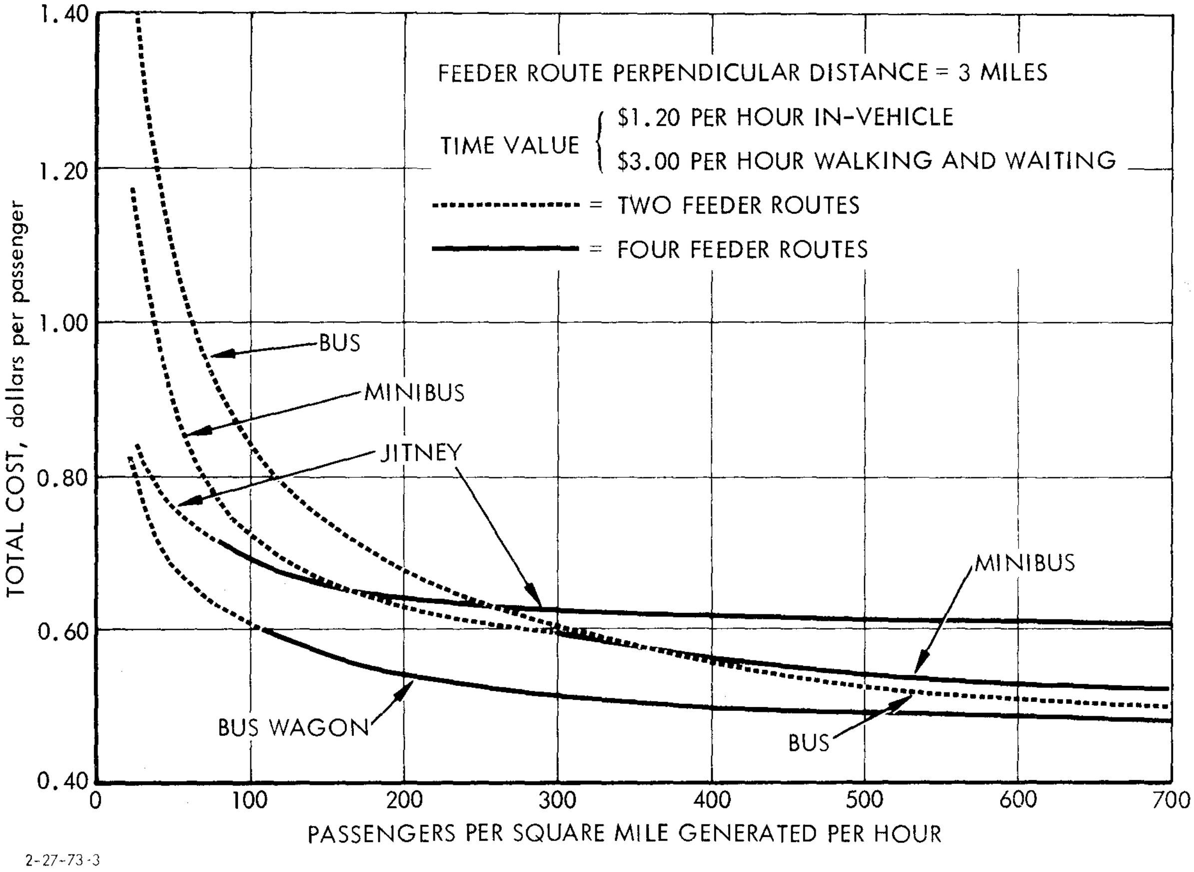

Figure 9. RAIL FEEDER RESIDENTIAL COLLECTION COST PER PASSENGER VERSUS PASSENGER DENSITY

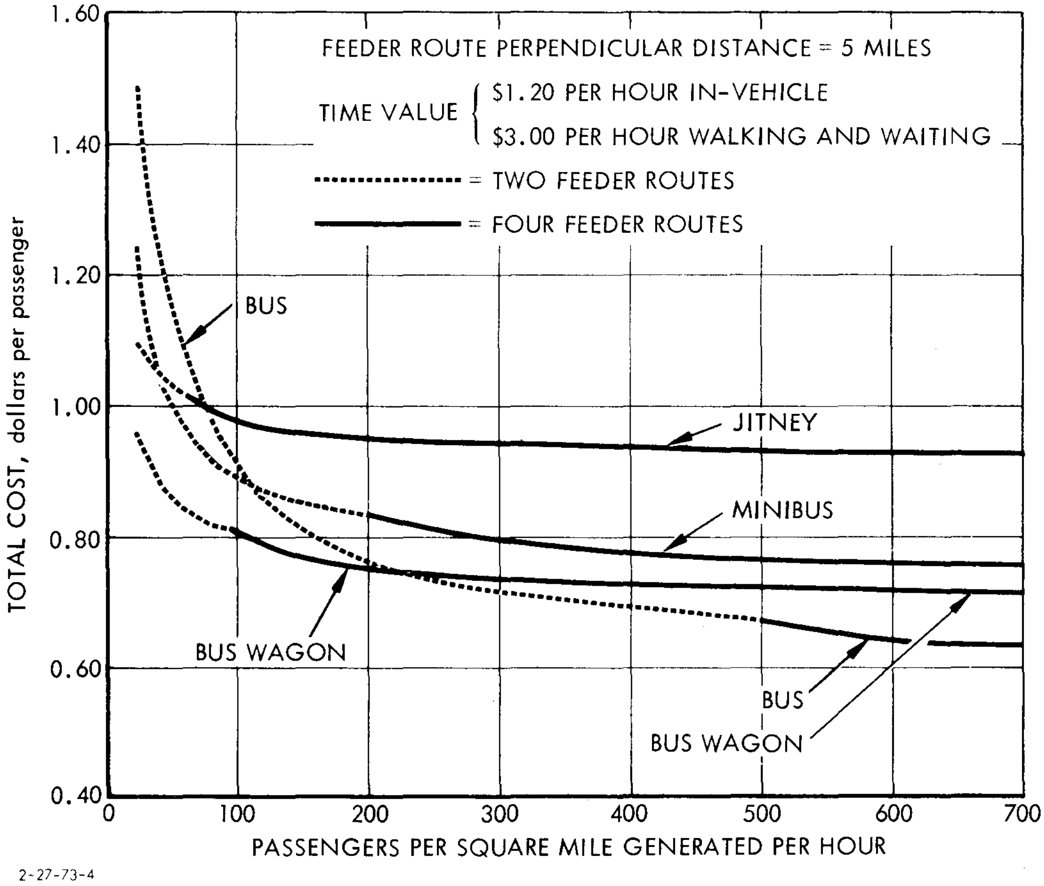

Figure 10. RAIL FEEDER RESIDENTIAL COLLECTION COST PER PASSENGER VERSUS PASSENGER DENSITY

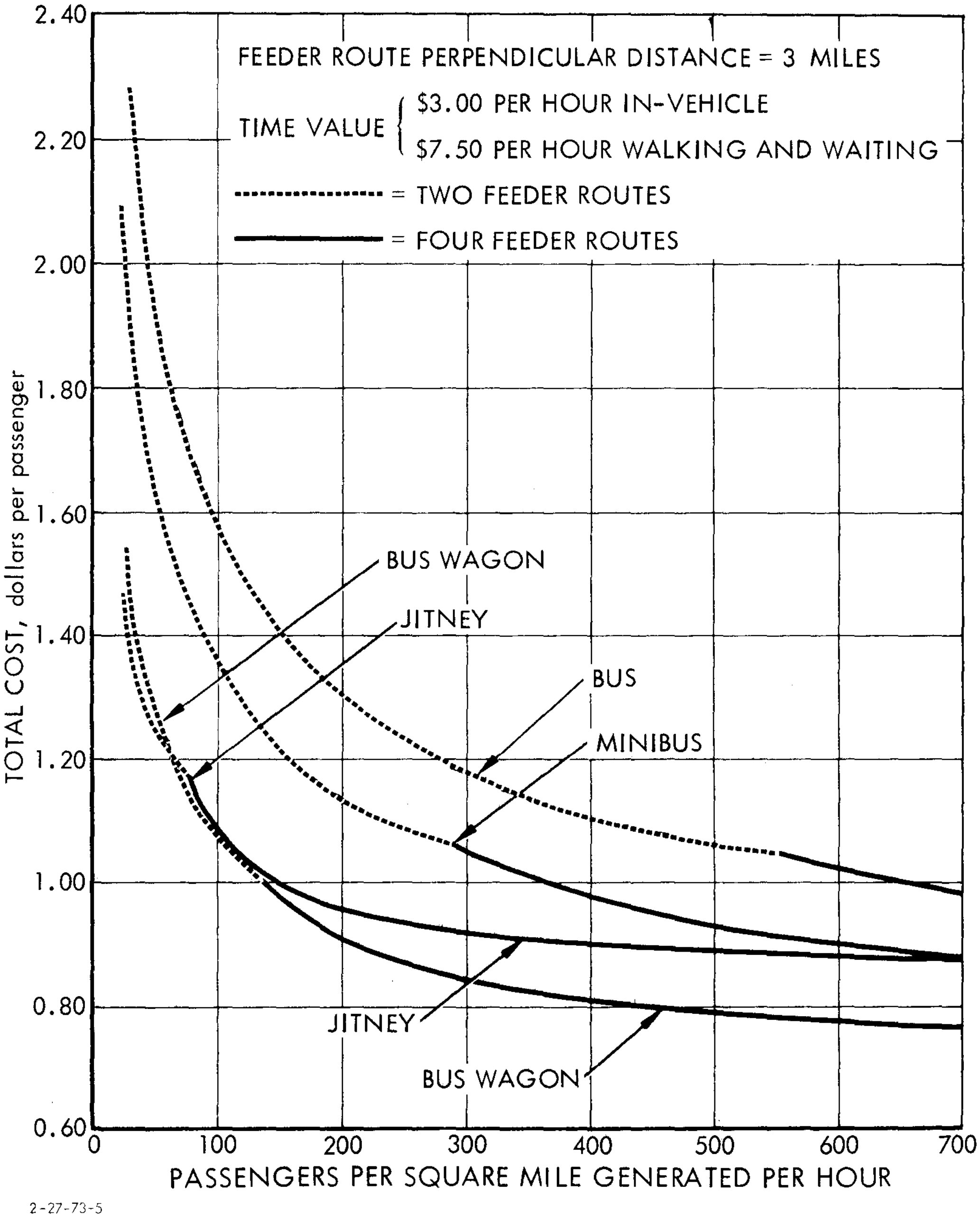

Figure 11. RAIL FEEDER RESIDENTIAL COLLECTION COST PER PASSENGER VERSUS PASSENGER DENSITY

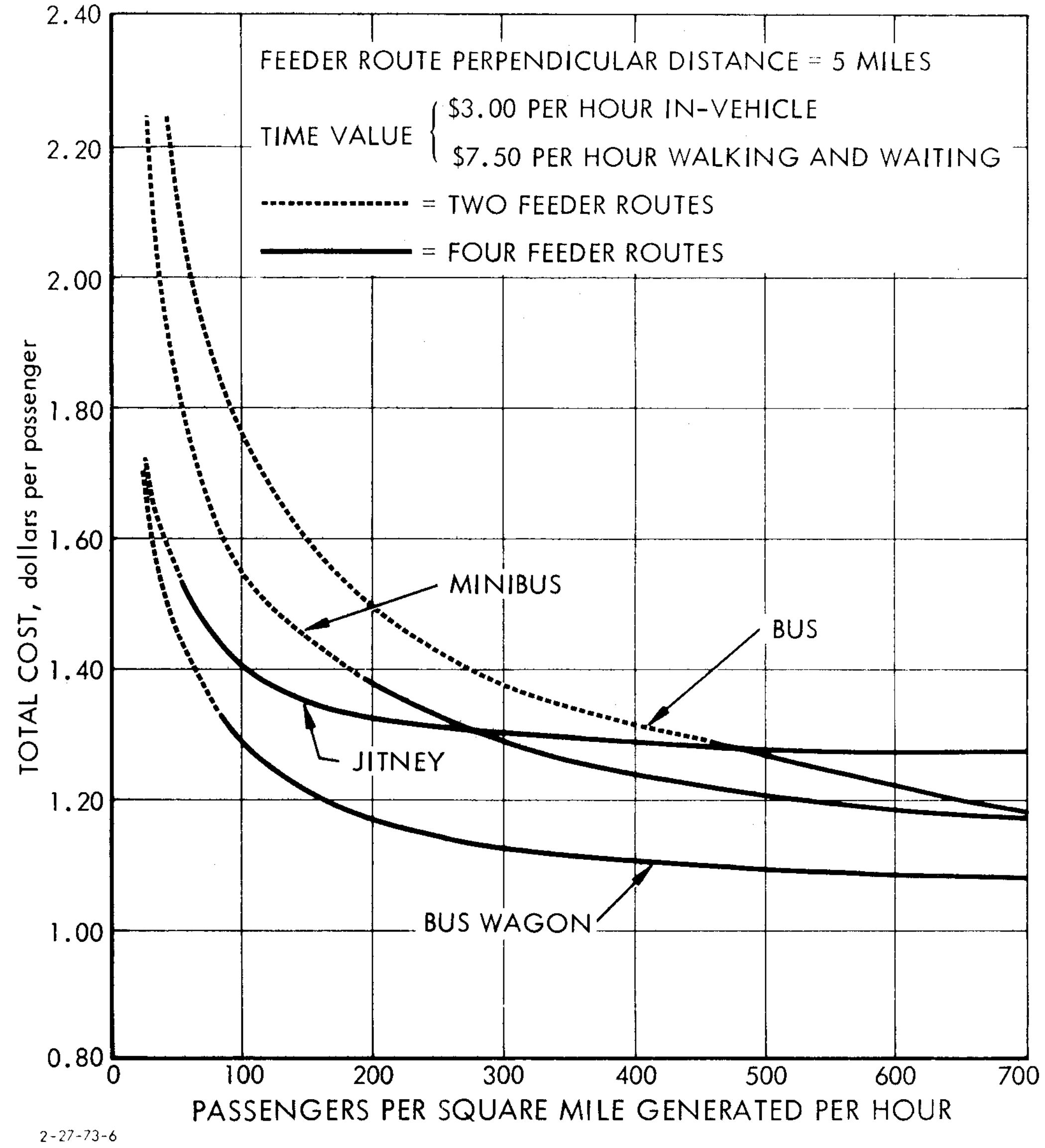

Figure 12. RAIL FEEDER RESIDENTIAL COLLECTION COST PER PASSENGER VERSUS PASSENGER DENSITY

increases service frequency and thus reduces waiting time. In addition, vehicle occupancy may be higher, thus reducing per-passenger supplier costs. For higher densities, the savings in access costs outweigh the increases in waiting and supplier costs, so that four routes are optimal. Note that the left portions of the cost curves in Figures 9 through 12 are dashed (two routes) and the right portions are solid (four routes). Greater passenger density is required to support the closer route spacing for larger vehicles.

Figures 9 through 12 allow a comparison of the effects of both route length and time value on the comparative full costs of the modes. Comparing Figure 9 with Figure 10, and Figure 11 with Figure 12 shows that, for any time value, larger vehicles become relatively more economic than smaller vehicles on longer routes. Supplier costs (low seat-mile costs) become relatively more important than waiting costs (high service frequencies). Comparing Figure 9 with Figure 11 or Figure 10 with Figure 12 shows that, for any route length, the advantage of smaller vehicles over larger vehicles increases with time value. People who value their time more highly are willing to pay higher fares, reflecting a higher seat-mile cost, for more frequent and faster service. The effect of frequency is more important than the effect of higher speeds, because in-vehicle time values are lower and the difference in speeds among modes is relatively slight.

Figures 9 through 12 indicate that the 8-passenger bus-wagon is nearly always the low-cost alternative, even though conventional buses may have lower supplier costs at high densities. People who value their time in the range of $3.00 to $7.50 per hour are willing to pay for the higher frequency and speed of the smaller vehicles. Conventional buses have lower full costs only for combinations of low time values, long routes, and high passenger densities.

5.3 RAIL LINE-HAUL AND CBD DISTRIBUTION

5.3.1 Line Description

Rail transit lines serve corridors of high-volume mass movement toward a limited area, the CBD. We consider three line lengths (L): 6, 10, and 14 miles (see Figure 13). The CBD distribution phase adds one more mile. Corridors are paired, with trains starting at one end of the line and picking up passengers as they traverse the line to the CBD. The passengers are discharged in the CBD, and

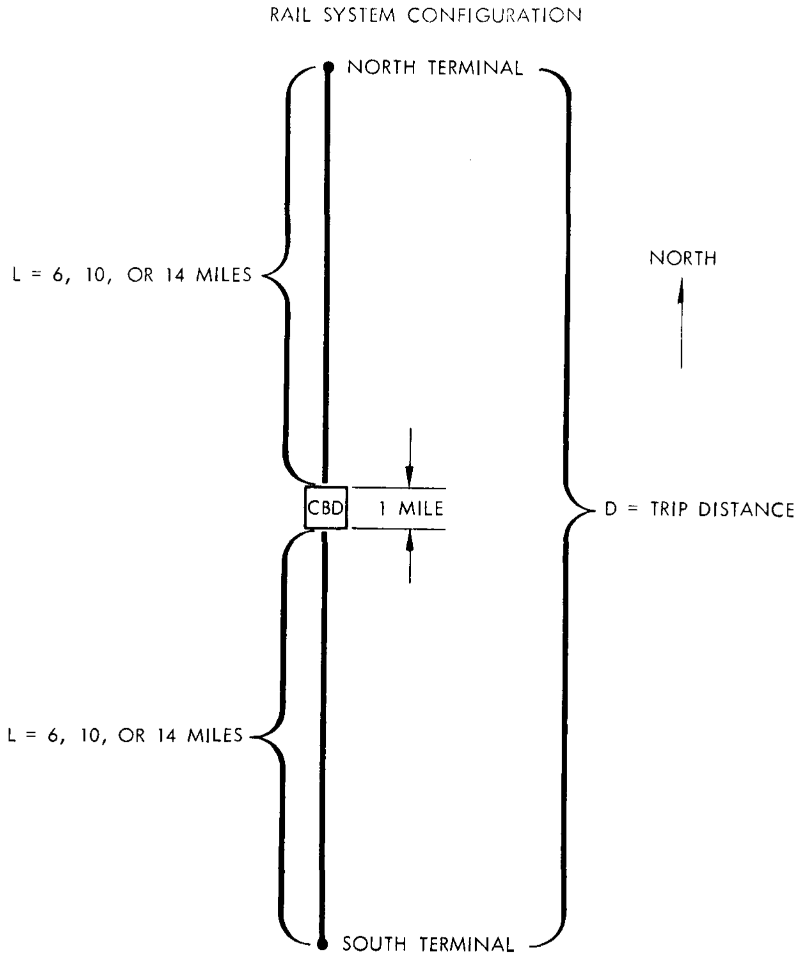

Figure 13. RAIL SYSTEM CONFIGURATION

the train proceeds, empty, to the end of the opposite line to begin another passenger-carrying trip. These operating assumptions are similar to those made by Meyer, Kain, and Wohl [5, Chapter 8].

In this study, reverse-direction travel was not considered in the comparisons. Put somewhat differently, it is assumed, in effect, that the system design is determined by, and all peak-hour supplier costs are allocated to, main haul commuter travel. Table 18, taken from [5], indicates that reverse direction and along-the-line service (passengers who disembark before reaching the CBD) are minor

Table 18. PEAK-HOUR REVERSE-DIRECTION AND ALONG-THE-LINE PASSENGER VOLUME

System	Outbound Passengers As a Percentage of Total 2-Way Flow	Inbound Passengers Disembarking Before Reaching CBD (Percent)
Pittsburgh		
Transit at Maximum Load Point	15	
Transit at Most Central Area	10	
Washington, D.C.		
Three major bus lines	16.5	
New York City (Rail Transit)		
Manhattan-Brooklyn	8	
Bronx-Manhattan	11	
Queens-Manhattan	7	
Eastside-Westside at 60th Street	12	
Chicago (Rail Transit)		
Congress-Douglas Park-Milwaukee	21	13
North Leg of North-South Line	40	
South Leg of North-South Line	13	
Cleveland (Rail Transit)		
Westside		4
Eastside		9
Both lines	14	
Toronto (Rail Transit)		
Yonge Street	10	30[a]
Philadelphia		
Rail system	23	

a. 4.5-mile line operates as a downtown distribution subway for most of its length.

Source: J. R. Meyer, J. F. Kain, and M. Wohl, "The Urban Transportation Problem," Cambridge, Massachusetts: Harvard University Press, 1966, pp. 184-185.

parts of transit system peak-hour usage. Rail systems can provide these services at zero or low marginal cost, but Meyer, Kain, and Wohl found that the extra costs or reverse-direction and along-the-line busway service were quite low also [5, p. 235].

5.3.2 Algebraic Relationship for Rail Transit

Access and Egress Cost

Inbound rail transit access cost and outbound egress cost have already been computed in Subsection 5.2.4. The CBD is assumed to be roughly one mile square, so that the average egress distance (or access distance for the outbound trip) is .25 mile. This average distance is computed as one-half the distance from a centrally located subway to the edge of the CBD. There are two offsetting correlations that a finer analysis could account for. First, stations are spaced at discrete intervals, for example, one-third to one-half mile apart, and some walking must take place parallel to the subway. This would cause the average distance to be somewhat greater than we have assumed. Second, employment would be more concentrated near the line, tending to reduce average walking distance.

CBD egress cost is calculated as follows:

$$e = .25v_3/S_a$$

where e is average egress cost in dollars per passenger, v_3 is walking-time value in dollars per passenger-hour, S_a is walking speed in miles per hour (assumed equal to 3), and .25 is average distance in miles.

Waiting-Time Costs

Trains and feeder vehicles are assumed to arrive at the transfer point without schedule coordination. Schedule coordination has its price, as the schedules must be "padded" if they are to be adhered to. At the peak-hour volumes contemplated, service on both the rail line and feeder lines is fairly frequent, and there is likely to be little benefit to coordination to offset its costs. Assuming random arrivals, waiting-time cost is

$$w = v_2/2F.$$

w is average waiting-time cost in dollars per passenger, F is the frequency of service on the rail line in trains per hour, and v_2 is waiting-time value in dollars per passenger-hour.

Transfer Time Cost

Unlike the integrated bus system, a rail transit system requires a transfer from a feeder vehicle to the train. We have assumed an arbitrary figure of 2 minutes. The feeder vehicle, if it is a 50-passenger bus, takes about 1 minute to unload [12, p. 346]. If smaller feeder vehicles are used, unloading time may be lower, but because more such vehicles would be required, the unloading area may be larger and the average walk longer. The remaining minute would allow 260 feet to be traversed at 3-miles per hour, a conservative estimate of the distance from the bus stop, through the station, and along the train platform to the train.

Transfer cost in dollars per passenger is, thus, $v_3(2/60)$, or $.033v_3$.

In-Vehicle-Time Cost

In-vehicle-time cost is given by

$$h = v_1\left(L/S_L + 1/S_D\right)/2,$$

where

h = in-vehicle-time cost in dollars per passenger

v_1 = in-vehicle-time value in dollars per passenger-hour

L = line length

l = CBD length in miles

S_L = line speed in miles per hour

S_D = CBD speed in miles per hour.

Division by two takes account of the fact that the average passenger travels one-half the length of the line.

Supplier Cost

Supplier costs can be conveniently broken down into operating cost and vehicle and way capital costs. Way capital costs are fixed-while operating and vehicle capital costs vary with service frequency and train length.

Operating and vehicle capital costs in dollars per trip (from the North Terminal to the South Terminal of Figure 13) for a train of X cars is

$$\alpha_X = \left(C_1 D + C_2 T\right) X + C_3 T,$$

where

C_1 = car operating cost, excluding train labor, in dollars per mile

D = trip distance in miles

C_2 = car capital cost in dollars per hour

T = round-trip time in hours

C_3 = train labor in dollars per hour.

D and T are given by

$$D = 2L + l$$

$$T = 1.083\left(2L/S_L + l/S_D\right).$$

Note that the CBD distance (one mile) is counted once per trip as the train continues out the opposite corridor of the line to begin a second trip. The term 1.083 in the time equation reflects an assumed layover time of 5 minutes per hour.

Supplier costs in dollars per passenger are

$$c = \left[\alpha_x F + (L + .5)C_4\right] \Big/ P_L,$$

where C_4 is the fixed way and structures cost in dollars per route-mile per hour and P_L is the number of passengers per hour on the North Corridor to the CBD. Note that only half the CBD route distance is assigned to each corridor.

Optimal Service Frequency and Train Length

Optimal service frequency was computed (for each passenger-loading) for train lengths of 2, 4, 6, 8, and 10 cars, using the squart-root rule derived above. If the square-root rule overfilled the train, service frequency was recomputed, assuming that the train was filled. Train capacity was based on each passenger having a seat. If the number of trains per hour exceeded the track capacity of the system, this train length was rejected. As costs were computed for successively larger passenger volumes, the minimum-cost solution was two-car trains up to track capacity, then four-car trains up to track capacity, etc., up to ten-car trains.

5.3.3 Passenger Loading, Line Capacity, and Relation to Passenger-Generation Densities

We have computed residential collection costs for passenger generation densities of 25 to 700 per square mile per hour for rail station service areas of 6 and 10 square miles, implying station volumes on the order of 150 to 7,000 passengers per hour. For lines 6 to 14 miles in length and feeder distances of 3 to 5 miles, these generation densities would imply line volumes on the order of 900 to 3,500 passengers per hour for the low passenger-generation density and 25,000 to 98,000 for the high generation density. The extremes of this range are unlikely, since passenger-generation densities are likely to vary within these limits over the metropolitan area.

Table 19 indicates that, with the exception of New York, peak-hour corridor volumes are likely to be in the range of 6,000 to 40,000 travelers per hour. These figures are for all modes; transit

Table 19. AVERAGE CBD AND CORRIDOR COMMUTER VOLUME, EVENING PEAK-HOUR

Number of Persons Leaving CBD Per Hour	City	Persons Per Corridor Per Hour
More than 800,000	New York	Above 60,000
250,000 - 800,000	none	40,000 - 60,000
200,000 - 250,000	Chicago	30,000 - 40,000
150,000 - 200,000	Philadelphia Boston Washington, D.C.	20,000 - 30,000
100,000 - 150,000	Los Angeles San Francisco	13,000 - 20,000
75,000 - 100,000	Cleveland Detroit Atlanta Pittsburgh New Orleans St. Louis Baltimore	9,000 - 13,000
50,000 - 75,000	Dallas St. Paul Minneapolis Providence Fort Worth Milwaukee	6,000 - 9,000
Less than 50,000	Miami Cincinnati Rochester Seattle Kansas City Denver	Below 6,000

Source: J. R. Meyer, J. F. Kain, and M. Wohl, "The Urban Transportation Problem," Cambridge, Massachusetts: Harvard University Press, 1966, p. 86.

passengers will, of course, be only a portion of total travelers. Three U.S. rail transit commuter lines are essentially single-corridor systems. Using the conversion factors of [31, Appendix VIIA], it is possible to estimate the weekday peak-hour inbound flow from the number of annual passengers. Peak-hour flows in 1971 for these lines were approximately as follows:

Port Authority Trans Hudson Corporation	29,000
Lindenwold Line (serving Philadelphia)	7,000
Shaker Heights Department of Transportation (serving Cleveland)	3,300

A recent study [32] included the following information on line-haul transit passenger volumes:

> . . . While rail transit has the potential for carrying large volumes of people, the only lines that meet this potential are a few in New York City where population density is uniquely suited for service by rail transit. The next most heavily traveled rail line, in the median of Chicago's Eisenhower Expressway, carried 10,000 persons in the peak-hour, roughly one-sixth of New York's peak lines, 25 percent less than are carried during the peak-hour in buses across the Oakland-San Francisco Bay Bridge, and less than half the passengers carried on the exclusive bus lane during peak-hours on the Northern New Jersey approach to New York's Lincoln Tunnel.

We have assumed a maximum train length of 10 cars, seating 79 passengers each, and minimum headway of 90 seconds (maximum frequency of 40 trains per hour). This implies a maximum line capacity of 31,600 seated passengers per hour, which should be adequate for all non-New York corridors. We have thus computed rail transit costs for volumes ranging from 1,000 to 31,000 passengers per hour. This should bracket the volumes likely to be attracted to a high-quality mass transit commuter line. This capacity is approximately the same as that used for the integrated bus (28,800 passengers per hour). The integrated bus capacity is established by the ability of CBD streets to absorb buses (see Subsection 5.4.2).

Table 20 matches the passenger-generation densities used to calculate residential collection costs (and integrated bus costs) to total line-haul volumes. The figures of Table 20 assume (1) uniform average passenger-generation densities along the line, and (2) uniform feeder lengths. These assumptions allow the rail costs on the one hand--based on total corridor line-haul volume--to be compared with residential collection and integrated line costs on the other hand. Other assumptions about the distribution of densities along the line could have been made, although it is unlikely that, given a total corridor volume, differences in full costs between rail and bus would be very sensitive to this distribution.

Table 20. TOTAL LINE-HAUL PASSENGERS IMPLIED BY PASSENGER-GENERATION DENSITIES

Passengers per Square Mile per Hour	Total Line-Haul Passengers					
	6-Mile Line		10-Mile Line		14-Mile Line	
	3-Mile Feeder	5-Mile Feeder	3-Mile Feeder	5-Mile Feeder	3-Mile Feeder	5-Mile Feeder
25	900	1,500	1,500	2,500	2,100	3,500
50	1,800	3,000	3,000	5,000	4,200	7,000
75	2,700	4,500	4,500	7,500	5,300	10,500
100	3,600	6,000	6,000	10,000	8,400	14,000
150	6,400	9,000	9,000	15,000	10,600	21,000
200	7,200	12,000	12,000	20,000	16,800	28,000
300	10,800	18,000	18,000	30,000	25,200	42,000[a]
500	18,000	30,000	30,000	50,000[a]	42,000[a]	70,000[a]
700	25,200	42,000[a]	42,000[a]	70,000[a]	58,800[a]	98,000[a]

a. Exceeds line-haul corridor capacity.

5.3.4 Costs for Rail Transit

We have made a sample calculation of rail transit costs based on the algebra developed above and cost information from Chapters 3 and 4. The sample calculation is as follows:

Parameter Values

"Low" time value $v_1 = \$1.20,\ v_2 = \$3.00,\ v_3 = \$3.00$

Line Length: $L = 6$ miles

$P_L = 10{,}000$ passengers per hour on single corridor

Supplier Costs

Distance: $D = 2L + 1$

$= 2 \times 6 + 1 = 13$ miles per train trip

Time: $T = 1.083\left(2L/S_L + 1/S_D\right)$

$= 1.083(2 \times 6/35 + 1/18)$

$= .432$ hour per train trip

Two-car train: $\alpha_2 = \left(C_1 D + C_2 T\right) 2 + C_3 T$

$= (1.87 \times 13 + 37.80 \times .432)\ 2 + 7.27 \times .432$

$= 40.64 \times 2 + 3.14$

$= \$84.42$ per train trip

Four-car train: $\alpha_4 = 40.64 \times 4 + 3.14$

$= \$165.70$ per train trip, etc.

Track passenger capacity with two-car trains: $79 \times 2 \times 40$

$= 6{,}320 < 10{,}000$

Optimal service frequency with four-car train

$$F_4^* = \sqrt{v_2 \times P_L/2\alpha_4}$$

$= \sqrt{3 \times 10,000/(2 \times 165.70)}$

$= \sqrt{90.52} \cong 9.5$

Check train capacity load $= 10,000/9.5 = 1,053$

Capacity $= 4 \times 79 = 316 < 1,053$

Feasible Frequency: $F_4^{**} = 10,000/316 = 31.6$

Supplier Costs: $c = \left[\alpha_4 F + (L + .5)C_4\right]/P_L$

$= (165.70 \times 31.6 + 6.5 \times 1,785)/10,000$

$= (5,236 + 11,602)/10,000$

$= \$.524 + \$1.160 = \$1.68$ per passenger

(\$.524 = cost per passenger, excluding way)

(\$1.68 = cost per passenger, including way)

User Time Costs

Transfer time cost: $r = .033v_3$

$= .033 \times 3$

$= \$.10$ per passenger

Waiting-time cost: $w = v_2/2F$

$= 3/(2 \times 31.6)$

$= \$.05$ per passenger

In-vehicle-time cost: $h = v_1\left(.5L/S_L + .5/S_D\right)$

$= 1.2\ (.5 \times 6/35 + .5/18)$

$= \$.14$ per passenger

Egress time cost: $e = .25v_3/S_a$

$= .25 \times 3/3$

$=$ \$.25 per passenger

User time cost: $u = .10 + .05 + .14 + .25$

$=$ \$.54 per passenger

Total Full Cost

$t = c + u$

$= 1.68 + .54$

$=$ \$2.22 per passenger (\$1.06, excluding way costs)

Figures 14 and 15 and Tables E-1 and E-2 of Appendix E summarize the results of the calculations for "low" and "high" time values, respectively, and for different line-haul distances. Figures 14 and 15 indicate that the cost per passenger becomes very high at low passenger volumes. The high cost per passenger is due to the allocation of the high way and structures cost to relatively few passengers.

To these costs must be added the residential collection costs computed above to obtain the full cost of the commuter trip to the CBD. For "low" time value, Figure 9 indicates that total full costs for the 3-mile feeder flatten out in the vicinity of \$.50 per passenger for densities greater than about 300. For the 5-mile feeder, Figure 10 shows costs in the \$.60 to \$.70 range are incurred at the same densities. The lowest costs are usually for the bus-wagon so that if conventional feeder buses are used, collection costs will be higher. Table 20 indicates that 300 passengers per square mile per hour are equivalent to at least 10,000 passengers per hour on the line-haul corridor. For lower densities and volumes, residential collection costs will be higher than those discussed above.

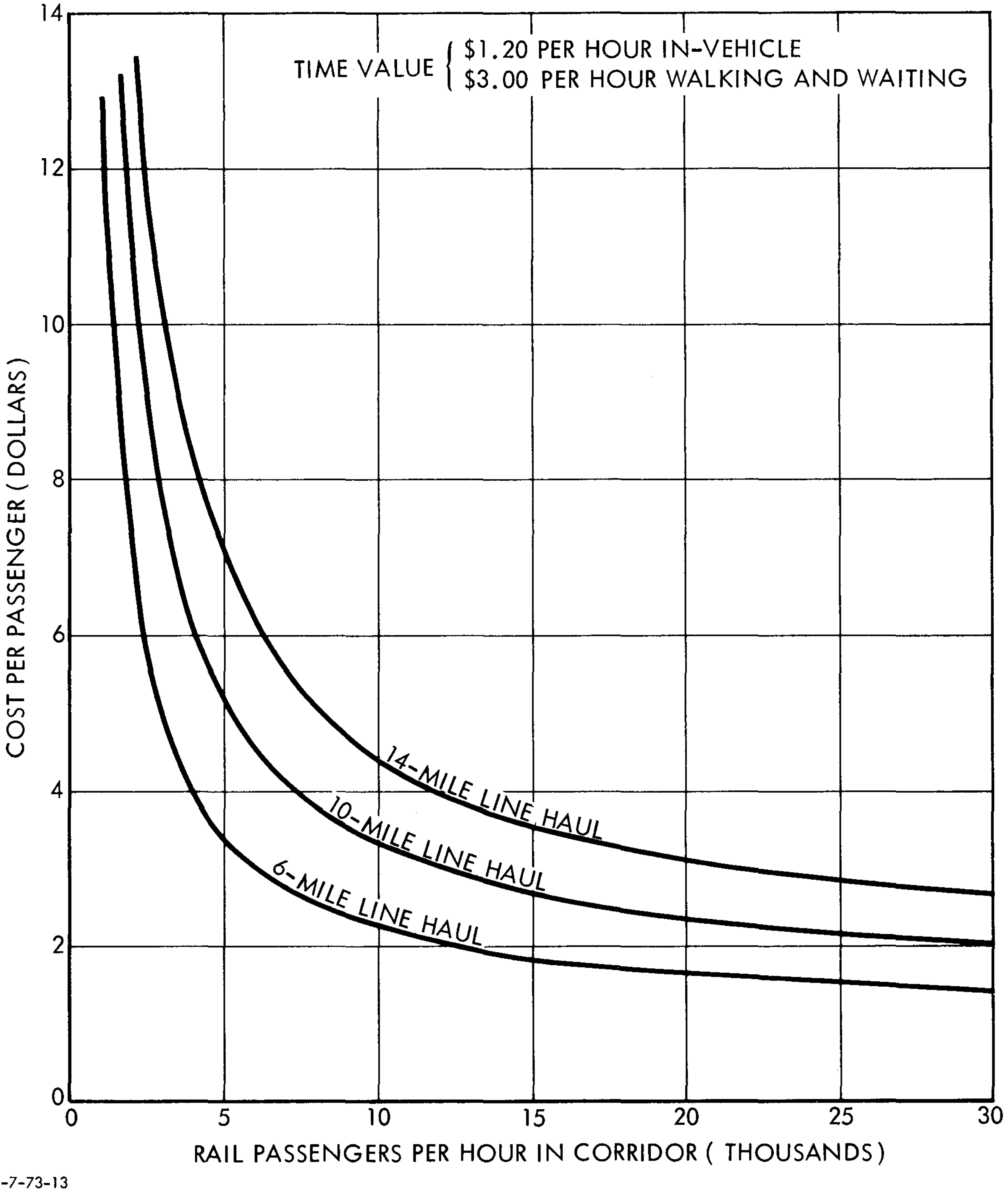

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Figure 14. RAIL TRANSIT COST PER PASSENGER
(Line Haul Only)

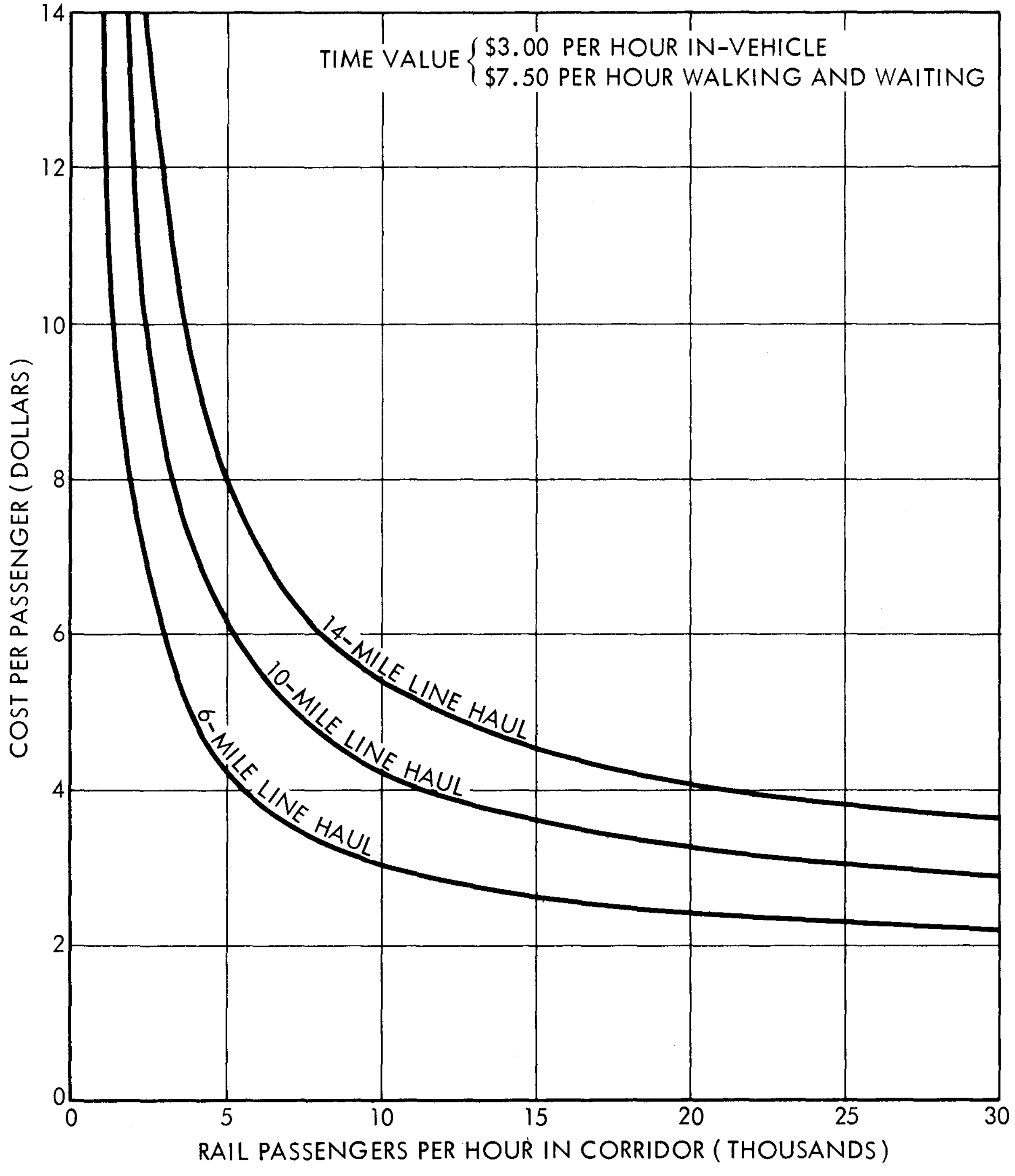

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Figure 15. RAIL TRANSIT COST PER PASSENGER
(Line Haul Only)

Figures 11 and 12 indicate that for "high" time values, collection costs do not flatten out as much at higher densities. Collection full costs of approximately \$.85 for 300 passengers per square mile per hour with a 3-mile feeder route, and \$1.10 for the 5-mile route are indicated in Figures 11 and 12. Again, these costs would be higher for lower densities or for higher-cost vehicles.

Rail full costs, including residential collection and line-haul costs, are discussed in Section 5.5 for various combinations of time values, feeder route perpendicular distance, and line-haul route distance.

5.4 INTEGRATED BUS

The integrated bus alternative uses the same vehicle to perform residential collection, line-haul, and CBD distribution. In the analysis of this alternative, we have assumed the same residential collection configuration as above (Section 5.2) and the same line-haul route configuration (Section 5.3). Instead of a rapid rail transit line, there would be either an exclusive busway or arterial street for the line-haul portion. CBD distribution is assumed to be via surface street in mixed traffic.

5.4.1 Algebraic Relationships for Integrated Bus

Access, Egress, and Waiting-Time Costs

Access time costs and waiting-time costs are computed by using the relationships derived for residential collection and distribution in Section 5.2.2. Egress time costs in the CBD are assumed to be identical to those for rail transit. Actually, bus service would probably be offered on several CBD streets, and judicious transfers among routes may save more in egress time costs than are involved in transfer waiting-time costs, so that the egress estimate may be somewhat pessimistic for the bus mode.

In-Vehicle-Time Costs

Average in-vehicle-time costs are the sum of collection, line-haul, and CBD time costs

$$h = v_1\left(D_f^1/S_f + D_L/S_L + .5/S_d\right).$$

D_f^1 is average distance spent on-vehicle in the collection phase and is $(L_f/2 + \frac{1}{4})$ miles for the four-route feeder system and $(L_f/2 + 5/24)$ for the two-route system [see equations (7a) and (7b) above]. D_L is line-haul distance in miles. We have assumed average D_L of 3, 5, and 7 miles, corresponding with total line distances of 6, 10, and 14 miles, the same as for rail. The CBD is one mile square so that the average distance traveled is .5 mile. S_f, S_L, and S_d are feeder, line-haul, and CBD speeds, respectively.

Supplier Costs

Supplier cost per round trip is also the sum of the collection, line-haul, and CBD phases. For vehicle costs (excluding costs of way and structures), trip costs per vehicle are

$$C_1D + C_2T,$$

where

C_1 = mileage-dependent costs in dollars per vehicle-mile

D = trip distance

C_2 = time-dependent costs in dollars per vehicle-hour

T = time per trip

D and T are computed by

$$D = 2D_f + 2D_L + 1$$

$$T = 1.083(2D_f/S_f + 2D_L/S_L = 1/S_d).$$

$2D_f$, $2D_L$ and 1 are the total distances traversed each trip on the collection, line-haul, and CBD portions of the trip. D_f equals $(L_f + \frac{1}{4})$ for the four-collection-route system and $(L_f + 5/24)$ for the two-route system [see equations (4a) and (4b) above].

Costs for way and structures for the residential collection portion are assumed to be zero as discussed in Section A.4.1. For the CBD distribution portion, and for the line haul over arterial streets in mixed traffic, way costs are computed on a vehicle-mile basis. For line haul via exclusive busway, costs are computed on a route-mile-hour basis, and allocated to the buses using the facility. Thus, total CBD and arterial street costs vary with service frequency, while exclusive busway costs are fixed and independent of service frequency.

The total cost per trip for integrated bus using an arterial street for the (express) line-haul portion of its journey is

$$\alpha_a = C_1D + C_2T + 2C_aD_L + C_d,$$

where the first two terms are vehicle costs as explained above, C_a is the cost per express bus-mile of arterial streets, and C_d is the cost per bus-mile of downtown streets.

When an exclusive busway is used for line haul, the round trip cost (not including the fixed busway cost) is

$$\alpha_e = C_1D + C_2T + C_d.$$

Note that C_2 is higher for high-speed expressway buses than for conventional buses, reflecting a higher capital charge, while C_1 is less because of the difference in operating speeds (see Chapter 3).

We allocate the cost of the L-mile busway among the passengers using it. With one-mile entrance spacing, 1/L of the total cost will be allocated to the passengers using each entrance. The passenger volumes at which exclusive busway full costs are less than arterial express full costs are derived in Subsection 5.4.3.

5.4.2 Optimal Service Frequency and Line Capacity

Optimal service frequency is computed so as to minimize the sum of waiting-time and supplier costs, subject to vehicle capacity, as explained in Subsection 5.2.2. In general, frequencies will be lower and loads higher, since the supplier cost, α, of an integrated trip is much higher than for a feeder-only trip. Recall that, given sufficient capacity, optimal service frequency is proportional to the square root of α, the supplier cost of a vehicle-trip.

The capacity of a busway system depends on both the capacity of the line-haul way and the capacity of the downtown street grid. The Highway Capacity Manual provides information on both capacities. A limited-access expressway operating under ideal conditions of uninterrupted flow has a capacity of 2,000 automobiles per lane-hour [12, p. 62]. A bus operating under these nonstop freeway conditions uses capacity equivalent to 1.6 automobiles [12, pp. 342-345], implying a capacity of 2000/1.6, or 1,250 buses per hour. This is equivalent to 1250 times 50, or 62,500 seated passengers per hour for a two-lane (one in each direction) busway.

The service speed on a busway depends on the volume of traffic. At maximum capacity, average speed is only 30 miles per hour. At 35 miles per hour, a flow of 1,875 autos (1,172 buses or 58,600 passengers) per hour can operate; at 45 miles per hour, the speed we assume in our cost calculations, 900 autos (563 buses or 28,150 passengers) per hour can operate.* These capacities may be compared

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* These speed-capacity relationships assume a busway designed to 60 mph free-flow standards [12, p. 62].

with the rail line capacity of 31,600 passengers per hour at a 35 mph speed computed above. Both line-haul capacity and speed are greater with a busway, because trains must make frequent stops while buses operate nonstop.

The capacity of a CBD street for high-volume distribution is limited by the service time (loading or unloading) of the bus at the busiest stop. The Highway Capacity Manual suggests as a rule of thumb for design purposes a 25-second service time and a minimum headway of 50 seconds per bus. If curbside stops are alternated and buses are allowed to leapfrog, with one-half the buses stopping at each stop, headway for the street would be 25 seconds. This is 2.4 buses per minute, or 144 buses per hour per street [12, pp. 346-348]. Actual observed bus volumes range upwards to 175 buses per hour on Michigan Avenue in Chicago [12, p. 340], but this volume may not be obtainable on most streets without queueing and added delays.

Based on 144 buses per hour per CBD street, a bus corridor feeding into four downtown streets (every third street, assuming 12 blocks per mile) would have a capacity of 576 buses, or 28,800 seated passengers per hour.

5.4.3 Costs for Integrated Bus Systems

Example calculations for integrated buses using both arterial streets and exclusive busways for the line haul are presented below.

INTEGRATED COMMUTER BUS (ARTERIAL EXPRESS
LINE HAUL)

Parameter Values

"Low" time value v_1 = \$1.20, v_2 = \$3.00, v_3 = \$3.00

D_L = 3-mile average line-haul distance (6-mile total line length)

Feeder routes $n = 2$

Feeder distance L_f = 3 miles

300 passengers per square mile per hour

Supplier Costs

Distance: $D = 2D_f + 2D_L + 1$

$= 2(3 + 5/24) + 2 \times 3 + 1$

$= 13.42$ miles per vehicle-trip

Time: $T = 1.083\left(2D_f/S_f + 2D_L/S_L + 1/S_d\right)$

$= 1.083(2 \times 3.208/15$
$+ 2 \times 3/20 + 1/9)$

$= .9085$ hour per vehicle-trip

$\alpha_a = C_1 D + C_2 T + 2C_a D_L + C_d$

$= \$.325 \times 13.42 + \$13.69 \times .9085$
$+ 2 \times \$.176 \times 3 + \$.878$

$= \$18.73$ per vehicle-trip

Passengers: $P_R = \text{PDEN } L_f/n$

$= 300 \times 3/2$

$= 450$ passengers per route per hour

Optimal service frequency: $F^* = \sqrt{v_2 P_R / 2\alpha_a}$

$= \sqrt{3 \times 450/(2 \times 18.73)}$

$= \sqrt{36.03}$

$= 6$

Check vehicle load: $\text{Load} = 450/6 = 75 > 50$

Feasible frequency: $F^{**} = P_R/K$

$= 450/50 = 9$ buses per hour

Supplier Cost: $c = \alpha_a/\text{Load}$

$= \$18.73/50 = \$.37$ per passenger

User Time Costs

Access time cost: $a = v_3/8S_a$

$= \$3.00/(8 \times 3)$

$= \$.13$ per passenger

Waiting-time cost: $w = v_2/2F$

$= \$3.00/(2 \times 9)$

$= \$.17$ per passenger

In-vehicle-time cost: $h = v_1\left[\left(L_f/2 + 5/24\right)S_f + D_L/S_L + 1/2S_d\right]$

$= \$1.20[(3/2 + 208)/15 + 3/20 + 1/(2 \times 9)]$

$= \$.38$ per passenger

Egress time cost: $e = .25v_3/S_a$

$= .25 \times \$3.00/3$

$= \$.25$ per passenger

Total user time cost: $u = \$.13 + \$.17 + \$.38 + \$.25$

$= \$.93$ per passenger

Total Full Cost

$t = c + u$

$= \$.37 + \$.93$

$= \$1.30$ per passenger

INTEGRATED COMMUTER BUS (EXCLUSIVE BUSWAY LINE HAUL)

Parameter Values

"Low" time value $v_1 = \$1.20,\ v_2 = \$3.00,\ v_3 = \$3.00$

D_L = 3-mile average line-haul distance (6-mile total line length)

Feeder routes $n = 2$

Feeder distance $L_f = 3$ miles

300 passengers per square mile per hour

Supplier Costs

Distance: $D = 2D_f + 2D_L + 1$

$= 2(3 + .208) + 2 \times 3 + 1$

$= 13.42$ miles per vehicle-trip

Time: $T = 1.083\left(2D_f/S_f + 2D_L/S_L + 1/S_d\right)$

$= 1.083(2 \times 3.208/15 + 2 \times 3/45 + 1/9)$

$= .728$ hour per vehicle-trip

$\alpha_e = C_1D + C_2T + C_d$

$= \$.317 \times 13.42 + \$14.84 \times .728 + \$.878$

$= \$15.93$ per vehicle-trip

Passengers: $P_R = \text{PDEN} \times L_f/n$

$= 300 \times 3/2$

$= 450$ passengers per route per hour

Optimal service frequency:

$$F^* = \sqrt{v_2 P_R / 2\alpha_a}$$

$$= \sqrt{3 \times 450/(2 \times 15.93)}$$

$$= \sqrt{42.37}$$

$$= 6.51$$

Check vehicle load:

$$\text{Load} = 450/6.51 = 69.2 > 50$$

Feasible service frequency:

$$F^{**} = P_R/K$$

$$= 450/50$$

$$= 9$$

Share of expressway costs:

$$c_w = \$275/\left(\text{PDEN} \times 2 \times L_f\right)$$

$$= \$275/(300 \times 2 \times 3)$$

$$= \$.15 \text{ per passenger}$$

Total supplier cost:

$$c = \alpha_e/50 + c_w$$

$$= \$15.93/50 + \$.15$$

$$= \$.47 \text{ per passenger}$$

User Time Costs

Access time cost: $a = \$.13$ (See calculation for arterial express line haul.)

Waiting time cost: $w = \$.17$ (See calculation for arterial express line haul.)

In-vehicle time cost:

$$h = v_1 \left[\left(L_f/2 + .208\right)/S_f + D_L/S_L + 1/2S_d\right]$$

$= \$1.20[(3/2 + .208)/15 + 3/45 + 1/(2 \times 9)]$

$= \$.28$ per passenger

Egress time cost: $e = \$.25$ (See calculation for arterial express line haul.)

Total user time cost: $u = \$.13 + \$.17 + \$.28 + \$.25$

$= \$.83$ per passenger

Total Full Cost

$t = c + u$

$= \$.47 + \$.83$

$= \$1.30$ per passenger

Note that, at the parameter values selected, full costs are equal for the two alternatives. Costs per passenger are greater for buses operating on busways than they are for buses operating on arterial streets, but the savings in user time costs and supplier vehicle costs equals the extra way costs. For larger volumes, the busway presents the more attractive alternative, but for smaller volumes the arterial street is less costly.

These example bus costs may also be compared with the example rail costs calculated in Section 5.3.4 and the residential collection costs calculated in Section 5.2.4. The example integrated bus costs, rail costs, and residential collection costs are based on a corridor volume of approximately 10,000 passengers per hour: the feeder areas and passenger-generation densities are identical. Total full cost by rail is \$2.22 plus \$.51 for collection by bus-wagon (costs are higher by conventional bus), for a total of \$2.73, or more than double the integrated bus costs of \$1.30. User time costs by feeder and rail are \$.22 + \$.54, or \$.76 as opposed to \$.83 per passenger for integrated buses operating on exclusive busways. Rail's much higher supplier cost buys virtually identical service, measured by user time costs. At higher volumes, integrated buses have lower user time costs than rail, while at lower volumes, the user cost advantage of rail is increased. This is due to the superiority of the bus-wagon as a residential collector, compared with the conventional bus, suggesting that buses on exclusive ways fed by smaller bus-wagons may be an attractive alternative to integrated bus service.

Tables F-1 through F-4 and F-5 through F-8 of Appendix F present the complete calculation for integrated bus for "low" and "high" time values, respectively. Full costs are presented in Figures 16 through 19.

Figures 16 through 19 indicate that busway costs are less than arterial costs for larger passenger volumes (associated with longer line-haul distances and higher passenger-generation densities). For equal passenger density, the total volume of passengers is greater the longer the feeder route and the line-haul distances. For the 3-mile feeder route with the 14-mile line haul, the capacity of CBD streets to absorb the buses from the arterial street or busway is reached at about 340 passengers per square mile per hour, or about 28,800 total line-haul passengers, and the curves for the 14-mile line haul in Figures 16 through 19 are stopped at this point.

The exact breakeven volume between arterial streets and busways is easily computed, since in the relevant range, buses operate at capacity. The computation can be illustrated for a 10-mile line with 3-mile feeders. A vehicle trip costs more on the arterial street,

$$\alpha_a - \alpha_e = 23.70 - 18.63 = \$5.07,$$

reflecting both higher vehicle-mile costs due to slower line-haul speeds which are not offset by the higher capital charges, and the variable charge for the arterial street. This amounts to

$$\frac{\$5.07}{(50 \times \frac{1}{2}L)} = .0203 \text{ per passenger-mile.}$$

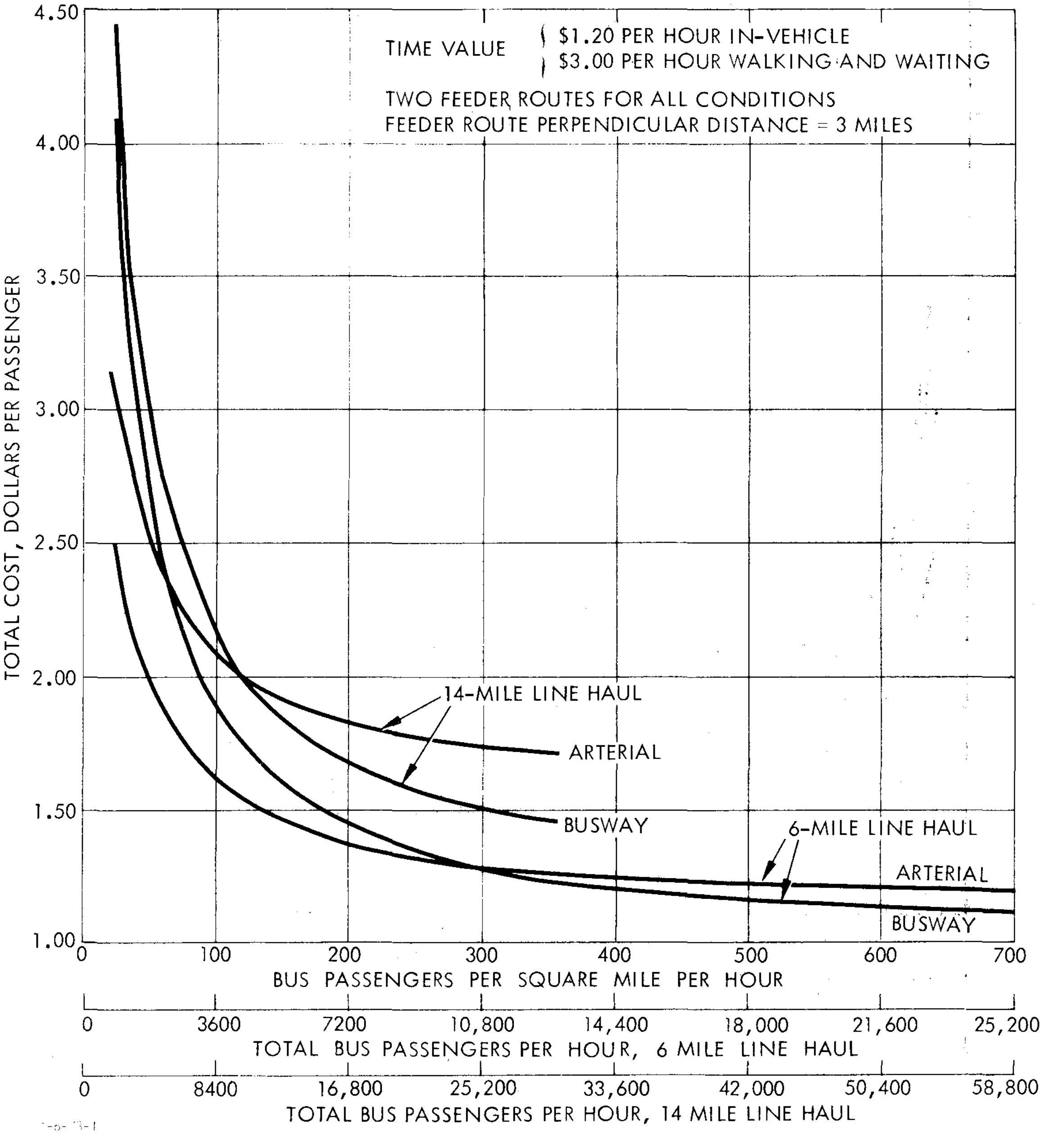

Figure 16. TOTAL PASSENGER COST FOR INTEGRATED BUS

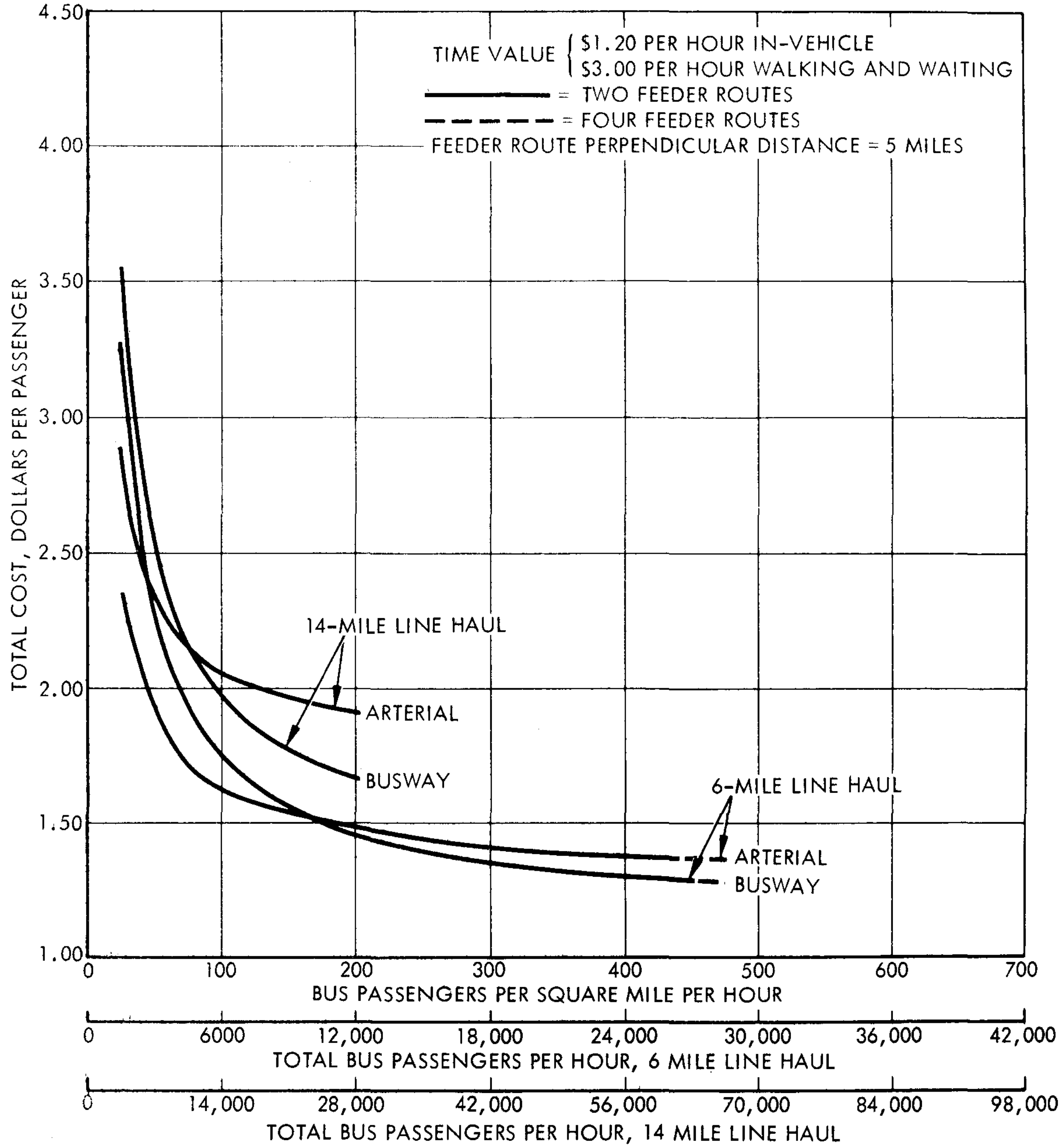

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Figure 17. TOTAL PASSENGER COST FOR INTEGRATED BUS

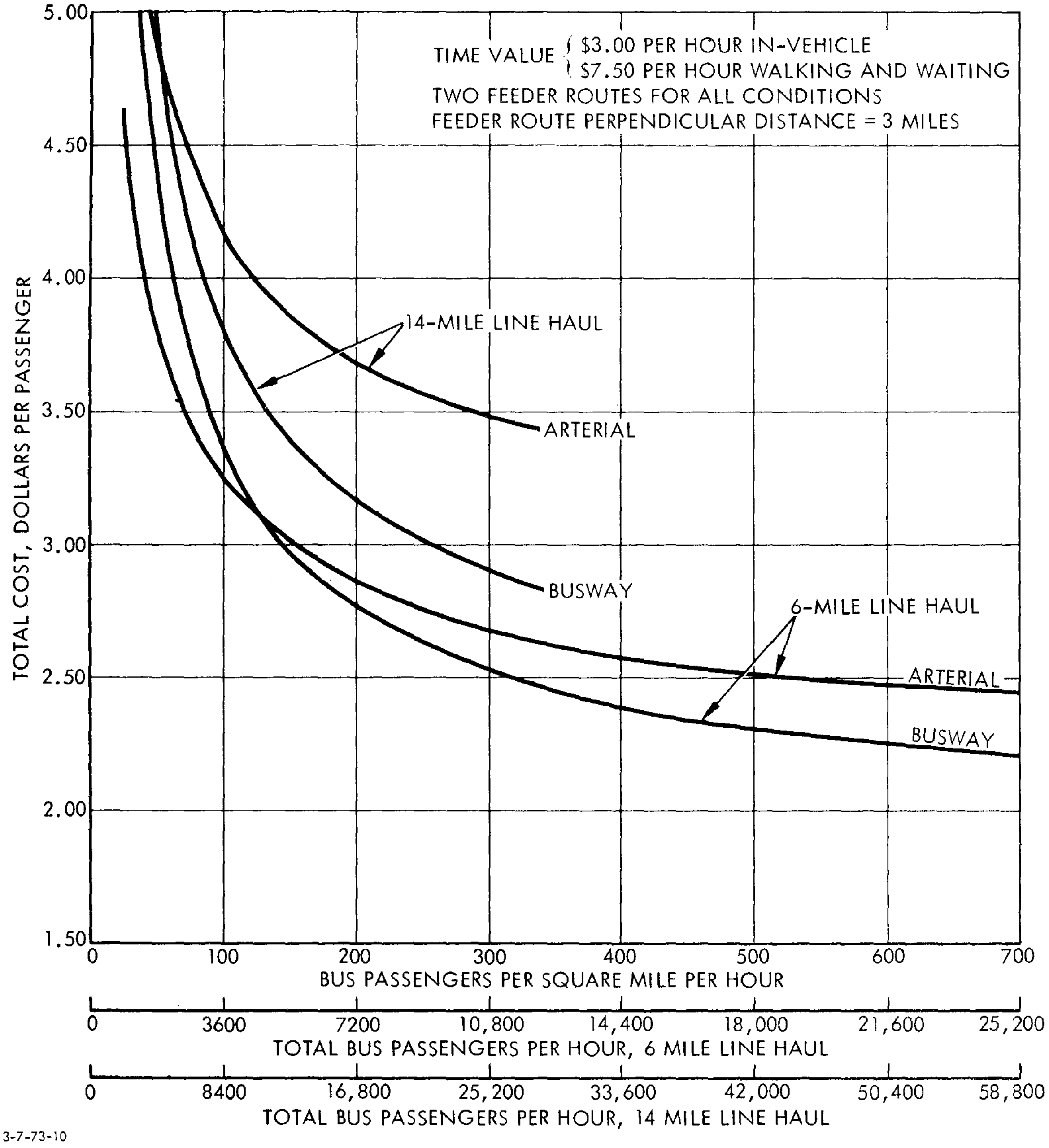

Figure 18. TOTAL PASSENGER COST FOR INTEGRATED BUS

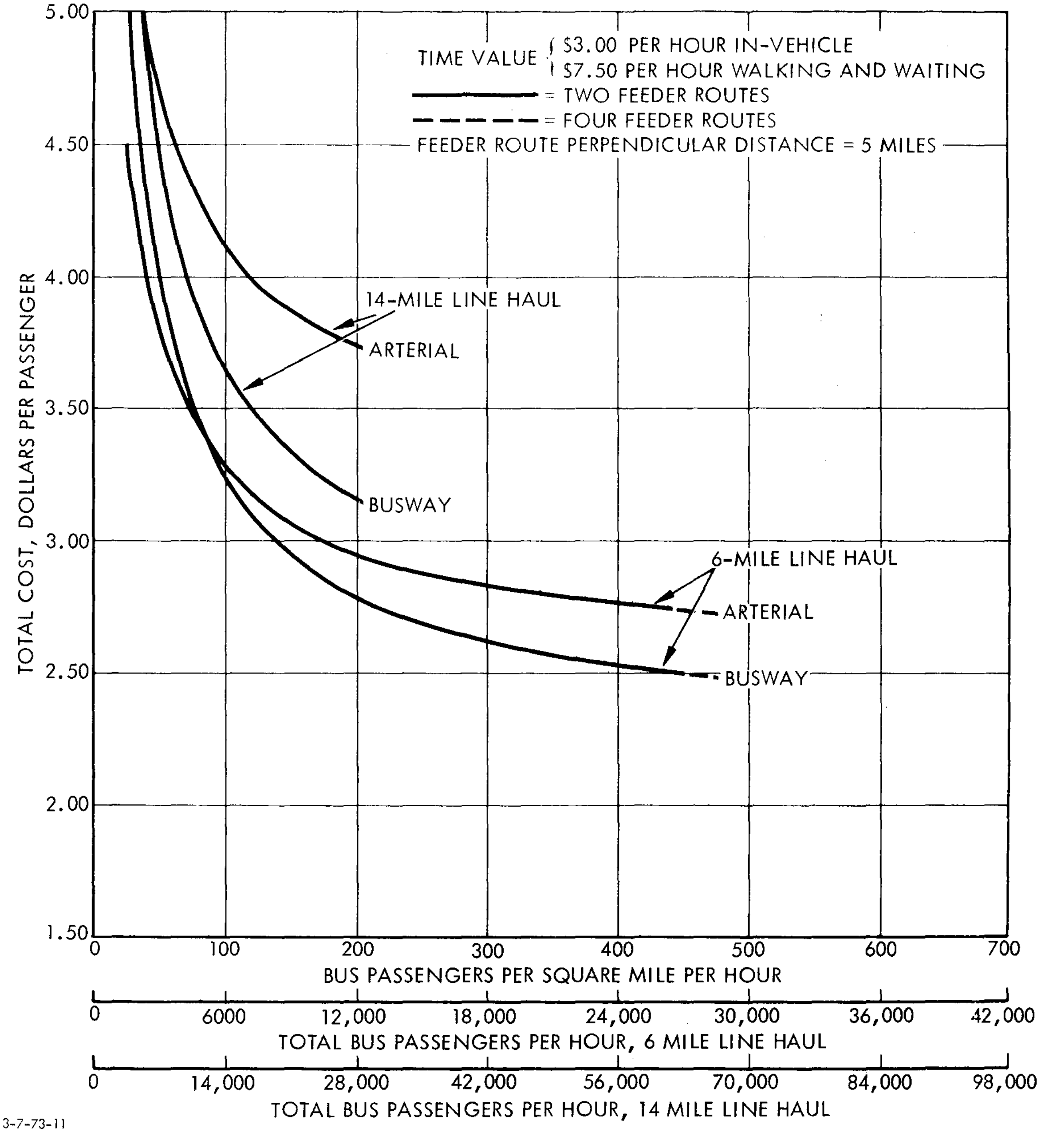

Figure 19. TOTAL PASSENGER COST FOR INTEGRATED BUS

For time values of \$1.20 per in-vehicle hour, in-vehicle time savings are

$$(1/20 - 1/45) \times \$1.20 = \$.0333 \text{ per passenger-mile.}$$

For a \$3.00 time value the savings would be \$.0833. Total variable full-cost savings would be

$$.0203 + .0333 = .0536, \text{ and}$$

$$.0203 + .0833 = .1036.$$

Since, on average, each passenger travels only one-half the length of the busway, there are two busway route-miles per average passenger-mile. A busway route-mile costs \$275 per hour, so that the breakeven passenger volumes are

$$\overline{P}_R = 2 \times 275/.0536 = 10{,}260 \qquad \text{(Low time value)}$$

$$\overline{P}_R = 2 \times 275/.1036 = 5{,}310 \qquad \text{(High time value)}$$

Breakeven volumes for other feeder and line-route lengths range from 10,100 to 11,000 for low time value, and from 5,300 to 5,500 for high time values.

5.5 COMPARISON OF RAIL AND BUS TRANSIT COSTS

Total bus and rail trip costs can be compared by comparing costs of integrated buses with those of a rail plus residential feeder combination. Table 21 is an example comparison for a "low" time value, 3-mile feeder route, and 10-mile line-haul corridor, with 18,000 corridor passengers per hour (corresponding to 300 passengers per square mile per hour in the residential areas).

For the residential collection portion of the trip, note that the vehicle costs for the 50-passenger bus are less than for the bus-wagon feeder; however, the greater frequency of service of the bus-wagon results in lower user costs, so that the total residential

Table 21. COMPARATIVE COST PER PASSENGER OF INTEGRATED BUS AND RAIL WITH 8-PASSENGER BUS-WAGON FEEDER

Type of Trip	Integrated Bus		Rail With 8-Passenger Bus-Wagon Feeder
	Arterial Street	Busway	
Residential Collection			
Vehicle Costs	$.17	$.17	$.29
Road Cost	0	0	0
User Time Cost	.43	.43	.22
Line Haul			
Vehicle Costs	.21	.14	.78
Road or Way Cost	.04	.15	.99
User Time Cost	.30	.13	.31
CBD Distribution			
Vehicle Costs	.04	.04	.05
Road or Way Cost	.02	.02	.05
User Time Cost	.32	.32	.28
Total Cost	1.53	1.40	2.97

Time Value {$1.20 Per Hour In-Vehicle
$3.00 Per Hour Walking and Waiting
Feeder Route Perpendicular Distance = 3 miles
Corridor Distance = 10 miles
18,000 Passengers Per Hour on Corridor

collection costs are $.60 for the integrated bus and $.51 for the bus-wagon.

For the line-haul portion of the trip, the vehicle and user costs for buses on the busway are less than for buses on an arterial street because of the higher speed possible on the busway (45 mph as opposed to 20 mph); however, the road costs are higher for the busway operation. Note that rail supplier costs are much higher. User costs are also higher for rail because they include the time required to transfer from the bus-wagon feeder to rail.

Both buses operate in mixed traffic in the CBD and their costs are the same; rail costs are closer to those of bus in the CBD because of the relative operating speeds (9 mph for bus and 18 mph for rail). Total trip costs are approximately twice as great for rail as for bus.

For other conditions, we compare rail and integrated bus costs by adding residential collection costs (Appendix D) to rail line-haul costs (Appendix E). In each case, the cost is the least-full cost configuration within each set of residential feeder parameters. These calculations are shown in Appendix G for various combinations of time values, feeder route perpendicular distances, and line-haul route lengths.

Figures 20 through 25 show total costs per passenger for rail (including residential collection) and integrated buses for various combinations of time values, feeder route perpendicular distances and line-haul route lengths. Note that buses operating on busways are the least costly at high passenger flows, while buses operating on arterial streets are the least costly at low passenger flows. For the various conditions covered, the cross-over (arterial versus busway) passenger volume varies from about 4,000 to 12,000 bus passengers per hour in corridor.

In all cases, total rail costs are markedly greater than those of integrated buses. The rail disadvantage increases with line-haul distance, but decreases with the number of transit passengers in corridor. The difference between rail and bus costs ranges from about $1 per passenger at high passenger volumes and 6-mile line haul to about $5 per passenger at low passenger volumes and 14-mile line haul. Rail's much higher supplier cost buys service virtually identical to that of integrated bus, measured by user time costs.

These results are based on the assumption that all passengers are seated. Most rail cars are designed to carry proportionally more standees than buses; however, in this study the number of seats per unit of floor area has been equalized for both the bus and rail car, so that the standee capacity of both is the same percentage of the seated capacity. An analysis of standees equal to 50 percent of seated passengers indicated that the total costs for the alternative systems remained nearly the same in both relative and absolute terms.

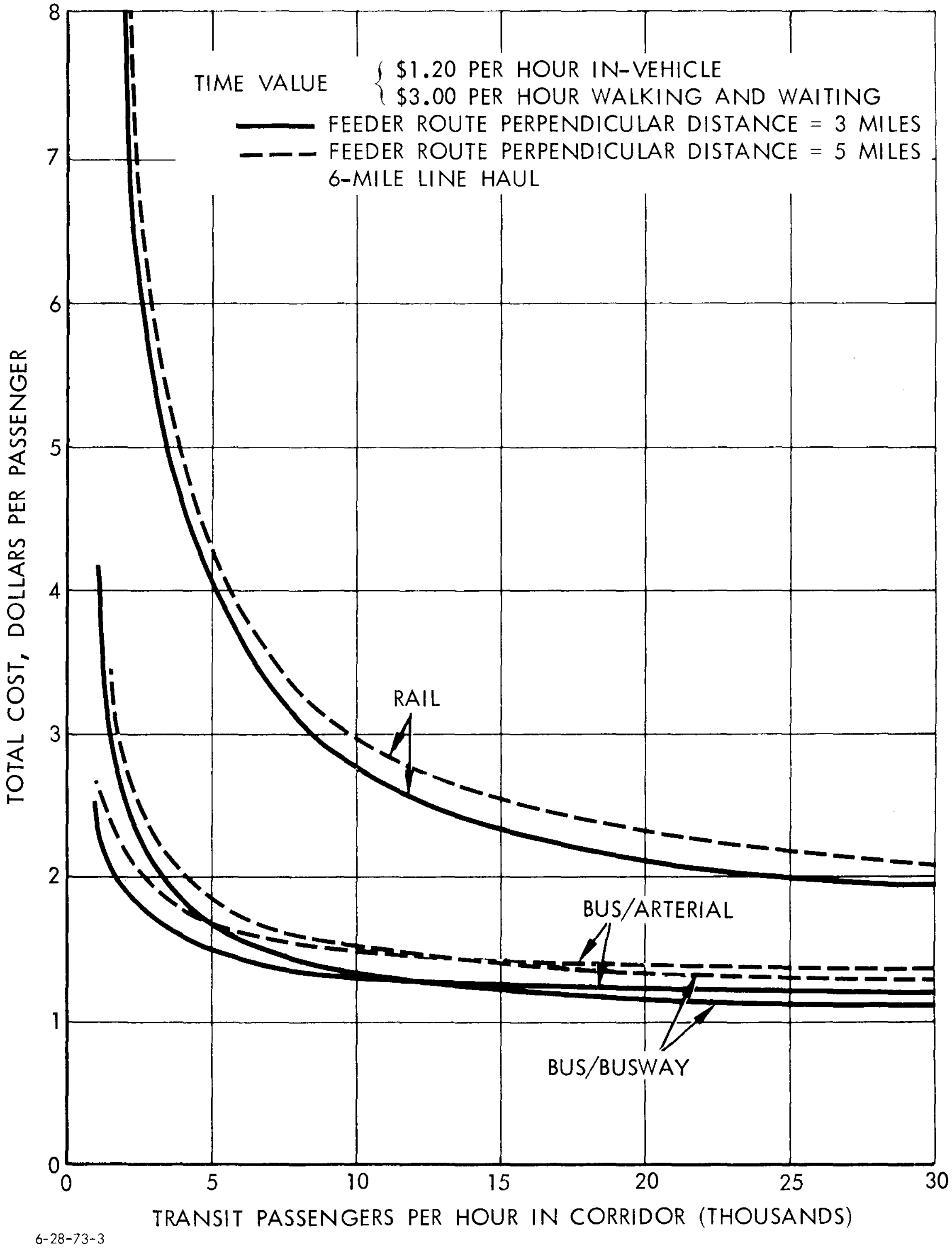

Figure 20. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER

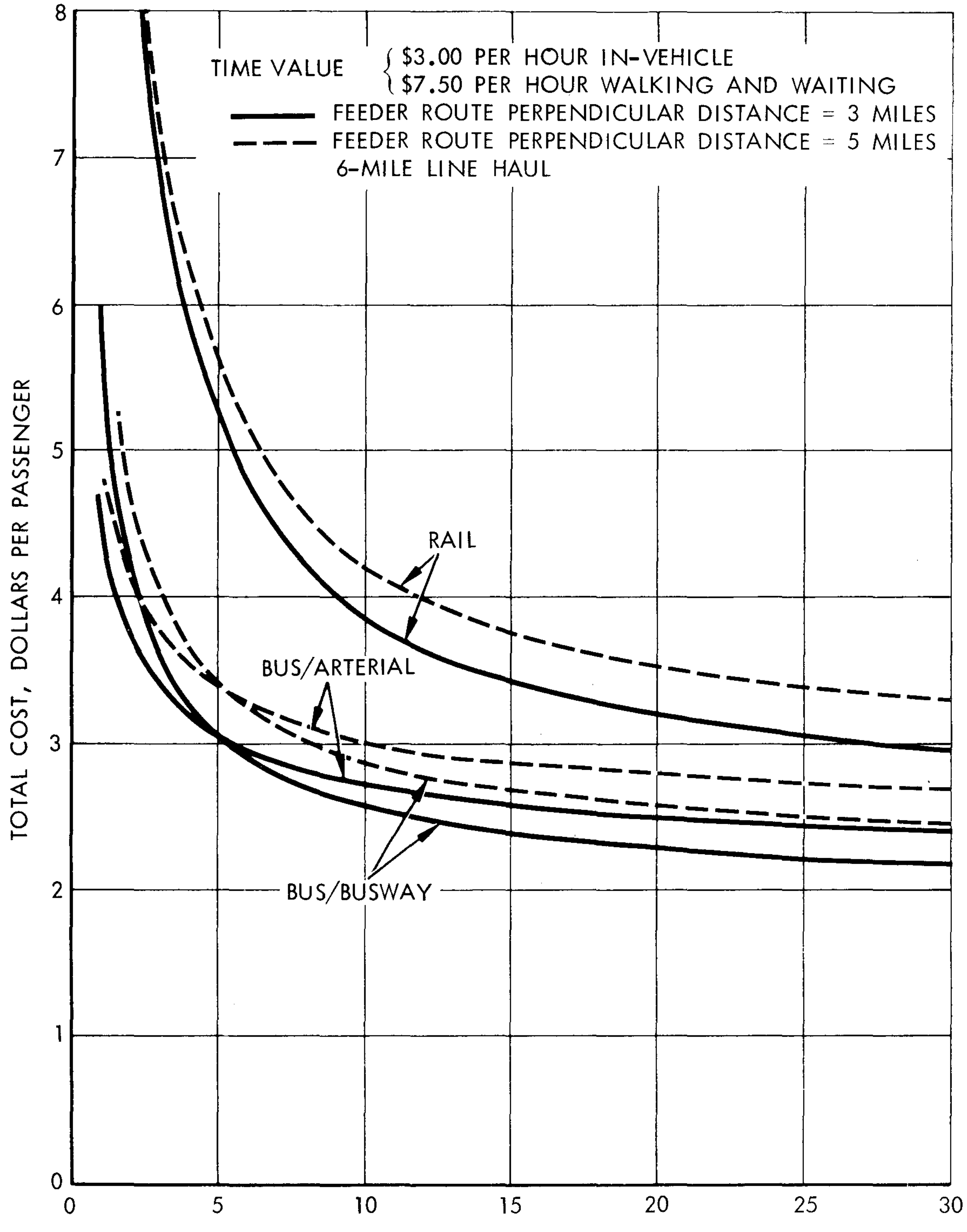

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Figure 21. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER

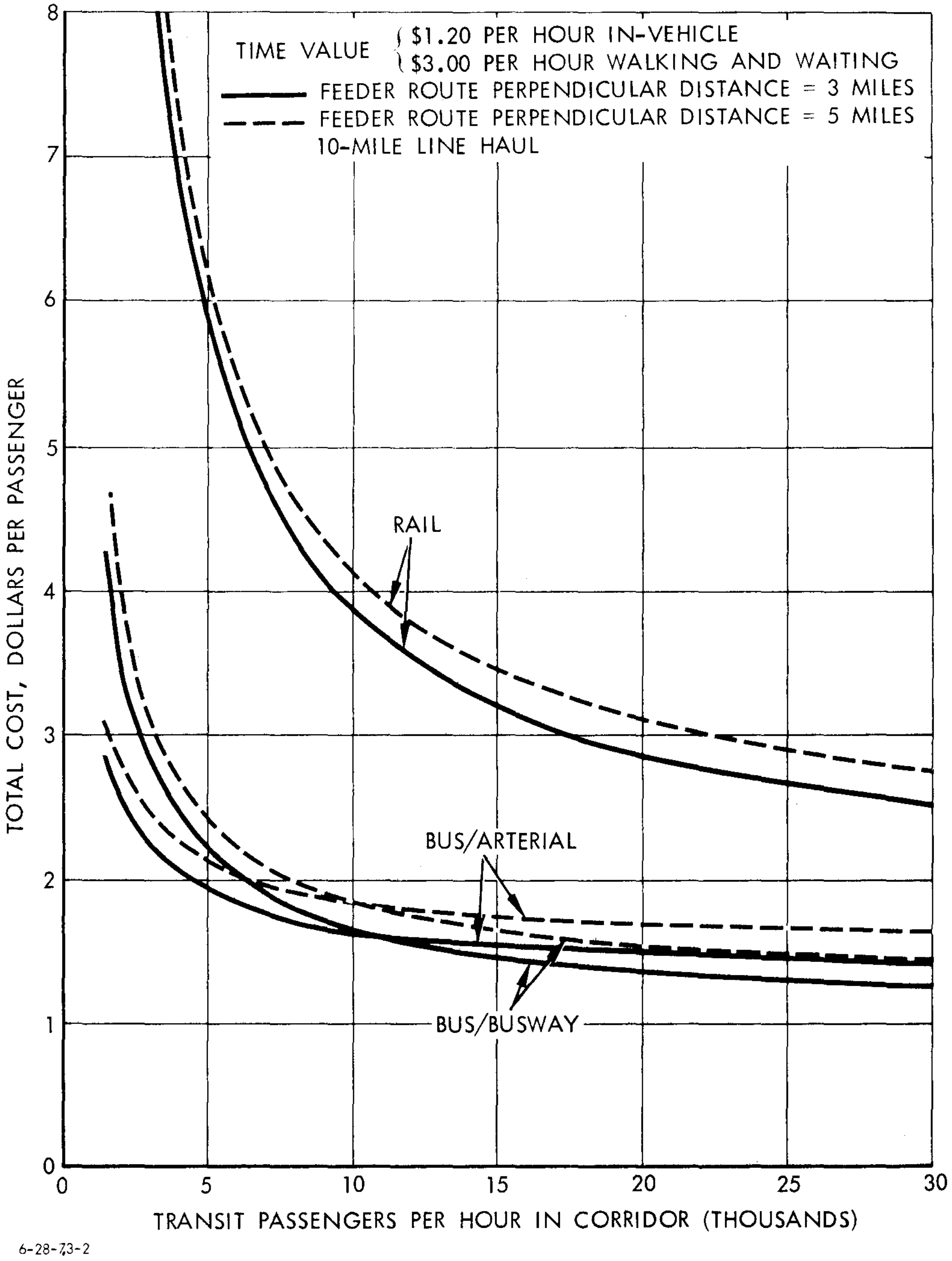
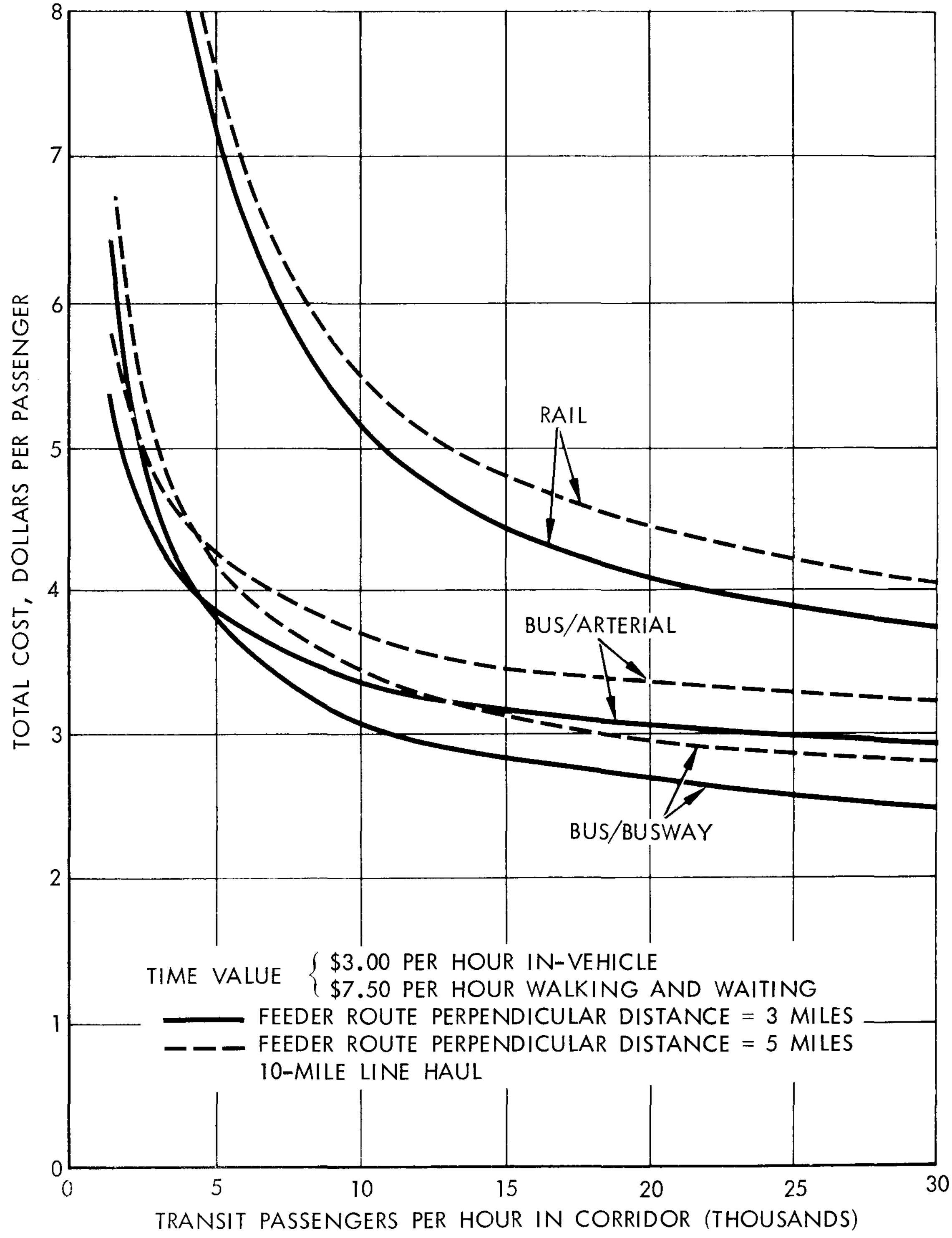
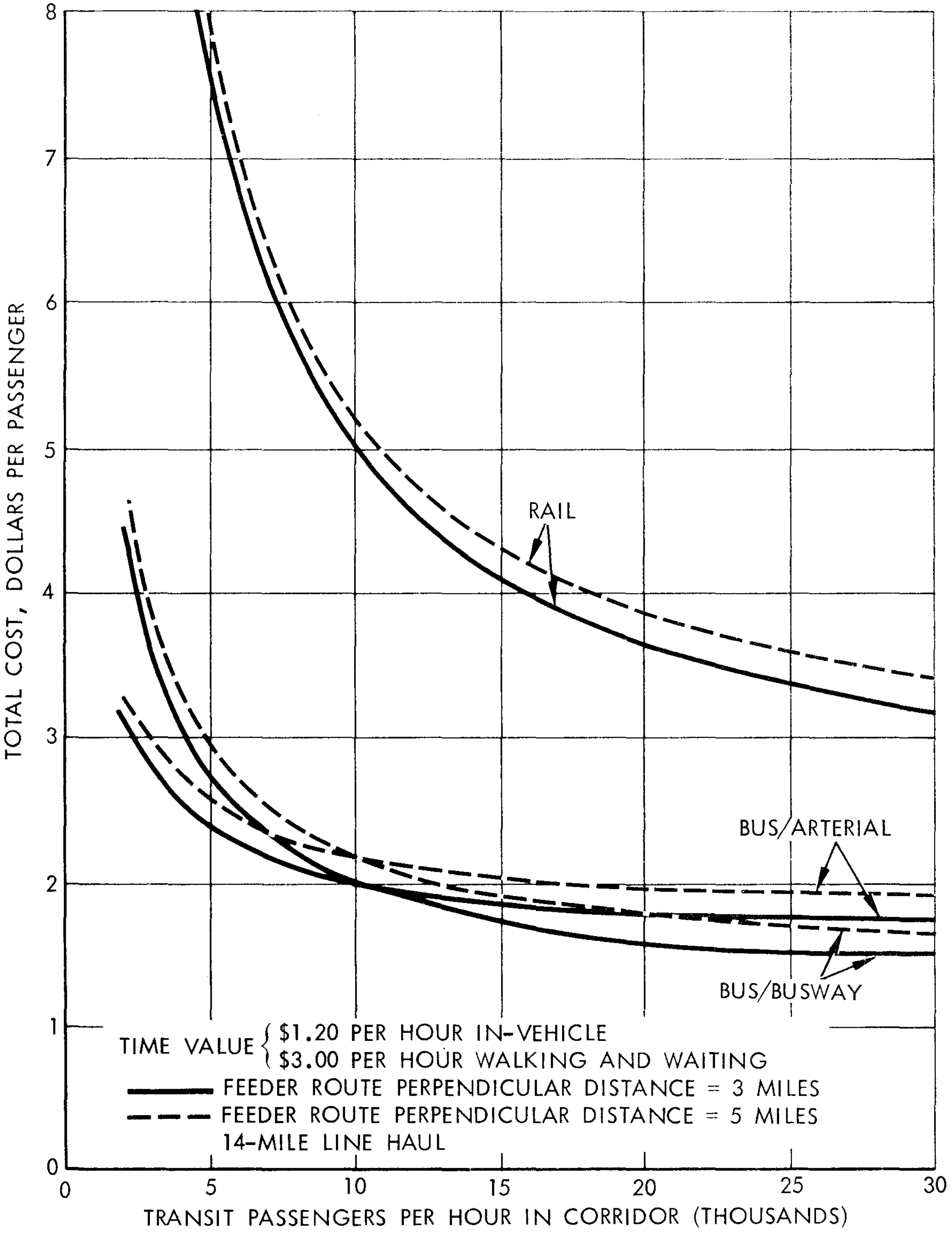


Figure 22. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER



6-28-73-5

Figure 23. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER



6-28-73-6

Figure 24. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER

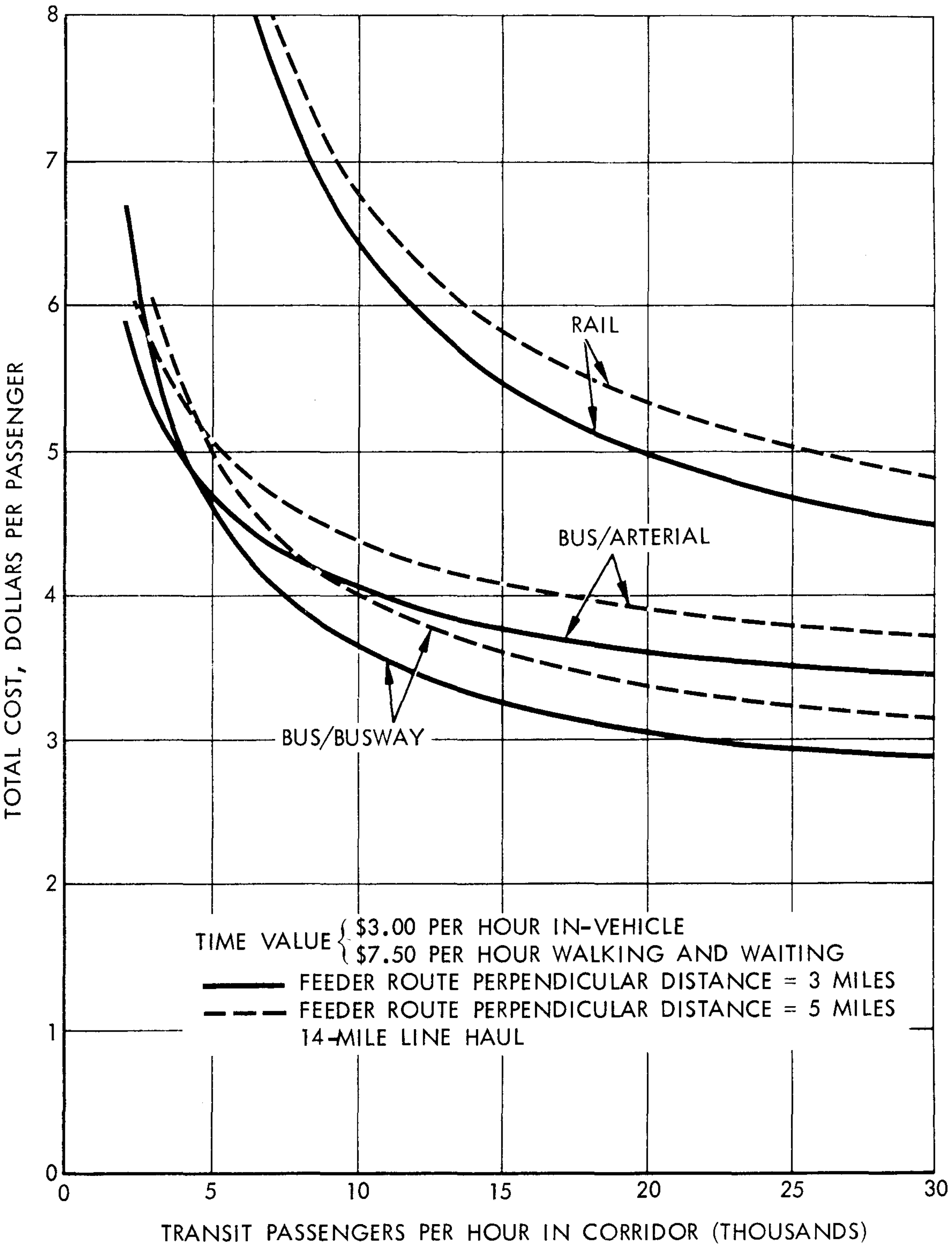


Figure 25. RESIDENTIAL COLLECTION PLUS LINE-HAUL COST PER PASSENGER

For example, for the conditions of Table 21 (18,000 passengers per hour on Figure 22), total costs per passenger were reduced from \$1.53 to \$1.45 for integrated buses operating on arterial streets, \$1.40 to \$1.35 for integrated buses operating on busways, and \$2.97 to \$2.70 for rail with 8-passenger bus-wagon feeder. These surprisingly small decreases are due mainly to the fact that, although vehicle costs are reduced, user time costs are increased because of lower vehicle frequency. Further, the busway and rail way costs per passenger remain the same, since those costs must still be allocated to the same total number of passengers.

Changes in the figures of Table 21 for 50 percent standees, rounded to the nearest cent, are given below:

Residential Collection

Bus vehicle costs drop from \$.17 to \$.11.

Bus user time costs increase from \$.43 to \$.51.

Line Haul

Vehicle costs drop from \$.21 to \$.14, \$.14 to \$.09, and \$.78 to \$.52.

Arterial street costs drop from \$.04 to \$.03.

Rail user time costs increase from \$.31 to \$.32.

CBD Distribution

Bus vehicle costs drop from \$.04 to \$.03; rail car costs drop from \$.05 to \$.03.

Road costs drop from \$.02 to \$.01.

The cost elements not mentioned above are the same with or without standees.

6. THE POLITICAL, REGULATORY, AND INSTITUTIONAL ENVIRONMENT

6.1 URBAN PUBLIC TRANSIT: POTENTIAL AND ACTUAL

> The "jitney" episode of 1914-1915, wherein private automobiles were used as rivals to street railways, is typically treated in histories of American urban transportation either as an historical aberration, or at most, as an incident which inseminated the engineering design of early buses. Rather, ... the jitney episode was central to the history of urban transportation, and, more specifically, the policy of putting down the jitney led directly to much of what is looked upon as most unsatisfactory in contemporary urban transport [33, p. 293].

> The most pernicious consequence of the taxicab monopoly ordinance has been the significant constraint imposed on [Chicago's] public transportation policy.... The fact that the illegal, but tolerated jitneys, operating licensed cabs with a capital value in excess of $15,000, can offer lower fares than the transit system on short hauls shows the possibilities of the public transit auto [34, p. 347].

To recapitulate the findings of our comparison of urban transportation capital alternatives, the 8-passenger bus-wagon jitney has generally lower full costs than conventional transit buses for low-density residential collection. The greater frequency of service and higher travel speed of the bus-wagon outweigh the bus' lower seat-mile costs. Buses are economical for long hauls and high densities, especially on high-speed busways for the line-haul portion of the trip. In comparison, rail transit has much higher full costs than express bus service. By inference, bus-wagons operating as jitneys are likely to have lower full costs than bus transit for inner city circulation services, those bus operations within the city other than peak-hour CBD commutation.

This menu of low full-cost alternatives contrasts sharply with the present U.S. urban transportation scene. Conventional local bus service offers what is universally acknowledged to be low-quality service (slow, infrequent, uncomfortable), at a high money cost per passenger. New rail systems are in various stages of completion in several cities, and existing rail systems are being reequipped. These new and refurbished rail systems are designed to offer a better quality service than existing bus transit for at least some peak-hour commuters, but at a very high money cost per passenger (not fully reflected in fares).

6.2 REGULATORY BARRIERS TO TRANSIT INNOVATION

That low full-cost transit alternatives have not emerged as the result of market forces is no accident, but is the result of institutional and political forces operating at the local, state, and Federal levels. Economic regulation in the form of control over transit prices and services and control of entry and exit, has excluded public transit alternatives such as the jitney. It has also inhibited the efficient utilization of the limited range of permitted alternatives. That economic regulation of fares, service, and entry should have this effect is, of course, no surprise. Federal subsidy programs, such as the UMTA Capital Grant Program, among other effects, tend to perpetuate the present organization of the industry, since most of these subsidy funds are used to support existing types of operations.

Recent theoretical advances and empirical research have resulted in the following picture of economic regulation. In an industry with many suppliers, regulation creates monopoly profits for the regulated firms by eliminating price competition and many aspects of service competition. Private collusion to fix prices, restrict output, and cartelize an industry is difficult to control because of the incentive to "cheat" and offer secret price concessions to win extra business from one's rivals [35]. Indeed, such private collusion is illegal under the Sherman Act (1890).

In the urban transit market, taxicabs are limited in number (except in Washington, D.C., as discussed below), and are not allowed to charge less than the metered rate, thus eliminating price competition. Bus and rail systems have exclusive franchises to serve their market areas, eliminating competition. Taxis are generally limited to metered rates. Typically, this results in long queues of taxis at places such as airports where returns at current meter rates are great, and shortages in ghetto neighborhoods and at peak hours where returns are smaller because of dangers or congested traffic. Bus companies are usually required to charge a flat fare during peak or base hours, for long or short hauls, and to offer service on thinly patronized routes even on weekends and evenings. Earnings from high-density routes apparently are being used to support low-density services. The reason usually stated is that competition would not serve the low-density areas very well and thus service to those areas would have to be subsidized somehow. But even though regulated firms are protected from public transit competition (i.e., for hire), they are still subject to competition from private autos.

6.3 THE RISE AND FALL OF THE JITNEY: A CASE STUDY IN REGULATION

Eckert and Hilton [33, pp. 301-303] have documented the rise of the jitney in 1914-1915 and its consequent rapid demise. This was a genuine innovation which, by market standards, was quite successful, spreading rapidly across the country in a year or so. Only an easily obtained chauffeur's license and a Model-T Ford were required to enter the industry, although the Model-T was far from ideal for this service. While some fleets were operated, the characteristics of free entry and exit, with substantial owner-driver or lessee-driver participation, were similar to those we have assumed for the jitney and bus-wagon alternatives.

The major problems with the jitneys were their high accident rate and occasional use for criminal purposes against or by passengers [33, pp. 306-307]. Undoubtedly, these problems could have been solved with a minimal system of registration and policing. If adequate safety and insurance standards had become widespread, it is likely that demand for this alternative would have increased. Vehicles more suitable than the Model-T would also have emerged: Eckert and Hilton report that "Charles E. Duryea, one of the inventors of the automobile, ...recommended a rear-engined vehicle with an air-cooled engine of a small number of cylinders--a virtually exact description of the present Volkswagon Microbus." Our cost-estimating relationship for jitneys and bus-wagons include liability insurance and other types of insurance based on taxicab costs. The results of our computations in Chapter 5 show that Duryea's analysis of vehicle requirements for jitney service was correct, since the bus-wagon alternative does have lower supplier plus user costs than the automobile. The only legal U.S. jitney operations, in Atlantic City and San Francisco, use bus-wagons.

Eckert and Hilton show conclusively that the jitneys were put out of business, not by economic forces, but by a political coalition headed by the street railways, whose earnings were being undermined by this new form of competition. Devices for eliminating the jitney included (1) franchises which were difficult or impossible to obtain and often required special taxes; (2) license fees and liability bonds, set at rates high enough to substantially increase jitney costs; (3) elimination of part-time operations through the imposition of requirements for long hours of service; (4) limitations on routes and schedules; (5) prohibition of short routes; (6) restrictions on operations competitive with streetcars. Safety regulations, to the extent that they were more stringent than those applied to private atuos and were adopted primarily to increase jitney costs, also served to limit the jitneys. Such legislation was adopted in city after city. By the early 1920s, jitneys had largely disappeared.

6.4 THE POLITICAL ARITHMETIC OF ECONOMIC REGULATION

That industry groups should be able to use the political and regulatory process to create and preserve monopoly power and its profits can be demonstrated by a numerical example: suppose a given political action will benefit 100 people in the amount of $10,000 each ($1,000,000 total) and impose costs of $15 each on 100,000 people ($1,500,000 total). There is a net deadweight loss to the economy of $500,000. But the gainers from the action are concentrated, and will find it to their advantage to discover the benefits to them of the action, to combine forces to lobby for its passage, and to support friendly legislators with campaign contributions and votes. It is also the big gainers (or losers) who plead their case before economic regulators. The losers in our example would not find it worthwhile even to discover the exact costs to them of the policy, much less to lobby, contribute, change their vote, or plead before a regulatory commission. The regulator and the legislator, balancing the competing claims presented by industry and big consumer groups, use control of price, service, and entry and exit to create monopoly profits and distribute them, to a greater or lesser extent, to vocal groups. In the case of the jitney, the voices that were heard were the trolley car operators, and, to some extent, merchants who feared the disruption of trade patterns established by the trolley lines. On the positive side, trolley cars contributed franchise tax revenue or free services, such as street lighting, to the city. The jitney operators, even when they banded together in trade associations, had little political power, because with free entry there were no monopoly earnings. Patrons, the major beneficiaries of the improved transit service (as evidenced by their support for the jitney when offered this alternative), though numerous, individually lost little when the jitneys were eliminated. A consumer lobby was not among the political forces deciding the fate of the jitney although there was some isolated newspaper support, [33, pp. 303-307, and 34, p. 347].

Washington, D.C. is the sole exception to stringent regulation of entry into the taxicab business, although its zone fare rates result in geographic uneveness in supply and the absence of a peak-hour fare differential results in scarcities of cabs during peak-load hours [1, p. 285]. The competitive character of the taxi industry in Washington, D.C. is often attributed to the fact that the city is controlled by the U.S. Congress whose members are not elected by residents of the District of Columbia. Thus, the taxi industry in that city is shielded from the kind of political pressures that brought about the demise of the jitneys.

6.5 THE "NEED" FOR CONVENTIONAL TRANSIT

Transit industry sources and others believe that there is a "need" for transit services, independent of the willingness or lack of willingness of patrons to pay for such service. Frequently cited rationales include the improvement of mobility for those disadvantaged persons who do not or cannot drive their own automobiles, the easing of congestion and pollution caused by private automobiles, and the reduction of "undesirable" urban sprawl caused in part by the private auto. These arguments are used to justify both public subsidies for transit and the exclusion of transit competition.

The MIT Urban Systems Laboratory [30] has presented evidence that private automobile and transit are close substitutes even for those who do not drive. The MIT report shows that nonschool trips per capita by unlicensed individuals are quite constant across cities, independent of the level of transit service. Where transit service is poor, there are many private auto trips made for the benefit of passengers rather than the driver. In a competitive transit market, many of the passengers in private automobiles would travel by other means such as the jitney.

The data presented in Chapter 4 indicate that private autos as well as transit buses pay far less than the true opportunity costs of their use of congested urban streets. A dollar value for pollution, if one could be established, would increase further the discrepancy between user fees and true costs. To the extent that buses and jitneys and private autos are substitutes, jitneys may reduce congestion, but the higher occupancy rate must be balanced against more frequent stops to pick up and discharge passengers. In the absence of pricing to ration street capacity and rationalize street usage, there may be grounds for excluding jitneys from certain areas; for example, the CBD in peak hours. The same rationale would call for exclusion at the same time of private auto travel in the restricted areas.

Proponents of rail transit believe that rail transit is the only technology capable of offering high-quality service. This study has presented evidence and analysis to the contrary; busway services offer approximately equal user time cost commutation at far lower supplier cost.

6.6 THE FEDERAL ROLE

Federal transit subsidy programs, limited as they are to established franchise holders, perpetuate the existing institutional organization of the industry. The UMTA Capital Grant Program has the added disadvantage of promoting uneconomical substitution of capital for labor. Buses are scrapped sooner than they should be to minimize the sum of annualized capital and operating costs, since only capital costs are subsidized [36].

Apparently, the UMTA Capital Grant Program partially explains the current popularity of capital-intensive rail transit systems, although BART was completed largely without Federal aid. Proponents of rail systems may also incorrectly perceive the costs and benefits relative to alternative transit systems or to noncapital alternatives such as road pricing. Increased experience with systems in place or under construction, coupled with the analysis of the data they generate, should further reduce the range of uncertainty associated with costs and benefits of the technologically advanced rail systems.

The question remains, how might Federal policy help achieve greater rationality in the choice among urban transportation capital alternatives? Based on our comparison of the full costs of rail and express bus systems, it seems difficult indeed to justify new rail systems. Bus systems, operating in express service and perhaps on exclusive ways could serve commuters at approximately equal user time cost and far lower supplier cost. Little institutional innovation would be required for the Department of Transportation to shift Federal support from rail to express bus systems.

Regulatory and legal innovations would be required to encourage genuine competition among all modes. A license to drive a car for hire as a jitney could conceivably result in an efficient mode of public transportation and it should be no more difficult to obtain than an ordinary chauffeur's license. It might be useful to have these licenses posted in the vehicle with the driver's photograph attached. Fares could be allowed to fluctuate according to demand and supply condition. Undoubtedly, they would be higher in peak times, in "dangerous" areas, in foul weather, or late at night. These high fares would call forth additional supplies in these times and places relative to a level fare. Fares would fall during non-peak periods, stimulating demand in slack periods and providing inexpensive transport for many who otherwise could not afford to travel. However, given the flexible nature of the technology, and the vast pool of private automobile drivers, it is unlikely that peak/off-peak fluctuation would be marked. It is likely that there would be considerable variation among routes, however, depending on demand and supply conditions. We might expect auxiliary services, such as delivery off the route, to be provided at extra cost.

Current insurance practices and liability laws may inhibit the introduction of jitneys. Most private auto policies exclude coverage in for-hire service. Taxicab insurance is much more expensive and would be appropriate for full-time, high-mileage jitneys. Taxicab insurance costs about the same as private auto insurance per vehicle-mile, and taxis are driven two to three times as far per year as private automobiles [31, p. 8-30]. The casual or part-time operator would need a different sort of policy, one giving coverage in for-hire service, but at a lower cost than the full-time policy. Since there is now no market for such policies, none now exists. UMTA could sponsor the development and issuance of insurance coverage by insurance companies for part-time jitney operators.

Police-type regulations governing stopping and parking by jitneys may prove to be beneficial. The danger of such regulations is that they might be used for anti-competitive purposes, by providing the means for established bus and taxi operators to inhibit the legitimate use of jitneys. The same vehicle safety regulations and traffic control laws that apply to private automobiles should probably also apply to jitneys.

A major obstacle to the introduction of a jitney service would be its effect on established bus firms. Both privately and publicly owned firms would probably be opposed to the introduction of this competition, because of the necessity of protecting profitable routes which earn monopoly returns from "cream skimming," and whose loss would impair the cross-subsidization of money-losing services. Our analysis suggests that bus service has a comparative advantage in high-density, long-haul services, and it is possible that bus service would be eliminated only from the unprofitable low-density routes. If at the same time fares were reduced on the presently highly profitable routes, the public would seem to gain much from competition.

One strategy which DOT could pursue would be to encourage jitney service in one or more cities without organized bus services. Table 22 contains a list of such cities with populations ranging upwards of 100,000. A city without conventional bus transit would not necessarily be the best place for an experimental jitney operation, but the power of organized groups with an interest in continuation of the present closed-monopoly organization of the industry would be somewhat less. Many of the cities listed in Table 22 probably do have franchised and regulated taxicabs, but perhaps funds from an UMTA demonstration grant might be used to compensate taxicab licensees for the loss in value of their franchises. If transportation is deregulated, existing taxicab companies would have the option of offering both taxicab and jitney services, depending on supply and demand conditions.

Table 22. CITIES CURRENTLY WITHOUT ORGANIZED LOCAL TRANSIT SERVICE

City	1970 Population	City	1970 Population
Independence, Mo.	111,630	Salina, Kan.	40,914
*Fremont, Calif.	100,869	*Allen Park, Mich.	40,747
*Irving, Texas	97,260	Denton, Texas	39,874
*Sunnyvale, Calif.	95,408	Greenville, Miss.	39,648
*Arlington, Texas	89,723	Casper, Wyo.	39,361
*Pasadena, Texas	89,277	*Texas City, Texas	38,908
*Garland, Texas	81,437	Marion, Ohio	38,646
Norwalk, Conn.	79,113	*Hutchison, Kan.	36,885
Kenosha, Wisc.	78,805	Redlands, Calif.	36,335
Odessa, Texas	78,380	*San Bruno, Calif.	36,254
Lorain, Ohio	78,185	*Bowling Green, Ky.	36,253
*Orange, Calif.	77,374	Findlay, Ohio	35,800
Anderson, Ind.	70,787	Port Huron, Mich.	35,794
*West Covina, Calif.	68,034	Idaho Falls, Idaho	35,776
*Tuscaloosa, Alabama	65,773	Midland, Mich.	35,176
*Mesa, Arizona	62,853	*Harlingen, Texas	33,503
Fort Smith, Ark.	62,802	Engelwood, Colo.	33,695
Great Falls, Mont.	60,091	*Lancaster, Ohio	32,911
*Westminster, Calif.	59,865	*Attleboro, Mass.	32,907
Midland, Texas	59,463	*Highland Park, Ill.	32,263
Port Arthur, Texas	57,371	Clarksville, Tenn.	31,719
*Mesquite, Texas	55,131	*Westfield, Mass.	31,433
*Provo, Utah	53,131	Cape Girardeau, Mo.	31,282
*Mountain View, Calif.	51,092	Kankakee, Ill.	30,944
Owensboro, Ky.	50,329	New Iberia, La.	30,147
*Newport Beach, Calif.	49,422	*Monrovia, Calif.	30,015
*Monterey Park, Calif.	49,166	Ft. Pierce, Fla.	29,721
Woonsocket, R.I.	46,820	Bartlesville, Okla.	29,683
So. San Francisco, Calif.	46,646	Missoula, Mont.	29,497
Haverhill, Mass.	46,120	*Kingsville, Texas	28,915
Muskegon, Mich.	44,631	Big Spring, Texas	28,735
Athens, Ga.	44,342	*Oak Ridge, Tenn.	28,319
Kokomo, Ind.	44,042	*Prairie Village, Kan.	28,138
*Baytown, Texas	43,980	*Gloucester, Mass.	27,941
*Rapid City, S.D.	43,836	Selma, Alabama	27,379
Taunton, Mass.	43,756	Marietta, Ga.	27,116
Ft. Collins, Colo.	43,337	Goldsboro, N.C.	26,810
Elkhart, Ind.	43,152	*Menlo Park, Calif.	26,734
Newark, Ohio	41,836	*Hilo, Hawaii	26,353
*Rockville, Md.	41,564	Lewiston, Idaho	26,068
*Lahabra, Calif.	41,350	El Dorado, Ark.	25,283
Victoria, Texas	41,349	*Orange, Texas	24,457
Cheyenne, Wyo.	40,914	Laurel, Miss.	24,145

*According to available records, never had local transit service.

Source: ATA Statistics Department, July 1972.

APPENDIX A

COSTS OF SUPPLYING URBAN PUBLIC TRANSPORTATION

APPENDIX A

COSTS OF SUPPLYING URBAN PUBLIC TRANSPORTATION

A.1 INTRODUCTION

There are many sources of cost information on public transportation, both published and unpublished, but most published data suffer from one or more defects which limit their usefulness for comparing alternative systems. First, most sources give estimated cost data for a single year. Over the past decade there has been a moderately high rate of inflation across the economy as shown by the Consumer Price Index, and an even higher rate in the labor-intensive urban public transportation industry. Further, costs of different elements of public transit systems have been increasing at different rates; for example, the price of new buses has been increasing much more slowly than the price of rail transit cars. Hence, it is very difficult to assemble and make compatible the data for different system elements at different periods. Second, much of the published data is of dubious value. Sources of costs are often not given or are obscure. Frequently, investigators are forced to use professional judgment to fill in important gaps. Presumably, all cost data are for systems with specific characteristics--equipment, speed, etc.--but often, important characteristics are not specified in published sources.

To remedy these defects, we have constructed cost estimates based primarily on information in IDA's Computerized Data Bank on Urban Public Transportation. The data base consists of computer tapes, based on reports by member firms to the American Transit Association (ATA) and International Taxicab Association (ITA), supplemented by other data obtained directly from individual transit properties. In addition, published sources have been mined for additional data to assemble a comprehensive picture of urban public transit costs.

In this report data are presented for past years in terms of the actual dollar value for the year of the data (current dollars). Based on trends in the cost of each element, costs are projected to 1972, 1980, and 1990, all expressed in 1972 dollars. In comparing competing systems, ideally, one should project the annual costs of each system over its lifetime and then discount the stream of costs to a present value for each system. Such a calculation requires a detailed time phasing of the planning, procurement, construction, and operating costs of each system. For simplicity, we have used 1980 costs (expressed in 1972 dollars) for all elements of all systems. This is a representative period for the operation of competitive systems being evaluated now.

We present costing methodologies and estimates of costs for both rubber-tired and rail-transit systems. The rubber-tired vehicles considered are 5-passenger jitney, 8-passenger bus-wagon, 19-passenger minibus, and 50-passenger buses (both conventional and expressway models). The costing of the rubber-tired vehicles is based primarily on taxi and conventional bus data. The rail systems are primarily those rapid transit systems currently operating in the U.S. and Canada, with some additional data presented for systems under construction and in other countries.

The elements of cost include (1) vehicle, roadway, and miscellaneous capital costs, and (2) vehicle and roadway operating and maintenance costs. For ease in comparison, we have converted the disparate elements of system costs, both capital and operating, into the common denominator of costs per vehicle-mile. The vehicle-mile costs used as examples are based on typical mid-range values for both the cost elements and annual vehicle miles. Some costs, such as fuel costs or bus purchase costs, are fairly constant for different operations in different cities. Other costs, particularly site-specific capital costs such as roadway or guideway right-of-way and construction costs, can vary considerably from these typical values. In all cases, we have tried to present our methodology and data in sufficient detail to allow the reader to adjust our results for locales with substantially differing costs for land and other specific inputs.

The basic cost data for currently operating systems form the inputs to the cost-estimating relationships presented at the end of this appendix. These relationships are used in the case studies reported in Chapter 5. The theory of peak-load pricing was used to derive an allocation of vehicle capital costs between peak and base services (technical details are given in Appendix B), and differential labor cost estimates were constructed for peak and base services. We have also allocated vehicle capital and operating costs between vehicle hours and vehicle miles to ascertain the effect of service speed on supplier costs.

A.2 SUMMARY

Costs per vehicle-mile have been developed for several vehicle types performing different public transit operations. The systems analyzed are shown in Table 10 of Chapter 3. The first three types of service (residential collection and distribution, line-haul, and CBD distribution) comprise the elements of peak-hour commuter travel. Representative route speeds for each vehicle type in each operating environment are shown. Cost elements considered for each system include both operating and capital costs. The costs are 1980 costs expressed in 1972 dollars. Cost figures are presented in the body of this appendix for 1972, 1980, and 1990, all expressed in 1972 dollars. 1980 is selected as a representative period for the operation of competitive systems being evaluated now.

In the case of the exclusive busway and rail rapid transit systems, the entire roadway (or track) cost was included in the system cost. In the case of rubber-tired vehicles operating on congested streets with other traffic, a portion of road operating and capital costs have been allocated to the public transportation vehicles.

One can argue that residential streets are needed for other purposes, regardless of public transit service. Residential streets are, in general, not made more expensive due to their use by public transit vehicles. Further, they are generally uncongested so that public transit vehicles do not impose significant delay costs on other vehicles. For these reasons, it is felt that the capital costs of residential streets should not be allocated to public transit vehicles.

All capital costs include an interest charge of 10 percent. A greater proportion of vehicle and way and structures capital costs are allocated to peak-hour than to base-hour service.

The final column shows the total of vehicle, miscellaneous, and way and structures costs. The cost per vehicle-mile for the rail transit system is much higher than for the 50-passenger bus systems. Even after accounting for the rail car's higher seating capacity, its cost per seat-mile is still much higher than for the large bus systems. The high rail transit costs are due primarily to high capital costs.

A.3 COST OF CONVENTIONAL RUBBER-TIRED VEHICLES

A.3.1 Vehicle Operating Costs for 50-Passenger Buses

The following paragraphs present a discussion of the costs involved in operating 50-passenger buses, both in conventional mixed traffic and along exclusive busways.

Conventional Mixed Traffic Service

Local transit bus costs for conventional services operating along arterial streets in mixed traffic may be estimated directly from the IDA Data Base [8]. Table 1 in Chapter 3 presents bus operating costs. The conversion from current to constant dollars is based on the Consumer Price Index (CPI) data of Table A-1.

Table A-1. CONSUMER PRICE INDEX, ALL ITEMS
(1967 = 100)

Year	Price Index	Year	Price Index
1949	71.4	1961	89.6
1950	72.1	1962	90.6
1951	77.8	1963	91.7
1952	79.5	1964	92.9
1953	80.1	1965	94.5
1954	80.5	1966	97.2
1955	80.2	1967	100.0
1956	81.4	1968	104.2
1957	84.3	1969	109.8
1958	86.6	1970	116.3
1959	87.3	1971	121.3
1960	88.7	1972	125.3[a]

[a] Estimate based on actual figures through May 1972.

Source: Monthly Labor Review, Volume 95, No. 7, p. 88, July 1972.

The various elements of bus operating costs increased at different rates from 1960 to 1970. The costs of some elements have inflated at a faster rate than the CPI (positive growth rates in constant dollars) while other elements have inflated at a lower rate than the CPI (negative growth rates in constant dollars). The total operating cost has been increasing about one percent per year in real terms.

The average seating capacity of the bus fleet was about 45 seats per bus in 1960 and 49 in 1969. This increase in average size will probably continue, but will be constrained, at least in operations on public streets, by the physical size of the vehicles. The largest modern buses in widespread use have 53 seats. An average seating capacity of 50 is assumed for 1972 and subsequent years.

The average bus-miles per bus-hour in 1969 was 12 [31, Table 3B.25]. However, the bus-hours on which this figure is based include turnaround times between trips. Fifteen miles per hour is, therefore, a good estimate for actual service speed on a conventional street in line-haul service.

Exclusive Busway Service

Buses on exclusive expressways operate at a substantially higher speed than those in typical local service. We have assumed that buses used for such expressway service are the same size as buses used in local service, but have more powerful engines and drive trains to permit higher sustained speeds. Busway speed is estimated at 45 mph, compared with 15 mph for conventional street service.

Bus operating costs on exclusive busways were estimated by the following two methods:

- The operating costs in conventional local transit service were adjusted by allocating cost categories to a per-mile or a per-hour basis and then adjusting the cost categories for the higher speeds on the expressway (See Table A-2).
- Intercity bus operating costs were used, together with the costs of conventional local transit service (See Table A-3).

The rationale for each method of estimation is discussed below.

Some categories of bus operating costs can be assumed to be primarily functions of either miles traveled or hours of operation, while others are a function of both miles traveled and hours of operation. Table A-2 presents the 1970 distribution of operating expenses and the assumed allocation per mile and per hour, by expense category, for buses operating in conventional local transit

Table A-2. DERIVATION OF BUS OPERATING COSTS ON EXCLUSIVE BUSWAY FROM BUS OPERATING COSTS IN CONVENTIONAL SERVICE, 1970

Category Number	Category Name	Conventional Operation			Exclusive Busway	
		Cost per Mile (Dollars)	Allocation of Cost per Mile (%)		Percent of Conventional Total Cost Per Mile	Cost per Mile (Dollars)
			On Per-Mile Basis	On Per-Hour Basis		
4	Equipment, Maintenance, and Garage	.140	19.2		19.2	.140
8	Drivers', Helpers' Wages, etc.	.335		45.8	15.3	.112
9-12	Fuel and Oil	.028	3.8		3.8	.028
	Other Transportation	.041	5.6		5.6	.041
13	Station	.001	0.1		0.1	.001
14	Traffic, Advertising, etc.	.005	0.7		0.7	.005
15	Insurance and Safety	.033		4.5	1.5	.011
17	Administrative and General	.088	6.0	6.0	8.0	.059
20	Operating Taxes and Licenses	.054		7.4	2.5	.018
21	Operating Rents, Net	.007	1.0	___	1.0	.007
	TOTAL	.732	36.4	63.7	57.7	.422

Table A-3. DERIVATION OF BUS OPERATING COSTS ON EXCLUSIVE BUSWAY FROM BUS OPERATING COSTS IN CONVENTIONAL LOCAL TRANSIT SERVICE AND IN INTERCITY SERVICE, 1970

Category Number	Category Name	Cost per Mile in Conventional Local Transit Operation (Dollars)	Cost per Mile in Intercity Service[a] (Dollars)	Cost per Mile on Exclusive Busway (Dollars)
4	Equipment, Maintenance, and Garage	.140	.112	.112
7	Transportation	.404	.260	.260
13	Station	.001	.126	.001
14	Traffic, Advertising, etc.	.005	.024	.005
15	Insurance and Safety	.033	.026	.020
17	Administrative and General	.088	.076	.059
20	Operating Taxes and Licenses	.054	.056	.030
21	Operating Rents, Net	.007	.014	.007
	TOTAL OPERATING COST	.732	.694	.494

[a] From National Association of Motor Bus Owners, Bus Facts, 1971, A Picture of the Intercity Bus Industry, pp. 25-26.

service. The third column presents the same cost-per-vehicle-mile figures as those shown in Table 1 of Chapter 3. The "Other Transportation" costs of Table A-2 are the difference between the total "Transportation" costs (Category 7) and Categories 8 through 12 (See Table 1). In Table A-2, Categories 4, 9 through 12, 13, 14, 21, and "Other Transportation" were estimated to be primarily a function of miles traveled, regardless of bus speed. On the other hand, Categories 8, 15, and 20 were estimated to be primarily a function of the number of bus-hours. Drivers' wages per bus-hour should be about the same, whether the bus averages 15 mph or 45 mph. Insurance costs, which reflect accident costs, should be more a function of exposure hours than of miles traveled; indeed, the accident rate per hour on an exclusive busway at 45 mph may well be less than the rate per hour in mixed traffic at 15 mph. Operating taxes and licenses are more a function of number of buses than of bus-miles, and hence are allocated on a per-hour basis. Category 17, Administrative and General, is estimated to be equally dependent on bus-miles and bus-hours.

Since busway speeds are three times street speeds, those costs that are a function of bus-hours will be reduced to one-third the amount in conventional service for service on exclusive busways. The next-to-last column of Table A-2 shows this reduction for items dependent on bus-hours of operation. Figures in the final column are obtained by multiplying the percentages of the next-to-last column by the cost per mile in conventional service of $.732; the resulting total cost per mile in exclusive busway service is $.422.

Table A-3 presents the derivation of costs of buses operating on exclusive busways from bus operating costs in conventional local transit service and in intercity service. Bus operating speeds on exclusive busways should be comparable to those in intercity service. The third column presents the same cost per vehicle-mile figures as those shown in Table 1 of Chapter 3. The next-to-last column presents costs for intercity bus operations [37]. Both sets of figures are based on the Interstate Commerce Commission uniform system of accounts. Reference [38] did not break down Category 7, Transportation. However, as Table 1 indicates, drivers' and helpers' wages are the major part of Transportation costs. For each category, the cost per mile on exclusive busways was estimated on the basis of the third and fourth columns of Table A-3.

Category 4, "Equipment, Maintenance, and Garage," should be more typical of the intercity figure because buses operating on intercity routes travel at approximately the same speeds as those on expressways. The Transportation category should also be more typical of the intercity figure. Since this category consists mainly of drivers' and helpers' wages, it should be less on a per-mile basis at the higher operating speeds. Away-from-home expenses for intercity drivers would tend to increase this cost. On the other hand, the reduced schedule peaking in intercity relative to local transit service would tend to reduce this cost in intercity service. We assume that these two effects cancel each other and that the intercity figure would be representative of operation on exclusive busways. Categories 13 and 14 are much higher for intercity service; they should be the same per bus-mile in local transit service on exclusive busways as they are in conventional local transit operation. Insurance and safety costs are less in intercity service; it is estimated that they will be even lower for buses operating on exclusive busways than for those operating with other traffic on intercity highways. Accordingly, this category is reduced from .026 for intercity service to .020 for exclusive busway service. Category 17, Administrative and General, was reduced from the .088 for conventional local transit service in proportion to the reduction in total costs as follows:

$$\frac{.494}{.732} \times .088 = .059.$$

The figure for Category 20, Operating Taxes and Licenses, should be less than the figures for both local and intercity operations. It should be less than the conventional local transit operation because payrolls, hence payroll taxes, would be less. Further, bus licenses are more closely related to number of buses (bus-hours) than to bus-miles, and so should be less per mile at higher operating speeds. Category 20 should be less for exclusive busway service than for intercity service because of lower payroll taxes and because buses do not require licensing for multi-state operation. Accordingly, Category 20 has been reduced from about .055 for local and intercity operations to .030 for exclusive busway operation. Category 21 is estimated to be the same as for conventional transit operation.

The second method yields an estimated total operating cost for exclusive busway operation of $.494 per bus-mile compared to $.422 obtained by the first method. The estimate derived by the second method may be somewhat high because it is derived from costs of intercity buses which are larger and more expensive than the upgraded local transit bus designed for exclusive busway operation. Nevertheless, it provides confirmation for the general methodology of allocating conventional transit vehicle costs between a per-hour component and a per-mile component. (The methodology for deriving our cost-estimating relationships is described in Section A.7.)

A.3.2 Vehicle Operating Costs for Jitneys

Jitneys are automobiles which operate on fixed routes and are, essentially, small (5-passenger) bus operations. We have been unable to obtain actual cost data on jitney operations, but since a jitney and a taxi are basically the same vehicle, costs per mile should be about the same for both; accordingly, jitney costs have been estimated from taxi costs in the sections below.

Taxi operating costs are presented in Table 2 of Chapter 3. We have assumed that the corresponding costs, with the exception of fuel costs, will grow over time at about the same rate as bus costs. Automotive anti-pollution regulation will probably affect taxi gasoline engines to a much greater degree than bus diesel engines, and result in much poorer fuel economy in the smaller vehicles. In the absence of better information, we have assumed a zero rate of growth in vehicle operation costs, which are largely gasoline costs, as a more reasonable choice than the -2.32 percent found for bus fuel costs. Projected costs for 1972, 1980, and 1990, all in 1972 dollars, are given in Table 2 of Chapter 3.

A.3.3 Vehicle Operating Costs for 8-Passenger Bus-Wagons and 19-Passenger Minibuses

Jitney operations can be conducted with an 8-passenger bus-wagon instead of a regular 5-passenger automobile. Bus-wagons are produced in this country by Chevrolet, Dodge, and Ford and their actual selling price in 1970 was about $4,200, compared with about $3,000 for a regular automobile taxi. It is possible to operate an 8-passenger bus-wagon at a lower seat-mile cost than a regular automobile.

The bus-wagon is somewhat bigger, heavier, and more expensive than a regular automobile. We have computed a cost per automobile mile in 1970 of $.025 for "Vehicle Operation" and $.020 for "Maintenance," or a total of $.045 for these two categories. It is estimated that these two categories would cost about 15 percent more for a bus-wagon than for a regular automobile, or about $.052 vs $.045. Other operating costs should be basically the same as for a regular automobile, so that the total operating cost in 1970 would be $.273 vs $.266 shown in Table 2 of Chapter 3.

The top panel of Table A-4 projects the costs of bus-wagon operation to 1972, 1980, and 1990, using the same growth factors assumed for the jitney.

The 19-passenger bus is intermediate in size and cost between the taxi and 50-passenger bus. We have, therefore, estimated operating costs for the 19-passenger bus by interpolation between the taxi and 50-passenger bus costs. Nineteen-passenger bus costs are likely to be closer to those of conventional buses than those of taxis. Accordingly, operating costs for 19-passenger buses have been obtained by assigning a weight of one-third for taxis and two-thirds for conventional buses. The bottom panel of Table A-4

Table A-4. OPERATING COSTS FOR 8-PASSENGER BUS-WAGON AND 19-PASSENGER MINIBUS

Cost Element	Dollars per Vehicle Mile			
	1970 (Current Dollars)	Constant 1972 Dollars		
		1972	1980	1990
BUS-WAGON				
Driver Cost	.156	.174	.199	.235
Vehicle Operation	.029	.031	.031	.031
Maintenance	.023	.025	.026	.028
Public Liability Insurance	.016	.018	.019	.021
General and Administrative Garage	.049	.055	.065	.080
TOTAL OPERATING COST	.273	.303	.340	.395
NINETEEN-PASSENGER MINIBUS (Based on weighting of 2/3 for bus and 1/3 for taxi)	.577	.635	.694	.774
50-Passenger Bus	.732	.805	.874	.968
5-Passenger Taxi	.266	.296	.333	.387

Source: Tables 1 and 21.

projects weighted average costs to 1972, 1980, and 1990 in constant 1972 dollars.

A.3.4 Vehicle Capital Costs for 50-Passenger Buses

Tables A-5 and A-6 present 1972 prices for large transit buses. Table A-5 shows prices paid under the UMTA Capital Grant Program. Table A-6 shows approximate prices for Flxible Company buses. Both sets of figures appear to be compatible; we will use a price of $43,000 for a 50-passenger bus.

Table A-5. 1972 PRICES OF TRANSIT BUSES PROCURED UNDER UMTA CAPITAL GRANT PROGRAM

Grantee	Date of Approval	Number of Seats	Price per Bus
Santa Ana, California	April 1972	45	$40,845
Sacramento, California	May 1972	49	$44,059
Dade County, Florida	May 1972	53	$45,676

Source: Urban Mass Transportation Administration, "Capital Grant Approvals through June 30, 1972."

Table A-6. 1972 TRANSIT BUS PRICES FOR FLXIBLE COMPANY BUSES

Size of Bus	Number of Seats	Approximate Price per Bus
Forty Feet	49-53	
8-Cylinder Engine		$43,500
6-Cylinder Engine		$41,500
Thirty-Five Feet	42-49	
8-Cylinder Engine		$41,000
6-Cylinder Engine		$39,000

Source: Letter dated 15 August 1972 from Mr. George Prytula, Marketing Manager, Transportation Systems-Eastern Region, Rohr Industries, Inc.

Table A-7 presents the wholesale price index for motor coaches. From 1949 to 1972, these prices have decreased by about .38 percent per year in real terms. We will assume that bus prices will continue to decrease at a rate of .38 percent per year in real terms in the future.*

Table A-7. WHOLESALE PRICE INDEX - MOTOR COACHES
(1967 = 100)

Year	Price Index	Year	Price Index
1949	72.7	1961	96.6
1950	73.3	1962	96.6
1951	75.7	1963	96.7
1952	76.7	1964	96.8
1953	78.3	1965	96.8
1954	78.6	1966	97.7
1955	79.3	1967	100.0
1956	83.6	1968	103.6
1957	90.2	1969	106.9
1958	93.7	1970	111.2
1959	96.0	1971	115.0
1960	95.8	1972	117.3[a]

a. Estimate based on actual figures through June 1972.

Source: <u>Wholesale Prices and Price Indexes</u>. U.S. Department of Labor, Bureau of Labor Statistics.

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* Large improvements in bus technology would tend to reverse this downward trend in bus costs in real terms.

An analysis of ATA data on bus fleets by property [38] indicates that the median age of buses retired in 1970 was about 15 years. Assuming no residual value, the yearly capital recovery cost is

$$\frac{i}{1 - \left(\frac{1}{1+i} \right)^n} \times P,$$

where

i = rate of interest
n = life in years
P = initial price.

An interest rate of 10 percent is a good average for the cost of capital in the private sector of the economy and has recently been established as a figure to be used in analysis of government projects as well [39 and 40]. Based on a price of $43,000 for buses in conventional service, a life of 15 years, no residual value, and an interest rate of 10 percent, the capital recovery cost per year per bus is .1313 times $43,000, or $5,650.

A median value for annual miles per bus in conventional service is 29,400 miles [31, Table 3B.22]. Based on this annual mileage, the capital recovery cost per bus-mile would be $5,650 divided by 29,400, or $.192. At a .38 percent annual decline in constant-dollar bus prices, 1980 capital recovery costs would be $5,460 per year or $.186 per bus mile, while 1990 costs would be $5,260, or $.179 per bus mile.

Buses operating in high speed busway service would require heavier driver trains and more powerful engines.

Buses designed for the higher speeds of exclusive busway service would cost about $5,000 more than conventional local transit buses [41, Section III]. Accordingly, a price of $48,000 is used for buses suitable for operation on exclusive busways. It is assumed that a bus operating on an exclusive busway will have the same annual mileage as a car on the Lindenwold Line; that is, 48,900 miles [31, Table 6B.13]. This is a little less than the average annual mileage of 52,000 for an intercity bus. The annual mileage of buses operating on exclusive busways is assumed to be much greater than that of buses operating in mixed-traffic, hence the life of buses operating on busways will be less than the life of mixed-traffic buses. We assume a life of 12 years for buses operating on exclusive busways; this is a typical life for intercity buses. Based on a price of \$48,000, a life of 12 years, no residual value, and an interest rate of 10 percent, the capital recovery cost per year is .1468 times \$48,000, or \$7,050. With an annual mileage of 48,900, the capital recovery cost per bus-mile would be \$.144 for exclusive busway buses. Projecting a decline of .38 percent per year in constant-dollar bus prices yields \$6,810 (\$.140 per bus-mile) for 1980, and \$6,560 (\$.139 per bus-mile) for 1990.

A.3.5 Vehicle Capital Costs for Jitneys

Table A-8 presents the price index for new automobiles. From 1949 to 1972, the price of new automobiles declined at an average annual rate of 2.03 percent in real terms.

In 1970, the average taxi cost about \$3,000, had an expected life of three years, a residual value of 10 percent, and an average annual utilization of 40,000 miles. The capital recovery cost per year [42] is:

$$(P-R)\left[\frac{i}{1-\left(\frac{1}{1+i}\right)^{n}}\right] + Ri,$$

where

i = rate of interest
n = life in years
R = residual value when sold at retirement
P = initial price.

Table A-8. CONSUMER PRICE INDEX - NEW AUTOMOBILES
(1967 = 100)

Year	Price Index	Year	Price Index
1949	82.8	1961	104.5
1950	83.4	1962	104.1
1951	87.4	1963	103.5
1952	94.9	1964	103.2
1953	95.8	1965	100.9
1954	94.3	1966	99.1
1955	90.9	1967	100.0
1956	98.5	1968	102.8
1957	98.4	1969	104.4
1958	101.5	1970	107.6
1959	105.9	1971	112.0
1960	104.5	1972	109.5[a]

a. Estimate based on actual figures through June 1972.

Sources: U.S. Department of Labor, Bureau of Labor Statistics *Handbook of Labor Statistics 1971* (Washington, D.C.), p. 268. U.S. Department of Labor, Bureau of Labor Statistics, *Monthly Labor Review* (Washington, D.C., August 1972), p. 108.

Using the above figures, the capital recovery cost per year is $1,120, or $.028 per mile.

It is unlikely that the downward trend in constant-dollar new automobile prices will persist over the next decade. Antipollution and safety regulations may be expected to substantially increase the prices of new automobiles; the decline in 1972 prices was probably a one-time reduction due to Federal excise tax reduction. We have assumed a constant price of $3,000 and hence a capital recovery charge of $1,120 per year ($.028 per vehicle mile) for 1972, 1980, and 1990 (in 1972 dollars).

A.3.6 Vehicle Capital Costs for 8-Passenger Bus-Wagons and 19-Passenger Minibuses

Bus-wagons have characteristics similar to automobiles, and should last about the same number of years or miles in comparable service.

We have estimated that the average taxi cost about $3,000 in 1970; we estimate that the comparable price for an 8-passenger bus-wagon in 1970 is $4,200. Assuming the same life, residual value, and utilization as for a taxi (see Section A.3.5), the capital recovery cost per year would be $1,570 vs $1,120 for the taxi. The cost per mile would be $.039 vs $.028. We assume that, like the automobile, bus-wagon prices and hence capital recovery charges will remain stable in real terms.

The price of a 19-passenger bus in 1972 was about $14,000 [30 and 43]. In 1970, the price would have been about $13,100. Since the life of a taxi is three years, and that of a regular bus is 15 years, we have assumed a life of 8 years for a 19-passenger bus, with no residual value. With these assumptions, the yearly capital recovery factor is .1874 and the yearly capital recovery cost in 1970 is .1874 times $13,100, or $2,460. Assuming the same annual mileage as for conventional local transit buses, the annual capital recovery cost per bus-mile would be $2,460 divided by 29,400, or $.084.

The corresponding figures for 1972, using the $14,000 figure and the same utilization assumptions, would be $2,620 per year or $.089 per mile. Assuming a decline in constant-dollar costs of .38 percent per annum (the same as for conventional buses), the 1980 capital recovery costs would be $2,535 per year and $.086 per mile, and the 1990 costs would be $2,440 per year and $.083 per mile.

Capital cost factors for rubber-tired vehicles are summarized in Table 3 of Chapter 3.

A.4 ROADWAY AND MISCELLANEOUS COSTS FOR RUBBER-TIRED VEHICLES

Rubber-tired transit vehicles, whether they operate on exclusive ways or in mixed traffic, require roadways, which involve capital expenditures for land and construction. Once installed, roadways incur costs for operations and maintenance. In this section, we provide estimates for roadways as well as for miscellaneous transit capital. In Appendix C, we compute the congestion costs imposed by buses on other traffic. The methodology of this chapter involves computing interest and depreciation on value of the road and allocating it among the users. The methodology of Appendix C involves computing the short-run opportunity cost of the road's use by transit vehicles. The rationale for choosing between the two concepts of road costing is explored further in the discussion of cost-estimating relationships.

A.4.1 Road Operating and Maintenance (O&M) Costs

In the case where buses operate on fairly congested urban arterial streets with autos and trucks, road O&M cost may be allocated among the users. If the bus system operates on an exclusive lane or busway, then the road O&M costs should be assigned completely to the bus operation.

The top panel of Table A-9 shows the cost of maintenance, administration, and law enforcement for all roads in 1970 as reported by the Federal Highway Administration. For local roads,

Table A-9. ROAD OPERATING AND MAINTENANCE COSTS, 1970

ALL ROADS, ALL UNITS OF GOVERNMENT	
Maintenance and Traffic Services	$4,793,000,000
Administration and Research	1,207,000,000
Highway Law Enforcement and Safety	1,234,000,000
Total O&M Cost	$7,234,000,000
Total Mileage	3,730,082
O&M Cost of Road Per Mile	$ 1,939
LOCAL MUNICIPAL ROADS AND STREETS, ALL UNITS OF GOVERNMENT	
Maintenance and Traffic Services	$1,290,000,000
Administration and Research	Not Available
Highway Law Enforcement and Safety	Not Available
Total O&M Cost	$1,874,000,000[a]
Total Local City Street Mileage	486,567
O&M Cost of Road Per Mile	$ 3,851[a]

[a] Including Administration and Law Enforcement categories prorated according to All Roads, All Units of Government.

Source: Department of Transportation, Federal Highway Administration, Highway Statistics 1970 (Washington, D. C.), Tables HF-10 and M2.

the same source gave only the maintenance and traffic services cost. We have assumed in the bottom panel of Table A-9 that the other two cost elements would be proportionally the same for local roads as they are for all roads; under this assumption the total local road O&M cost in 1970 was $3,851 per mile. Assuming an average of 2.5 lanes for local roads, the cost per lane-mile was about $1,540.

The increase in highway O&M costs over time is shown in Table A-10. These costs increased by an average of 1.73 percent per year in constant dollars over the 1950 to 1970 period. Assuming

Table A-10. HIGHWAY MAINTENANCE AND OPERATION COST INDEX
(1967 = 100)

Year	Price Index	Year	Price Index
1950	51.3	1961	79.8
1951	56.4	1962	82.1
1952	59.3	1963	84.3
1953	60.3	1964	86.4
1954	62.6	1965	89.7
1955	64.1	1966	97.8
1956	66.3	1967	100.0
1957	70.3	1968	102.8
1958	72.9	1969	110.4
1959	75.2	1970	116.8
1960	78.4		

Source: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 1970 (Washington, D.C.), p. 83.

this same rate of growth in costs in real terms, the O&M cost per lane-mile in 1972 (in 1972 dollars) would be

$$\$1,540 \times (1.0173)^2 \times \frac{125.3}{116.3} = \$1,720.$$

The corresponding figures for 1980 and 1990 are $1,970 and $2,340, respectively.

For local transit bus operation on public roads, these costs should be split between the local bus and the other users of the road. It would be preferable to split maintenance costs according to the direct effect of buses and automobiles on maintenance. Similarly, administration and law enforcement costs should be split between buses and automobiles according to the direct effect of buses and automobiles on these costs. If information were available on a wide range of road O&M costs and levels of bus and auto traffic, then such an allocation could be made by multiple-regression analysis. In the absence of such data, we propose that this allocation be based on the percent of total road capacity utilized by the bus operation.

The Highway Capacity Manual (HCM) assumes as a base case that trucks and through buses comprise 5 percent of urban peak-period traffic [12, p. 142]. In calculating capacity, each truck and through bus is equivalent to about two automobiles.* However, local transit buses, because of their frequent stops, interfere much more with the flow of traffic. Their impact on capacity depends on a number of items, such as number of lanes, parking conditions, location of bus stops on block (near-side/far-side/mid-block, etc.). For typical conditions during busy traffic times in large cities, the Highway Capacity Manual indicates that each local transit bus is equivalent to about seven to thirteen automobiles, insofar as road capacity is concerned. We will assume a factor of 10 in the following calculation.*

The Highway Capacity Manual indicates the following typical flow on major streets per lane-hour during busy traffic times in large cities [12, pp. 23-24, 142-143]:

Automobiles	840
Trucks and through buses	45
Local buses	15
Total	900

---

* For line-haul express service (closed door), each bus is assumed to be equivalent to two automobiles; for CBD distribution, each bus is assumed to be equivalent to ten automobiles. See Table 9 of Chapter 3.

This flow could be expressed as equivalent pure automobile flow as follows:

Automobiles	840 x 1 =	840
Trucks and through buses	45 x 2 =	90
Local buses	15 x 10 =	150
Total Equivalent Automobile Flow		1,080

Hence, the proportion of road O&M cost assignable to the local transit buses in this example would be 150/1,080.

Average daily traffic per lane for the conditions above would be approximately 6,500 vehicles. Total local bus flow per lane per year would be

$$\frac{15}{900} \times 6{,}500 \times 365 = 39{,}600.$$

Road O&M cost per bus-mile in 1972 (in 1972 dollars) would be

$$\left(\frac{150}{1{,}080} \times \$1{,}720\right) \div 39{,}600 = \$.006.$$

Note that local transit buses use about five times as much street capacity as identical vehicles operating without stops to pick up and discharge passengers. We estimate that jitneys would also use more capacity than automobiles, but since jitneys make far fewer passenger stops per vehicle-mile than do buses, the factor should be somewhat less. We estimate that one jitney uses as much capacity as three cars, so that the share of road costs apportioned to jitneys should be about 30 percent of local transit bus costs under similar operating conditions. Accordingly, road O&M costs would be about $.002 per jitney-mile.

Road O&M costs for bus-wagons should be similar to those for jitneys. For minibuses, a one-third to two-thirds weighted average of jitney and bus costs yields an estimated $.005 per minibus-mile for road O&M costs. In effect, the weighting implies that minibuses use about 77 percent of the capacity of a large bus, assuming both are used in local service. The minibus is smaller and makes fewer stops per vehicle-mile, since it tends to be full more often than a large bus and, therefore, does not stop for passengers as often.

The same methodology would yield somewhat higher costs for relatively uncongested residential streets, where buses or jitneys may be operating in feeder service. This is because an assumed constant cost per lane-mile would be allocated among fewer vehicles. In our judgment, attempting to allocate O&M and capital costs among users, if it is to be done at all, makes sense only in cases where capacity constructed is variable. Presumably, residential streets possess a minimum threshold size needed to serve the neighborhood, and their capacity is not determined by the traffic moving along them. Hence, we have not attempted to derive an allocated roadway capital cost for residential street operation.

The volume of bus traffic on an exclusive busway in integrated bus service is limited by the ability of the downtown network of streets to absorb buses from the exclusive busway. The <u>Highway Capacity Manual</u> indicates that buses can operate in the CBD at minimum headways of about 25 seconds during peak traffic periods if adequate bus stops are provided and the buses stop at alternate stops [12, p. 347]. These conditions permit near-maximum bus flows in mixed CBD traffic. If the exclusive busway has three exits into three different downtown streets, number of buses that the downtown streets can absorb is computed as follows:

$$\frac{3 \times 60 \times 60}{25} = 432 \text{ buses per hour.}$$

Using the ratio of average daily traffic to peak-hour traffic derived earlier, the total bus flow per exclusive busway lane per year would be derived as follows:

$$\frac{6500}{900} \times 432 \times 365 = 1{,}140{,}000.$$

However, the above flow would exist only at the downtown end of the exclusive busway. Since buses in integrated service would enter the busway at different points, they would not all travel the entire length of the busway. Since relatively few buses would enter the busway at the points farthest out, the average bus-miles per lane-mile would probably be about one-third of the above figure, or about 400,000 bus-miles per lane-mile per year.

The O&M cost in 1972 (in dollars) per lane-mile for local municipal roads and streets is $1,720. It is assumed that exclusive busway O&M costs would be comparable. Therefore, exclusive busway O&M cost per bus-mile in 1972 (in 1972 dollars) would be $1,720 divided by 400,000, or $.004.

A.4.2 Right-of-Way Land Costs

The estimation of right-of-way (ROW) costs for urban roads is difficult. The principal problems are that, (1) the costs depend on the specific characteristics of the location in question, (2) the out-of-pocket cost for land acquisition is often less than the true market value of the land used, and (3) the width of ROW chargeable to vehicle operation is uncertain. Each of these problems is discussed below.

In comparing different analyses of ROW costs, one faces the problem of costs expressed in different dollar units and different periods of time. Based on the market price of sites for single family homes, it appears that urban land prices have been increasing in real terms at about 5 percent per year [44, p. 132, Vol. II]. We have used this figure and the CPI to convert ROW costs to 1972 prices expressed in 1972 dollars.

As discussed in Chapter 3, the most convenient way to account for the location effect on land price is to express the price as a function of population density (see Figure 4 of Chapter 3).

Actual expenditures for ROW are shown in Table A-11 for 1970. The increase in municipal street mileage in 1970 over 1969 divided by the right-of-way cost in 1970 indicates an average ROW cost of

Table A-11. MUNICIPAL STREET RIGHT-OF-WAY COSTS, 1970

Characteristic	1969	1970	Increase
Mileage	476,361	486,567	10,206
ROW Cost		\$ 73,700,000[a]	
Total Capital Outlay		\$1,210,000,000	
ROW Cost per Mile		\$ 7,250	\$ 7,250

a. Figure not available for 1970. ROW number prorated according to 1969 amount in this category.

Source: Department of Transportation, Federal Highway Administration, Highway Statistics 1969 and Highway Statistics 1970, (Washington, D. C.), Tables HF-2, HF-10, and M-2.

\$7,250 per mile. Assuming the average municipal street has two and one-half lanes, the ROW cost per lane-mile is \$2,900. Correcting this value for 1972 yields the following:

$$\$2,900 \times (1.05)^2 \times \frac{125.3}{116.3} = \$3,440.$$

This figure is representative of the Meyer, Kain, and Wohl (MK&W) values of around 2,000 persons per square mile (see MK&W solid line, Figure 4 of Chapter 3). They stated, "analysis of right-of-way costs from data obtained from the Bureau of Public Roads, and information from other sources, provide strong evidence that right-of-way costs as a percentage of total costs or construction costs increase with net residential density from 5 percent or less at very low density to 50 percent or more at high densities." The figures of Table A-11 indicate ROW costs are about 6 percent of "total capital outlay."

The MK&W method is evidently based on figures similar to those of Table A-11, which reflect only out-of-pocket payments for ROW. If a street is rebuilt or a new street is constructed over ROW already owned by the municipality, no ROW cost is included. Actually, the land does have opportunity cost (the municipality could sell it) and this opportunity cost should be reflected in the true cost of the roadway. However, it seems more correct to charge only for the lane width--not for sidewalks, planting areas, etc.--so that the lower RMC curve of Figure 4 of Chapter 3 seems to be the most correct representation of true ROW cost. We will use it in our calculation of ROW costs.

A representative residential density for large cities (other than New York) is about 13,000 people per square mile out to the beginning of the suburbs (for example, the District of Columbia without the surrounding Maryland and Virginia suburbs). At this population density, the lower RMC curve of Figure 4 of Chapter 3 shows a cost per lane-mile of about $340,000 in 1972 (in 1972 dollars). Since land has infinite life, the capital recovery factor is equal to the rate of interest [5, p. 178]. Therefore, annual land cost per lane-mile is .10 times $340,000, or $34,000. If we assume the same mixed traffic conditions as in Section A.4.1 and allocate land cost in a similar manner to the road O&M cost, the land cost per bus-mile in 1972 (in 1972 dollars) would be computed as follows:

$$\left(\frac{150}{1,080} \times \$34,000\right) \div 39,600 = \$.119.$$

Capital recovery charges for 1980 would be $50,200 per lane-mile and for 1990 $81,800, assuming a 5 percent annual growth rate. Bus-mile costs would be $.176 and $.287, respectively. Using the same conversion factors as those described in Section A.4.1, jitney and bus-wagon costs would be 30 percent of this figure, or $.036 per vehicle-mile in 1972, while minibus costs would be 77 percent or $.092 per vehicle-mile. 1980 and 1990 costs for jitney would be $.053 and $.087, respectively, and for minibus would be $.136 and $.221.

The annual ROW cost per lane-mile for an exclusive busway is assumed to be the same as for a regular arterial street, $34,000. However, the entire ROW cost of the busway must be allocated to the bus operation. At an average bus flow of 400,000 bus-miles per lane-mile (see Section A.4.1), the ROW cost per bus-mile in 1972 (in 1972 dollars) is $34,000 divided by 400,000, or $.085.

Assuming 5 percent annual growth, the annual capital recovery charges would be the same per lane-mile as for arterial streets in 1980 and 1990. In terms of bus-miles, 1980 ROW costs would be $50,200 divided by 400,000, or $.126, and 1990 costs would be $81,800 divided by 400,000, or $.205.

A.4.3 Roadway Construction

Conventional Four-Lane Arterial

A publication by Stanford Research Institute contains data on roadway construction costs [45, pp. 100-114]. These costs depend principally on number of lanes, type of construction (at-grade, elevated, depressed), and population density. Data are presented in 1963 dollars which indicate a representative cost for urban areas of about $1,800,000 per route-mile for a four-lane road. Table A-12 indicates that the composite price index for highway construction has increased from 86.4 in 1963 to 135 in 1972. Hence, representative construction cost per lane-mile for a four-lane urban road in 1972 is computed as follows:

$$\$1,8000,000 \times \left(\frac{135}{86.4}\right) \div 4 = \$703,000.$$

MK&W use a composite road life of 35 years [5, p. 178]. Using an interest rate of 10 percent, and assuming no residual value, the capital recovery cost per year per lane-mile is .1037 times $703,000, or $73,000 (in 1972 dollars).

If we assume the same mixed traffic conditions as those described in Section A.4.1 and allocate construction cost in a similar manner to the road O&M cost, the construction cost per bus-mile

Table A-12. COMPOSITE PRICE INDEX FOR FEDERAL-AID HIGHWAY CONSTRUCTION
(1967 = 100)

Year	Price Index	Year	Price Index
1951	81.8	1962	83.8
1952	84.1	1963	86.4
1953	81.0	1964	86.9
1954	76.4	1965	90.3
1955	74.3	1966	96.1
1956	84.0	1967	100.0
1957	87.7	1968	103.4
1958	85.6	1969	111.8
1959	82.0	1970	125.6
1960	80.1	1971	131.7
1961	80.7	1972	135[a]

[a] Estimate based on actual figures through second quarter 1972.

Source: U.S. Department of Transportation, Federal Highway Administration, Price Trends for Federal-Aid Highway Construction, Second Quarter 1972.

in 1972 (in 1972 dollars) would be derived in the following way:

$$\left(\frac{150}{1,080} \times \$73,000\right) \div 39,600 = \$.260.$$

As before, jitney and bus-wagon costs would be 30 percent of this figure, or $.078, while minibus cost would be 77 percent, or $.200.

Table A-12 indicates that the composite price index for highway construction has increased from 81.8 in 1951 to 135 in 1972, a total increase over the 21-year period of only 2.2 percent in constant dollars. However, the composite highway construction index and the CPI have not moved together; from 1952 to 1955 and from 1957 to 1960 the construction index decreased while the CPI increased; since 1964, the construction index has increased more rapidly than the CPI. We believe that the long-term trend is probably more realistic for future projections than the trend of the last few years. Because the long-term trend (since 1951) shows virtually no growth in constant dollars, we will assume that real road construction costs will remain constant in the future.

Residential Streets

Table A-13 indicates that the average cost per route-mile for urban residential road construction in 1970 was $111,350. Since most municipal street mileage consists of residential streets, this figure should be representative of residential street construction cost. Assuming an average of two and one-half lanes, the cost per lane-mile would be about $45,000 in 1970. Using the composite highway construction price index of Table A-12, the cost in 1972 would be derived as follows:

$$\frac{135}{125.6} \times \$45,000 = \$48,400.$$

This compares with $703,000 for the more costly line-haul type of road discussed above. The capital recovery cost per year per lane-mile is .1037 times $48,400, or $5,020, compared with $73,000 for the urban arterial road.

Exclusive Busways

Table 4 of Chapter 3 presents the construction costs of busways. The average cost of $1,400,000 per lane-mile is double the cost of $703,000 used for a four-lane urban road. The limited-access features of the busway may account for the difference.

Table A-13. MUNICIPAL STREET RIGHT-OF-WAY AND CONSTRUCTION COSTS, 1970

Category	Amount
Right-of-Way	\$ 73,700,000[a]
Construction	1,136,300,000[a]
TOTAL CAPITAL OUTLAY	\$1,210,000,000
Year	Mileage
1970	486,567
1969	476,361
Increase in 1970	10,206
Costs per Additional Mile	Amount
ROW per Additional Mile	\$ 7,250
Construction per Additional Mile	111,350
TOTAL PER ADDITIONAL MILE	\$118,600

a. Figures not available for 1970. Right-of-Way and Construction numbers prorated according to 1969 amounts for these categories.

Source: Department of Transportation, Federal Highway Administration, Highway Statistics 1969 and Highway Statistics 1970 (Washington, D. C.), Tables HF-2, HF-10 and M-2.

Assuming the same capital recovery factor as before, annual cost per busway lane-mile is .1037 times \$1,400,000, or \$145,000. Furthermore, the entire construction cost of the busway must be allocated to the bus operation. At an average bus flow of 400,000 bus-miles per lane-mile (see Section A.4.1), the cost per bus-mile (in 1972 dollars) is \$145,000 divided by 400,000, or \$.363. This cost is also assumed to remain constant in the future in real terms.

A.4.4 Miscellaneous Capital Costs

MK&W have estimated an investment in yards and shops of approximately \$4,500 per bus; they have estimated a 50-year life for yards and shops [5, p. 216]. We have no information on the trend of these other capital costs over time. If we assume that they have been increasing at the same rate as the CPI, and that the \$4,500 figure was representative of the 1964 time period, the cost in 1972 would be about \$6,100 (in 1972 dollars). We assume that this figure will remain constant in real terms in the future.

Based on a cost of \$6,100, a life of 50-years, no residual value, and an interest rate of 10 percent, the capital recovery cost per year is .1009 times \$6,100, or \$615. Using the median value for annual miles per bus of 29,400 [31, Table 3B.22], the capital recovery cost per bus-mile would be \$615 divided by 29,400, or \$.021. For the higher annual mileage of busway buses, the figure would be \$615 divided by 48,900, or \$.013.

For taxicabs, miscellaneous capital costs are imbedded in the "Other (General and Administrative, Garage)" cost category. Information on the size of these other capital costs could not be found, but they are probably quite small relative to the cost of the taxicab itself and may be ignored. Following the methodology of the earlier sections, we have assumed miscellaneous capital charges for 8-passenger bus-wagon are also zero, while for the 19-passenger minibus, they are two-thirds conventional bus, or \$410 per year (\$.014 per vehicle-mile).

A.5 TYPICAL FULL COSTS FOR CONVENTIONAL RUBBER-TIRED SERVICES

The costs per bus-mile derived above for conventional operations on urban streets in mixed traffic are summarized in Table 5 of Chapter 3. The projected cost growth in real terms from 1972 to 1990 is moderate and is largely attributable to increases in bus operating costs and right-of-way costs.

Table 5 of Chapter 3 also summarizes costs for busway operations. Operating costs for busway operations are lower than for conventional service, because of the greater average speed involved. Bus capital costs are also lower, because the effect of greater assumed annual mileage more than balances the higher initial costs and shorter life. Busway costs are estimated to be higher because, even though the limited access busway handles more bus-equivalent vehicles per hour in nonstop service than the arterial street handles in local service, costs are twice as great per lane-mile. These are typical comparisons only.

Comparable costs for jitneys, bus-wagons, and minibuses are presented in Table 6 of Chapter 3. The 8-passenger bus-wagon costs include an allowance for somewhat higher vehicle operating and capital costs but are otherwise the same as for jitneys. The 19-passenger minibus costs, with the exception of vehicle capital costs, were constructed by averaging jitney (one-third weight) and bus (two-thirds weight) costs.

A.6 RAIL RAPID TRANSIT

A.6.1 Rail Operating Costs

Rail transit operating costs are presented in Table 7 of Chapter 3. The costs shown are average values for U.S. properties in operation in 1960 and 1970 (see Table A-14).

The various elements of rail transit operating costs increased at different rates from 1960 to 1970. The costs of some elements have inflated at a greater rate than the CPI (positive growth rates in constant dollars) while others have inflated at a lower rate than the CPI (negative growth rates in constant dollars). The total operating cost has been increasing about 2.66 percent per year in real terms.

Table A-14 shows total operating costs, by property, for 1960 and 1970. Average operating cost increased 71 percent over the decade and median operating cost increased by 60 percent. In real terms, average operating costs increased 2.7 percent per annum and median operating costs increased 2.0 percent per annum. Note that one property, Lindenwold, was added between 1960 and 1970. Excluding

Table A-14. TOTAL RAIL RAPID TRANSIT OPERATING COSTS, BY PROPERTY (U.S. PROPERTIES ONLY)

Property	Operating Cost Per Passenger-Car-Mile (Dollars)		
	1960	1970	1970/1960
New York City Transit Authority	.70	1.24	
Chicago Transit Authority	.70	1.06	
Massachusetts Bay Transportation Authority	1.42	3.06	
Southeastern Pennsylvania Transportation Authority	.79	1.39	
Port Authority Trans Hudson Corportation	1.36	2.04	
Lindenwold Line	--	1.18	
Cleveland Transit System	.48	.98	
Shaker Heights Department of Transportation	.95	1.53	
Public Service Coordinated Transport, Newark	1.00	1.64	
Average	.92	1.57	1.71
Median	.87	1.39	1.60
Average (excluding Lindenwold)		1.61	1.85
Median (excluding Lindenwold)		1.46	1.67

Source: Wells, John D., *et al*, *Economic Characteristics of the Urban Public Transportation Industry*, Institute for Defense Analyses for U.S. Department of Transportation, February 1972. (Section VI).

this property from the 1970 totals, the growth in the average was 85 percent and in the median 67 percent.

A.6.2 Rail Car Capital Costs

Table A-15 presents data on price and characteristics of rail transit cars. The price per car is given in both current dollars and 1972 dollars (converted by the CPI of Table A-1). The price per car in 1972 dollars vs. year ordered is plotted in Figure 1 of Chapter 3.

Some of the price increase indicated in Figure 1 of Chapter 3 is associated with higher quality cars. It is not likely, however, that car quality will continue to increase at this rate in the future.

Table A-16 shows the wholesale price index for railroad rolling stock. This index was not reported before 1961. Over the period shown in the table, the price of railroad rolling stock decreased in real terms. In comparison, the wholesale price index for motor coaches also decreased, by about 0.38 percent per year in real terms, from 1949 to 1972 (see Table A-7). Auto prices decreased 2.03 per year in real terms over the same period (see Table A-8).

In addition to the quality effect, the small, irregular market for rail transit cars probably also contributes to the high rate of increase in rail transit car prices compared to conventional rail car, motor bus, and auto prices. As Table A-17 indicates, the number of rail cars delivered per year since 1949 is quite small and irregular compared to the number of motor buses. Conventional railroad cars and autos are built in even larger numbers than buses. Because of the limited market, rail rapid transit car manufacturers have not been able to automate their production processes to the same degree that bus, conventional rail, and auto manufacturers have. As a result, rail transit car prices have increased much more rapidly in the face of increased wage rates.

Table A-15. PRICE AND CHARACTERISTICS OF RAIL TRANSIT CARS

Date Ordered	Delivery Date	Builder	Ordered By	Price Per Car		Type of Car	Seats per Car	Dimensions	Average Empty Weight (lb.)	MPH Maximum Speed
				Current Dollars	1972 Dollars					
1950		St. Louis	Boston Metropolitan Transit Authority	48,958	85,089	Steel	48	L. 49'9" H. 11'9" W. 8'7"	A car 47,700 B car 53,652	
1950-51		St. Louis	Chicago Transit Authority	37,736 38,983	63,170 65,257	Aluminum	50	L. 48'3" H. 11'10" W. 9'4"	40,500	
1952		Gloucester Ry.Carriage & Wagon Co.	Toronto Transit Commission	76,950	121,273	Steel	62	L. 57' H. 11'11" W. 10'4"	84,370	
1952 & 1954		Gloucester Ry. Carriage & Wagon Co.	Toronto Transit Commission	96,000	150,144	Aluminum	62	L. 57' H. 11'11" W. 10'4"	73,440	
1953 & 1954		St. Louis	Chicago Transit Commission	60,907 61,444 61,761	95,441 96,288 96,779	Aluminum	50	L. 48'3" H. 11'10" W. 9'4"	42,000	
1954		St. Louis	Cleveland Transit System	61,433	95,651	Steel	54	L. 48'9" H. 11'9" W. 10'4"	A car 54,658 B car 53,652	
1954		St. Louis	Cleveland Transit System	70,676	110,042	Steel	52	L. 48'9" H. 11'9" W. 10'4"	56,620	
1955		Gloucester Ry. Carriage & Wagon Co.	Toronto Transit Commission	88,920	138,893	Steel	62	L. 57' H. 11'11" W. 10'4"	82,750 76,700	
1955 & 1956		St. Louis	Chicago Transit Authority	68,648	106,404	Aluminum	A-47 B-51	L. 48'3" H. 11'10" W. 9'4"	A car 40,800 B car 40,300	
1956 & 1957		St. Louis	Chicago Transit Authority	68,648 61,682 62,653	103,796 93,263 94,731	Aluminum	A-47 B-51	L. 48'3" H. 11'10" W. 9'4"	A car 42,600 A car 44,400 B car 42,250 B car 43,900	
1956 & 1957		Pullman Standard	Metropolitan Transit Authority Boston	74,987 80,000	113,380 120,960	Steel	48	L. 55'4" H. 11'11" W. 9'4"	A car 57,540 B car 58,620	
1957		St. Louis	Cleveland Transit System	76,409	113,544	Steel	54	L. 48'9" H. 11'9" W. 10'4"	A car 53,245 B car 53,990	
1957		St. Louis	Cleveland Transit System	83,117	123,512	Steel	52	L. 48'9" H. 11'9" W. 10'4"	57,050	
1957		St. Louis	Port Authority Trans-Hudson Corp.	86,000	127,796	Steel	44	L. 51'3" H. 11'8" W. 8'10"	66,000	
1957		St. Louis	Port Authority Trans-Hudson Corp.	96,000	142,656	Steel	44	L. 51'3" H. 11'8" W. 8'10"	68,000	
1958		St. Louis	Chicago Transit Authority	77,564	112,235	Aluminum	A-47 B-51	L. 48'3" H. 11'10" W. 9'4"	A car 44,400 B car 43,900	
1958		St. Louis	Chicago Transit Authority	72,654 72,862 73,254	105,130 105,431 105,999	Aluminum	46	L. 48'3" H. 11'10" W. 9'4"	44,900 44,600 45,700	50
1959		Budd	Philadelphia Transportation Company	97,616	140,079	Stainless Steel	54	L. 55'4" H. 12'9" W. 9'1"	51,300	55*
1959		Budd	Philadelphia Transportation Company	88,756 89,013	127,365 127,734	Stainless Steel	56	L. 55'4" H. 12'9" W. 9'1"	48,730	55*
1962		Montreal Locomotive Works	Toronto Transit Commission	107,097	148,115	Aluminum	84	L. 74'9" H. 11'11" W. 10'4"	59,700	50*

Sources: Institute for Rapid Transit (IRT), *Post-War Rapid Transit Cars*, *Data Book One*, April 1962, and *Data Book Two*, Second Edition, April 1965. IRT, *Rapid Transit Car Data, Book Three*, 1971. *IRT Digests* and *IRT Newsletters*, 1971-72. *Wall Street Journal*, October 2, 1972, p. 8.

Table A-15. (Continued)

Date Ordered	Delivery Date	Builder	Ordered By	Price per Car: Current Dollars	Price per Car: 1972 Dollars	Type of Car	Seats per Car	Dimensions	Average Empty Weight (lb.)	MPH Maximum Speed
1962		Pullman Standard	Massachusetts Bay Transit Authority	109,626	151,613	Steel	54	L. 69'10" H. 12'6" W. 10'4"	71,650 69,500	55
1963		Pullman Standard	Chicago Transit Authority	105,500	144,113	Aluminum	A-47 B-51	L. 48'3" H. 12'0" W. 9'4"	46,890	65*
1963		Canadian Vickers	Montreal Transportation Commission	133,868	182,864	Steel	40	L. 56'5" H. 12' W. 8'3"	60,000	50*
1963		Canadian Vickers	Montreal Transportation Commission	76,973	105,145	Steel	40	L. 53" 10" H. 12' W. 8'3"	44,000	50*
1964		Hawker-Siddeley	Toronto Transit Commission	98,920	133,344	Aluminum Alloy	83	L. 74'9" H. 11'11" W. 10'4"	55,340	50*
1964		St. Louis	Port-Authority Trans-Hudson Corp.	111,485	150,282	Aluminum	43	L. 51'3" H. 11'8" W. 9'3"	58,400	70
1964		St. Louis	Port-Authority Trans-Hudson Corp.	98,729	133,087	Aluminum	46	L. 51'3" H. 11'8" W. 9'3"	55,800	70
1966		Pullman-Standard	Cleveland Transit System	171,208	220,687	Stainless Steel & Fiberglass	80	L. 70'3" H. 12' W. 10'5"	64,775	55
1966		St. Louis	Port-Authority Trans-Hudson (A-cars)	128,925	166,184	Aluminum & Fiberglass	41	L. 51'3" H. 11'8" W. 9'3"	58,000	70
1966		St. Louis	Port-Authority Trans-Hudson (C-cars)	116,890	150,671	Aluminum & Fiberglass	42	L. 51'3" H. 11'8" W. 9'3"	55,300	70
1966	In operation Feb. 1969	Budd	Port-Authority Transit Corp.	191,000 (single) 178,000 (pair)	246,199 229,442	Stainless Steel	72 (single) 80 (pair)	L. 67'10" H. 12'4" W. 10'2"	79,500 74,800	75
1966		Hawker-Siddeley	Montreal	120,000	154,680	Aluminum	A-76 B-80	L. 76'9" end 47'9" inter. H. 6'9" W. 10'4"	62,300 (end) 61,500	55
1967	June 1969	Budd	Chicago Transit Authority	125,000	156,625	Stainless Steel	A-47 B-51	L. 48'3" H. 12' W. 9'4"	44,500	70
1968	In operation Sept. 1969	Pullman-Standard	Massachusetts Bay Transit Authority	171,292 (single) 161,105 (pair)	205,892 193,648	Aluminum	60 (single) 64 (pair)	L. 69'10" H. 12'4" W. 10'	64,300 (single) 60,800 (pair)	70
1969		Rohr	Bay Area Rapid Transit District	233,100	265,967	Aluminum	72	L. 75' H. 10'6" W. 10'6"	56,500	80
1969	Summer 1971	Rohr	Bay Area Rapid Transit District (B-cars)	229,900	261,289	Aluminum Alloy	72	L. 70' H. 10'6" W. 10'6"	55,000	80
1970		Pullman-Standard	Cleveland Transit System	251,950	271,350	Stainless Steel	80	L. 70'3" H. 12'0" W. 10'5"	64,000	55
1970		Hawker-Siddeley	Toronto Transit Commission	151,210	162,853	Aluminum	83	L. 74'9" H. 11'11" W. 10'4"	55,500	55
1970		Hawker-Siddeley	Port-Authority Trans-Hudson (A-cars)	184,000	198,168	Aluminum Stainless Steel Trim	33	L. 51'3" H. 11' W. 9'3"	59,000	70
1972	Summer 1974	Rohr	Washington Metropolitan Area Transit Authority	306,000	306,000					
1972		Pullman-Standard	NYC-MTA	298,000	298,000			L. 75'		
1972	1973-1974	Rohr	Bay Area Rapid Transit District	370,000	370,000	Aluminum Alloy	72	L. 75' H. 10'6" W. 10'6"	56,500	80

*These cars are capable of higher speeds, but controls are set to cut off at approximately the speed indicated.

Table A-16. WHOLESALE PRICE INDEX - RAILROAD ROLLING STOCK (1957-59 = 100)

Year	Price Index	Year	Price Index
1961	100.2	1967	103.6
1962	100.5	1968	106.8
1963	100.5	1969	112.4
1964	100.5	1970	119.2
1965	100.9	1971	
1966	101.2	1972	

Sources: 1961-1966: Wholesale Prices and Price Indexes. (1963 and 1966 issues), U.S. Department of Labor, Bureau of Labor Statistics.

1967-1970: Telephone conversation with Bureau of Labor Statistics personnel.

We expect that the rate of increase in rail transit car prices will be somewhat lower in the future because, (1) car quality will probably increase at a lower rate, and (2) new rail transit systems and the extension of older systems should enlarge and stabilize the market for rail transit cars. The impact of these changes on the rate of increase in rail transit car prices is difficult to quantify, but car prices will probably increase at about 4 percent per year in real terms, as opposed to the 6.43 percent increase from 1950-1972.

MK&W assume a service life of 30 years for rail transit cars [5, p. 178]. Based on a 1972 car price of $306,000, a life of 30 years, no residual value, and an interest rate of 10 percent, the capital recovery cost per year is .1063 times $306,000, or $32,500. The 1980 and 1990 costs would be, respectively, $44,480 and $73,390.

Table A-17. NEW PASSENGER EQUIPMENT DELIVERED TO TRANSIT SYSTEMS IN THE UNITED STATES

Calendar Year	Rail Rapid Transit Cars	Motor Buses
1949	415	3,358
1950	199	2,668
1951	140	4,552
1952	0	1,749
1953	0	2,246
1954	260	2,225
1955	288	2,098
1956	376	2,759
1957	469	1,946
1958	428	1,698
1959	210	1,537
1960	416	2,806
1961	468	2,415
1962	406	2,000
1963	658	3,200
1964	640	2,500
1965	580	3,000
1966	179	3,100
1967	85	2,500
1968	384	2,228
1969	650	2,230
1970	308	1,442
1971[a]	250	2,514

a. Preliminary

Source: American Transit Association, *'71 - '72 Transit Fact Book*.

The median annual car-miles per active passenger car for U.S. rail transit properties in 1970 was 36,700 [31, Table 6B.13]. Based on this annual mileage, the capital recovery cost per car-mile would be $32,500 divided by 36,700, or $.886. The 1980 and 1990 costs would be $1.21 and $2.00.

A.6.3 Other Rail Transit Capital Costs

In this analysis we will aggregate all capital costs other than cars into a single "other capital cost" category, which we will then relate to route miles. These other costs include land, roadbed, supporting and enclosing structures, track, power supply, signal system, stations, shops and yards, offices, etc.--in short, all the capital facilities making up a rail transit system, other than cars.

Table A-18 presents data on the capital costs of rail transit systems built in North America since World War II. Where the cost without cars was not given directly, we have estimated it to be 88 percent of total cost, including cars. Cost per route-mile was calculated in both current and 1972 dollars. In coverting from current 1972 dollars, we used the approximate mid-year of construction. The cost per route-mile in 1972 dollars vs. mid-year of construction is plotted in Figure 6 of Chapter 3. The cost per route-mile ranges from about $4 million to $113 million (in 1972 dollars).

MK&W assume a service life of 50 years for rail transit capital costs other than cars [5, p. 178]. Although the land has an infinite life, the capital recovery factor is nearly the same for 50 years as for an infinite life; therefore, we will include land with the fixed equipment in calculating capital recovery cost. Using an interest rate of 10 percent, and assuming no residual value, the capital recovery cost per year per route-mile is .1010 times $23,200,000, or $2,340,000. 1980 costs would be $2,550,000 and 1990 costs $2,840,000.

Table A-18. RAIL TRANSIT SYSTEM COSTS
(All Dollars are in Millions)

System	Route Miles	Description	Cost With Cars	Cost Without Cars	Start Date	Completion Date	Assumed Mid-Year	Cost per Route Mile (without cars)	
			Current Dollars	Current Dollars				Current Dollars	1972 Dollars
ATLANTA[a]	50	16 miles elevated	1,400	1,230[b]	Early 1973		1977		24.6
BALTIMORE									
Phase I[c]	28	7.3 miles subway 7.0 miles elevated 13.7 miles surface, cut and fill	656	577[b]	Early 1974	1979	1977		20.6
BOSTON									
South Shore[d]	6.2	New bridge over Neponset River; Most on RR ROW			1966	Sep. 1971	1969	12.1	13.8
Haymarket-North[e]	6.1	4,000 foot tunnel under Charles River. Remainder on RR ROW. New bridge over Mystic River. Two and three tracks		166	Sep. 1966	1975	1971	27.2	28.1
CHICAGO									
Milwaukee, Dearborn, Congress[f]	4.0	Subway	40	35.2[b]		Feb. 1951	1949	8.8	15.5
Eisenhower[f]	9.0	Majority at-grade in freeway median	29	25.5[b]	1955	June 1958	1956	2.8	4.4
Dan Ryan[gh]	9.5	Majority at-grade in freeway median	51.7	40	1967	Sep. 1969	1968	4.2	5.0
Kennedy[h]	5.2	6,200 feet underground; rest at-grade in freeway median	55.8	48	1967	Feb. 1970	1968	9.2	11.1
CLEVELAND									
Initial System[i]	14.9	All on RR ROW		38.9	1953	1958	1955	2.6	4.1
Airport[j]	4.1	Includes 1800-foot tunnel	18.6	15.2	June 1966	Apr. 1969	1968	3.7	4.4
MEXICO CITY[k]	26		400	352[b]	Apr. 1967	Nov. 1970	1969	13.5	15.5
MONTREAL									
Initial System[l]	13.7		213	187.4[b]	Apr. 1962	Oct. 1966	1964	13.7	18.5
Extension[m]	29			430	Oct. 1971	1978	1975		14.8
NEW YORK									
63rd Street[n]	3.2	All cut and cover and tunnel; two tracks east of 2nd Ave.; four tracks west of 2nd Ave.		360	Fall 1969	1978	1974		112.5
2nd Ave. (34th Street to 126th Street)[n]	4.7	All cut and cover and tunnel; two tracks except for 27 city blocks which are four-track		363	Oct. 1972	1978	1975		77.2
2nd Ave. (34th Street to Whitehall Street)[n]	3.6	All cut and cover and tunnel		240	Oct. 1972	1978	1975		66.7
PHILADELPHIA									
Lindenwold Line[o]	14.5	4 miles refurbished track 10.5 miles new track on existing roadbed	92	78.3	1966	Feb. 1969	1967	5.4	6.8
SAN FRANCISCO[p]	75	24.2 miles elevated double track 27.5 miles a-grade double track 20.2 miles subway 3.6 miles tube	1,400	1,342	1964	Late 1972	1968	17.9	21.5

Table A-18. RAIL TRANSIT SYSTEM COSTS (Continued)
(All Dollars are in Millions)

System	Route Miles	Description	Cost With Cars	Cost Without Cars	Start Date	Completion Date	Assumed Mid-Year	Cost per Route Mile (without cars)	
			Current Dollars	Current Dollars				Current Dollars	1972 Dollars
TORONTO									
Yonge[q]	4.6	3.2 miles cut and cover 1.4 miles open cut	66	54.5	Sep. 1949	Mar. 1954	1952	11.9	18.7
University[q]	2.4	1.4 miles cut and cover 1.0 miles tunnel	40	36	Nov. 1959	Feb. 1963	1961	15.1	21.1
Bloor - Danforth[q]	8.0	6.8 miles cut and cover 7.7 mile tunnel .5 mile bridge	160	143.8	Feb. 1962	Feb. 1966	1964	18.0	24.2
Bloor - Danforth[q] extensions	6.2	3.9 miles cut and cover 1.6 miles open cut .4 mile tunnels .3 mile bridges		77.7	Mar. 1965	May 1968	1967	12.6	15.8
Yonge extension[q,r]	4.0	Mostly tunnel and cut		79.6	Fall 1968	1974	1971	19.9	20.6
WASHINGTON[s]	98	8.7 miles elevated 33.8 miles surface 8.0 miles freeway median 21 miles cut and cover 11 miles earth tunnel 15 miles rock tunnel .5 miles sunken tube	2,910	2,560[b]	Dec. 1969	1979	1974		26.2

a. "Atlanta Votes for Rail Transit," Modern Railroads, January 1972, p. 93.

b. Cost of cars assumed to be 12 percent of total cost.

c. Baltimore Region Rapid Transit System Phase I Plan, Prepared by the Metropolitan Transit Authority, Jan. 1971, and Phone Conversation with Mr. Gottfeld, Metropolitan Transit Authority, Nov. 21, 1972.

d. 1971 Annual Report, Massachusetts Bay Transportation Authority.

e. UMTA Capital Grant Project Files MASS-UTG-3 and -5, and phone conversation with Mr. Robert Davidson, MBTA, Nov. 24, 1972.

f. "Chicago Transit History and Progress," Chicago Transit Authority Pamphlet, Chicago, Illinois. (No date.)

g. 1969 Annual Report, Chicago Transit Authority, p. 4, and "New Ryan Route," IRT Newsletter, June 1969, p. 2.

h. "New Kennedy and Ryan Routes Nearing Completion," IRT Newsletter, June 1969, p. 3, and 1970 Annual Report, Chicago Transit Authority, p. 3.

i. Highway Research Circular No. 91, "Cleveland Transit and Parking Operations," by G. Ihnat. Jan. 1969.

j. "Rapid Transit Links City to Airport," Engineering News-Record, November 17, 1966, p. 75, and M. Wohl, An Analysis and Evaluation of the Rapid Transit Extension to Cleveland's Airport, The Urban Institute (Washington D.C., August 1971).

k. "Mexico City's Sistema De Transporte Collectivo," Metropolitan, September/October 1971, p. 36.

l. Automotive Safety Foundation, Urban Transit Development in Twenty Major Cities. (Washington, D.C., 1967), p. 40.

m. 1971 Annual Report, Montreal Urban Community Transit Commission, p. 21.

n. Letter from L. Ingalls, New York City Transit Authority, to N. Asher, Institute for Defense Analyses, Dec. 14, 1972.

o. "To Open New Lindenwold (N. J.) Rapid Transit Line," IRT Newsletter, February 1969, p. 6 and "Full Service on New Lindenwold Line Expected to Begin in Mid-February," p. 25.

p. "BART'S Last Track," IRT Digest, September/October 1971, p. 24.

q. "Transit in Toronto," published by Toronto Transit Commission, 1970, p. 64-66.

r. 1968, 1969, and 1971 Annual Reports, Toronto Transit Commission.

s. "Green Light for Washington's Subway," IRT Newsletter, November 1969, p. 1., and "Washington Metro," Modern Railroads, January 1972, p. 88.

Table A-19 presents data on annual car-miles related to miles of track. The "Miles of First Main Track" are equivalent to the "Route-Miles" of Table A-18. The larger systems tend to have more miles of single track per mile of first main track indicating that much of the system has three or more tracks along its route. The smaller systems tend to have two tracks. The annual car-miles per mile of first main track vary greatly. Shaker Heights, a lightly traveled single commuter line between Cleveland and suburban Shaker Heights, has an average of only about 40,800 cars passing over each mile of route per year, while New York has an average of 1,520,000 cars passing over each mile of route per year. Using the median value of 458,000 annual car-miles per route-mile, the rail transit capital costs (other than cars) would be $2,340,000 divided by 458,000, or $5.11 per car-mile in 1972 (in 1972 dollars).

Table A-19. MILES OF TRACK AND ANNUAL CAR-MILES

Property	Year	Miles of First Main Track	Total Miles of Single Track	Miles of Single Track per Mile of First Main Track	Annual Car-Miles	Annual Car-Miles per Mile of First Main Track
New York City Transit Authority	1970	237	842	3.55	359,824,006	1,520,000
Chicago Transit Authority	1970	90	243	2.70	51,488,994	572,000
Massachusetts Bay Transportation Authority	1970	59	151	2.56	9,273,000	157,000
Toronto Transit Commission	1970	21	60	2.86	22,735,322	1,082,000
Southeastern Pennsylvania Transportation Authority	1968	32	65	2.03	14,623,027	458,000
Montreal Urban Community Transit Commission	1970	16	33	2.06	18,369,540	1,147,000
Port Authority Trans-Hudson Corporation	1970	14	35	2.50	9,250,708	660,000
Lindenwold Line	1970	14	34	2.43	3,670,012	262,000
Cleveland Transit System	1970	19	43	2.26	4,561,148	240,000
Shaker Heights Department of Transportation	1970	30	66	2.20	1,226,050	40,800
Public Service Coordinated Transport, Newark	1970	4	9	2.25	604,382	151,000

Source: IDA computerized Data Bank on Urban Public Transportation.

A.6.4 Total Rail Transit Costs

The costs per rail transit car-mile are summarized in Table 8 of Chapter 3. The table presents costs for 1972 and projections for 1980 and 1990, all expressed in 1972 dollars. All three cost elements are expected to increase in real terms; the increase in total costs is significant over this period of time. For an actual system, the costs should ideally be properly time-phased. For example, a new system on which construction will start in 1975 and which would be completed in 1985 would have a mid-year of other-than-car-capital costs of about 1980, car capital costs for 1983 (year the cars were ordered) and operating costs starting in 1985. As explained above, for simplicity, we have used 1980 costs for all elements of all alternatives in the cost-estimating relationships derived below and in the case studies reported in Chapter 5.

A.7 SUPPLIER COST-ESTIMATING RELATIONSHIPS

The cost data assembled above form the basis for supplier cost-estimating relationships which are used in the case studies of Chapter 5. Before proceeding to the details of the estimating relationships, it should be useful to consider Table 9 of Chapter 3, which summarizes the results of applying the supplier cost-estimating relationships to the operating conditions assumed in the case studies.* All costs are as projected to 1980 (in 1972 dollars).

The estimating relationships divide the total cost into an hourly component and a mileage component, so that the actual cost per mile depends on the operating speeds indicated in the table.** Hourly costs are converted to mileage costs by dividing by the

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* The costs in Table 9 do not include an allowance for vehicle layover at the end of a route. The models in Chapter 5 do include a layover allowance.

** Operating speeds used are explained more fully in Chapter 5.

appropriate speed in miles per hour; total costs are obtained by adding these costs to the other mileage costs. The theory of peak-load pricing and the theory of joint products were used to derive ex post allocations of bus and rail vehicle capital costs and way and structure costs between peak services and off-peak (base) services, assigning a preponderance of capital costs to peak services. Bus driver wages were adjusted to account for union labor contracts which raise the marginal wage of peak drivers relating to off-peak. The way and structure costs for vehicles in mixed traffic are expressed in dollars per vehicle-mile, while costs for exclusive ways are expressed in dollars per route-mile hour. This allows the vehicle-mile costs of exclusive ways to depend on utilization.

Three different services and six vehicle types were analyzed. The three services (residential collection and distribution, line haul, and CBD distribution and collection) apply to peak-hour commuter travel. Residential collection costs vary from $.32 per vehicle-mile for jitneys to $1.31 per vehicle-mile for high-speed expressway buses. There is a progression of costs from small vehicles to large vehicles, with jitneys cheapest and expressway buses most expensive. The difference is most pronounced for peak hour, since the institutional and technological characteristics of bus transit (union labor, specialized vehicles) tend to increase the ratio of peak to base costs. Jitney services, in contrast, are supplied by automobiles which have many alternative uses when not supplying transit services and which require no special skills to operate. The jitney costs assume no institutional barriers to entry, a condition not met in this country at present, as discussed in Chapter 6. Line-haul costs (exclusive of way and structures) are $.65 for high-speed bus vs. $3.05 for rail rapid transit. Way and structure costs are $275 per route-mile-hour for an exclusive busway vs. $1,785 for rail. Rail costs are much higher than bus costs, and service speeds are lower because of station stops. CBD distribution is also more expensive via rail, although as explained in Chapter 5, capacities are somewhat higher.

The derivation of cost-estimating relationships follows. Under vehicle costs, bus, jitney, bus-wagon, and minibus costs are discussed in turn, followed by rail transit operating costs. Street, busway, and rail costs are included in the discussion of way and structure costs. Appendix B derives an allocation of vehicle capital costs between peak and base services.

Table A-20 shows the allocation of driver and capital costs to peak and off-peak hours. All cost elements not listed in this table are considered to be equal per vehicle-mile in peak and off-peak service. The only exception is minibus driver costs, which are derived as a weighted average of driver costs for 50-passenger bus and jitney. Jitney driver costs are equal in peak and off-peak service, while 50-passenger bus driver costs are twice as high per peak hour as per off-peak hour. Capital costs are allocated to peak hours as shown by the percentages of Table A-20. It is estimated that there are 1,000 peak hours per year. Hence, total capital costs per year are multiplied by the percentages of Table A-20 and then divided by 1,000 to obtain capital costs per peak hour.

Table A-20. ALLOCATION OF DRIVER AND CAPITAL COSTS TO PEAK AND OFF-PEAK HOURS[a]

Cost Element	Allocation to Peak Hours	Allocation to Off-Peak Hours
50-Passenger Bus and Rail Car Operator Costs[b]	Peak cost per hour = 2 times off-peak cost per hour	
Minibus, 50-Passenger Bus, and Rail Car Vehicle Capital Costs	85%	15%
Arterial and CBD Streets	76%	24%
Busway and Rail Way and Structures	70%	30%

a. Cost elements not listed in this table are considered to be equal per vehicle-mile in peak and off-peak service.
b. Minibus driver costs are a weighted average of 50-passenger bus and jitney driver costs.

A.7.1 Vehicle Cost-Estimating Relationships

Buses

1980 bus operating costs are projected to be $.874 (Table 1 of Chapter 3). Applying the allocation between mileage and hourly costs discussed in Section A.3.1, $.304 varies with mileage *per se*, while the remainder depends on hours *per se*. The hourly cost is $6.90, using a 12 mph average speed, of which $5.12 is drivers' and helpers' wages, etc., and $1.78 is other hourly costs.*

Several studies have estimated that the marginal cost of a peak driver-hour is about double that of a base driver-hour [30, 46]. The following work rules are typical in union contracts with large bus operations [30, p. 3-5]:

1. No part-time employees. All employees are guaranteed eight hours pay.
2. No overtime. No driver may be behind the wheel more than eight hours per day.
3. If the eight working hours are spread over more than ten hours, the eleventh hour will be paid at time and one-half, the twelfth and thirteenth will be paid at double time. No shift may be spread over more than thirteen hours.

Given that transit operations are subject to morning and evening peaks, such work rules mean that it costs substantially more to add a driver in peak service than in base service. It is possible to construct a rough estimate of the peak and base marginal driver cost, based on the known average wage and an estimated average division between peak and base service. The average bus travels 29,400 miles per year. At 12 mph, 12,000 miles (41 percent) would be traveled during the 1,000 annual peak hours, leaving 17,400 base miles (59 percent) per year. The average of drivers' and helpers' wages is $5.12 per hour. The assumed division of bus-miles and,

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* 12 mph is used because it is the average speed associated with the ATA costs.

hence, bus-hours between base and peak services yields the following equation, where X is the base hour wage rate for drivers and helpers and 2X is the peak-hour wage:

$$\left(\frac{17,400}{29,400}\right) X + \left(\frac{12,000}{29,400}\right) 2X = 5.12.$$

Solving for X yields a base wage for drivers and helpers of \$3.64 per hour and a peak-hour wage of \$7.27.

In peak services, operating costs would be \$.304 per mile plus \$9.05 per hour, of which \$7.27 would be drivers' and helpers' wages and \$1.78 would be other hourly costs. For base services, the same \$.304 per mile and the same nondriver hourly cost of \$1.78 would apply. Adding \$3.64 for drivers' and helpers' wages yields a base hourly cost of \$5.42.

Estimated vehicle capital cost for buses operating on exclusive busways is \$6,810 per year. For reasons explored in Appendix B, we allocate 85 percent of this cost to peak services, implying an hourly peak capital cost of \$5.79. The less elaborate buses which operate in standard services cost \$5,460 per year, or \$4.64 per peak-hour.

Derivation of hourly base period capital charges is somewhat more complex. For conventional service at 12 mph, there would be 17,400 divided by 12, or 1,450 base-hours per year, among which 15 percent of the annual capital charges would be allocated. Therefore, the cost per hour would be found by multiplying the annual capital charge by .15 and dividing it by 1,450 for .000103. For conventional service, the hourly capital charge would be .000103 times \$5,460, or \$.56.

Jitneys

We construct the jitney cost-estimating relationship from taxi costs. Table 2 of Chapter 3 shows that the 1980 operating cost per mile is \$.333, of which \$.199 was for the driver, leaving \$.134 per vehicle-mile for nondriver operating costs. Of this amount, \$.065 was for other expenses such as general and administrative and garage expenses. The remainder, \$.669, was the operating cost for the vehicle itself.

A jitney service may need a much less elaborate administrative structure than a taxi service, as there would be no need to maintain telephone paging facilities or dispatches. Nevertheless, some administrative costs might still be incurred for scheduling and coordination. In the absence of better information, we have used the same \$.065 for "other" expenses for jitney. The mileage component of operating expense would thus be \$.065 plus \$.069, or \$.134 per vehicle-mile.

In conventional taxi service, 12 miles are driven per man-hour [31, Table 8.14]. At a driver operating cost of \$.199 per mile, this amounts to \$2.39 per hour actually worked. We assume that taxi drivers earn a tip income amounting to 30 percent of this figure, so that the true wage of taxi drivers is \$3.10 per hour.* Thus, jitneys are assumed to cost \$.134 per mile plus \$3.10 per hour to operate, exclusive of capital costs.

The typical taxi cab costs around \$3,000, lasts for 3 years, and is driven 40,000 miles per year or 120,000 miles altogether. At the 20 mph jitney operating speed, this would amount to 2,000 hours per year, or approximately 40 hours per average week. Assuming a residual value of 10 percent, and an interest rate of 10 percent, capital charges would be \$1,116 per year, or \$.558 per hour of use.

These capital costs are probably overstatements of the capital costs which are likely to be encountered in this type of service. It is probable that jitney drivers would use the automobile for personal transportation during nonworking hours, particularly if the jitney driver were supplying his services part time in the peak hours. Part of the return from being in this industry would be to have a personal automobile at low opportunity cost. The cost figures

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* A taxi driver typically earns about one-half the metered fare, so that a tip of 15 percent amounts to about 30 percent of his earnings.

which we use assume no alternative use for the automobile when it is not supplying public transit services. This is perhaps a defensible assumption for bus transit, charter revenues notwithstanding. It is less realistic in the case of the automobile, particularly when the automobiles are owned or leased by their operators and are thus available for personal use when they are not being used to supply public transportation services.

Bus-Wagons

Eight-passenger bus-wagon costs are estimated to be identical to jitney costs, except for slightly higher "vehicle operation" and "maintenance" costs (see Section A.3.3 and Table A-4) and capital costs (see Section A.3.6). The mileage component of operating cost is .007 higher, or $.141 when the same adjustments as for jitneys are applied. The $3.10 hourly driver and overhead charge would be the same. Annual capital costs for a bus-wagon are .372 times $4,200, or $1,562, assuming the same use and life as for jitneys. Capital costs would thus be $.781 per hour.

Minibuses

Nineteen-passenger minibus operating costs were estimated above (Section A.3.3) by taking a weighted average of taxi or jitney costs (one-third weight) and conventional bus costs (two-thirds weight). We have used the same weights for the cost-estimating relationship. The effect of this assumption is to cause peak minibus operating costs to be somewhat higher than base operating costs, although the differential is not as great as for conventional buses.

The estimated hourly components of jitney and peak- and base-hour bus-operating costs are, respectively, $3.10, $9.05, and $5.42. The weighted average for peak hours is $7.07 and for base hours is $4.65 per minibus-hour. The mileage components of operating costs are $.134 for jitneys and $.304 for buses. The weighted average is $.247 per vehicle-mile for minibus.

Annual vehicle capital-recovery costs are estimated at \$2,535 (Section A.3.6). We assume the same 85 percent/15 percent allocation of capital costs between base and peak services as for conventional bus. Thus, peak-hour capital costs would be computed as follows:

$$.85 \times \frac{\$2,535}{1,000} = \$2.15 \text{ per hour.}$$

Base costs would be

$$.15 \times \$2,535 \div 1,450 = \$.26 \text{ per hour.}$$

Rail Transit

We have assigned all operating costs either on a per-car-mile basis or per-train-hour basis in the cost-estimating relationship. The average total operating expense per car-mile is \$.20 (Table 7 of Chapter 3) of which \$.326 was wages of trainmen, leaving \$1.87 for operating expenses other than trainmen wages. At an average operating speed of 20 mph, trainmen wages would amount to \$6.52 per car-hour. When one considers that some subway systems run trains of eight cars or more with only two men (a motorman and guard), the hourly cost seems excessive. The newer systems being built, beginning with the Lindenwold line, are designed for automatic train operation, with only one attendant on board. From all accounts, the skill level required of this attendant is somewhat less than the skill level required of conventional subway operators. The train is designed to accelerate, run, and decelerate without human intervention, stopping precisely at the correct spot on the train platform. The function of the train operator, other than psychological security of the passengers, is to (on some systems) open and close the doors and to be on hand in case something should happen to the automatic system [10].

In view of these considerations, we have assumed a train labor cost somewhat less than the train labor cost encountered by existing rapid transit operations. Specifically, we have assumed that train operators could be hired at approximately the same wage as bus drivers, and have used the peak-hour bus driver wage as our estimate of the peak-hour on-train labor component of these modern systems. In Table 9 of Chapter 3 we have assumed two-car trains, so that the driver cost per car-hour is one-half that of conventional bus ($3.64 versus $7.27). We have not made any corresponding adjustment to the other operating costs of the system. The automated controls undoubtedly raise the initial cost of the transit system. To the extent that they also increase operating cost, the operating cost of existing transit systems (on which our costs are based) will understate the true operating cost. Thus, our cost-estimating relationships are likely to be somewhat generous to rail rapid transit operations.

Rail transit cars incur an annual capital recovery cost of $44,480 per car-year, or $37.80 per peak car-hour, assuming the same 85 percent allocation to peak services as for bus.

A.7.2 Way and Structure Cost-Estimating Relationships

Exclusive busway and rail rapid transit way and structure costs must, of course, be allocated to the public transit vehicles which use them. But it would be inappropriate, economic theory suggests, to allocate costs evenly over all vehicles or over all passengers without further evidence that this is appropriate for the case at hand. Rather, these facilities must be regarded as supplying jointly at least two types of services--peak-hour capacity and base-hour capacity.

Neither would it be appropriate to apply the methodology, developed in Appendix B, for allocating vehicle costs between peak and base services. That methodology is based on the fact that the size of the vehicle fleet, which is variable, is determined by peak-hour demands. Rapid-transit lines and busways cannot, for all practical purposes, be made smaller than two tracks or two lanes. At the levels of bus or rail traffic contemplated in the case study of Chapter 5, capacity is not a binding constraint and congestion is of minimal importance. Thus, the peak-capacity and base-capacity services satisfy the classic fixed-proportions joint-products model.

A competitive firm normally compares the sum of joint product prices with the total cost of producing the bundle, rather than attempting to allocate costs arbitrarily *a priori* between the products. In analyzing the costs and benefits of a rail or bus transit way, the value (benefit) of peak capacity plus the value of off-peak capacity should be compared with the capital recovery charge. In the absence of such benefit measures, surrogate measures of the relative size of the peak and base benefits must be developed. This is the approach we have taken.

The busway and rail alternatives compared in Chapter 5 should have similar traffic characteristics, so the same methodology is applicable to both. From 40 to 50 percent of daily bus transit patronage in large cities occurs during the four morning and evening peak hours [5, p. 95]. For rapid rail systems, the range is from 45 to 60 percent and, for commuter railroad, 65 to 70 percent. The more specialized the system to long-distance CBD commuting, the greater the peaking factor. This is confirmed by comparing private automobile, the least specialized mode, where the percentages are 25 to 45 percent.

The new rail rapid systems, such as Lindenwold, BART, and Washington Metro, combine the characteristics of most existing rail rapid transit and commuter rail systems. Thus, we may expect the peak-hour factor to be in the neighborhood of 60 percent.

The relative benefits depend not only on the relative level of patronage between peak and base periods, but also on the relative price elasticity of demand and relative operating costs. Compared with base ridership, peak riders probably have fewer good alternative modes, enjoy less flexibility as to number of trips or time of day, and find it more difficult to reorient their trips' origins and destinations. All of these factors cause peak demand to be less elastic and to raise the benefits per peak passenger, compared with base service. Similarly, vehicle-load factors are likely to be somewhat lower in base services, which means that the operating costs per passenger may be higher. This also causes the net benefits from way and structure capacity <u>per se</u> to be higher per passenger in peak service.

Quantitative evidence on the magnitude of these effects is not available. In the absence of such evidence, we have assumed the benefit per peak passenger to be 1.5 that of base passengers, and have allocated costs on that basis. If 60 percent of the passengers ride during the peak hours, and the relative weight is 1.5:1, then the allocation of way and structure cost to peak hours is given by:

$$\frac{(.6 \times 1.5)}{(.6 \times 1.5 + .4)} = .692 = 70\%.$$

Section A.4.2 indicates that 1980 busway land costs $50,200 per lane-mile-year and busway construction costs $145,000 per lane-mile-year. O&M costs are $1,970 per lane-mile-year (see Section A.4.1), for a total of $197,170. Busway costs per lane-mile-hour for peak hours would be computed as follows:

$$.70 \times \frac{197,170}{1,000} = \$138.$$

For a two-lane busway, this amounts to $275 per route-mile-hour.

Section A.6.3 projects 1980 rail noncar capital costs to be $2,550,000 per route-mile-year. Thus, costs would be .70 times $2,550, or $1,785 per peak-hour.

Mixed-traffic systems require that both public transit vehicles and nontransit vehicles be considered. Residential collection and distribution for CBD commuters takes place on relatively uncongested roads. As explained in Section 3.4, it is inappropriate to allocate the fixed charges of these roads among various classes of traffic. O&M costs are assumed to be covered by the fuel taxes paid by vehicle operators.

There remains an allocation for costs of arterial streets used by express buses in mixed traffic, and for CBD streets. To the extent that metropolitan street and expressway capacity is variable, it is sized to meet peak-hour demands. The example of street usage cited above in Section A.4.1 indicates that a typical peak-hour flow is 1,080 auto equivalents per lane-hour, or 1,080,000 per year during the peak. The number of auto equivalents is about 1.2 times the actual vehicle count. Average daily traffic is 6,500 vehicles per lane, or 365 times 1.2 times 6,500, or a total of 2,847,000 auto equivalents per lane-year. Thus, about 38 percent of auto equivalent volume occurs during peak hours. This compares with the 25 percent to 45 percent range cited in [5].

The street costs per bus- or jitney-mile in mixed traffic estimated in Section A.4 assumed an equal allocation for all vehicle-miles, whether peak or base. If, on the other hand, all costs are allocated to the peak, peak costs would be 1/.38, or 2.6 the numbers cited there. This represents the other extreme of cost allocation.

For peak service, we have doubled the Section A.4 capital costs per vehicle-mile. This accounts for about 2 times .38, or 76 percent of total roadway costs, and leaves 24 percent of costs to be allocated among the remaining 62 percent of traffic which occurs during the base period. The base-period costs are found by multiplying the overall average vehicle-mile costs by .24 divided by .62, or .4.

The estimated cost for an exclusive way is less than the allocated share of arterial street costs for bus flows per lane of

$$\frac{275}{(2 \times .878)} = 157 \text{ or more per peak hour.}$$

Taking account of the greater vehicle-miles achieved by buses operating on high-speed ways lowers the flow at which busway supplier costs match conventional express service costs to 110 buses per hour per lane.* These crude comparisons are for line-haul routes and make no allowance for the slightly higher cost of expressway buses in residential and CBD collection and distribution or for the user in-vehicle-time cost savings from expressway operations. The model in Chapter 5 includes these refinements.

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* Mixed-traffic costs equal busway costs when

$$1.10 + .878 = .647 + \frac{275}{2X},$$

where X is the number of buses per hour (there are X round trips and 2X one-way trips).

APPENDIX B

ALLOCATION OF VEHICLE CAPITAL COSTS BETWEEN PEAK AND OFF-PEAK SERVICES

APPENDIX B

ALLOCATION OF VEHICLE CAPITAL COSTS BETWEEN PEAK AND OFF-PEAK SERVICES

If there are two peak hours in the morning and two in the afternoon, for 250 working days per year, this amounts to 1,000 peak traffic hours per year. The remaining hours of the year would be spent out of operation or in operating the base service. Any _a priori_ allocation of capital costs among these services is bound to be arbitrary. Recent contributions to the peak load, marginal-cost pricing literature suggest that competitive markets would probably allocate all or most of these capital costs to the peak hours of service, and none or relatively little of these capital costs to off-peak service. (The theory of peak-load pricing is discussed in [47], [48], and [49].) Before detailing the numerical results of this method of cost allocation, it should be useful to review its theoretical basis.

Buses are usually owned and operated by the same firm, or, if they are leased, are typically leased for long terms. In discussing a "benefit maximizing" scheme of cost allocation, it is nonetheless useful to imagine that transit firms lease their vehicles on an hourly basis from a competitive bus-leasing industry. The pricing and investment rules for such a hypothetical industry are the same as the pricing and investment rules for a benefit maximizing public agency: (1) set the lease price per hour equal to short run marginal cost during each demand period, and (2) adjust the stock of buses to the point where the marginal return of holding an extra bus equals the marginal cost of holding the bus. The competitive bus leasing industry (or the benefit maximizing bus supply agency) would exactly break even when these rules are followed, covering all operating, interest, and depreciation charges, including a "normal" return on equity capital. From an accounting standpoint, such pricing and investment rules would "allocate" all or most of the bus capital costs to the peak period, although this "allocation" would be ex post rather than a priori.

Figure B-1 diagrams the basic model. The hypothetical competitive bus-leasing industry supplies buses and all other inputs, and pays all of the capital and operating costs. Let us suppose that the firms in the industry own a stock of buses which are capable of supplying B_0 bus-hours per hour of service. (Normally, this would require more than B_0 buses, when allowances are made for spares, but we ignore this complication.) We consider first the case where buses last a given number of years, independent of utilization. Then, we examine the opposite case where buses last a given number of use-hours, independent of the number of years. The life of a bus probably lies somewhere between these two extremes.

First, assume that buses last a given number of years, say 15, regardless of utilization. In Figure B-1, the average operating cost per bus-hour is a constant, regardless of the number of bus-hours supplied each hour, and it is impossible to supply more than a capacity rate of bus-hours per hour. Thus, the short run marginal cost is equal to the average operating cost up to capacity B_0, at which point it becomes vertical. If the industry adds buses to its fleet, this investment moves the vertical portion of the marginal cost curve to the right by the corresponding number of units, signifying that capacity for supplying bus-hours during each hour has been increased to a higher level, such as B_1. Note that capital charges are independent of utilization, once the capacity is established.

The curves labeled D_{Base} and D_{Peak} are demand curves by the transit industry for bus-hours during the base and peak periods, respectively. They represent willingness of transit operators to pay for bus-hours, and are derived ultimately, of course, from the

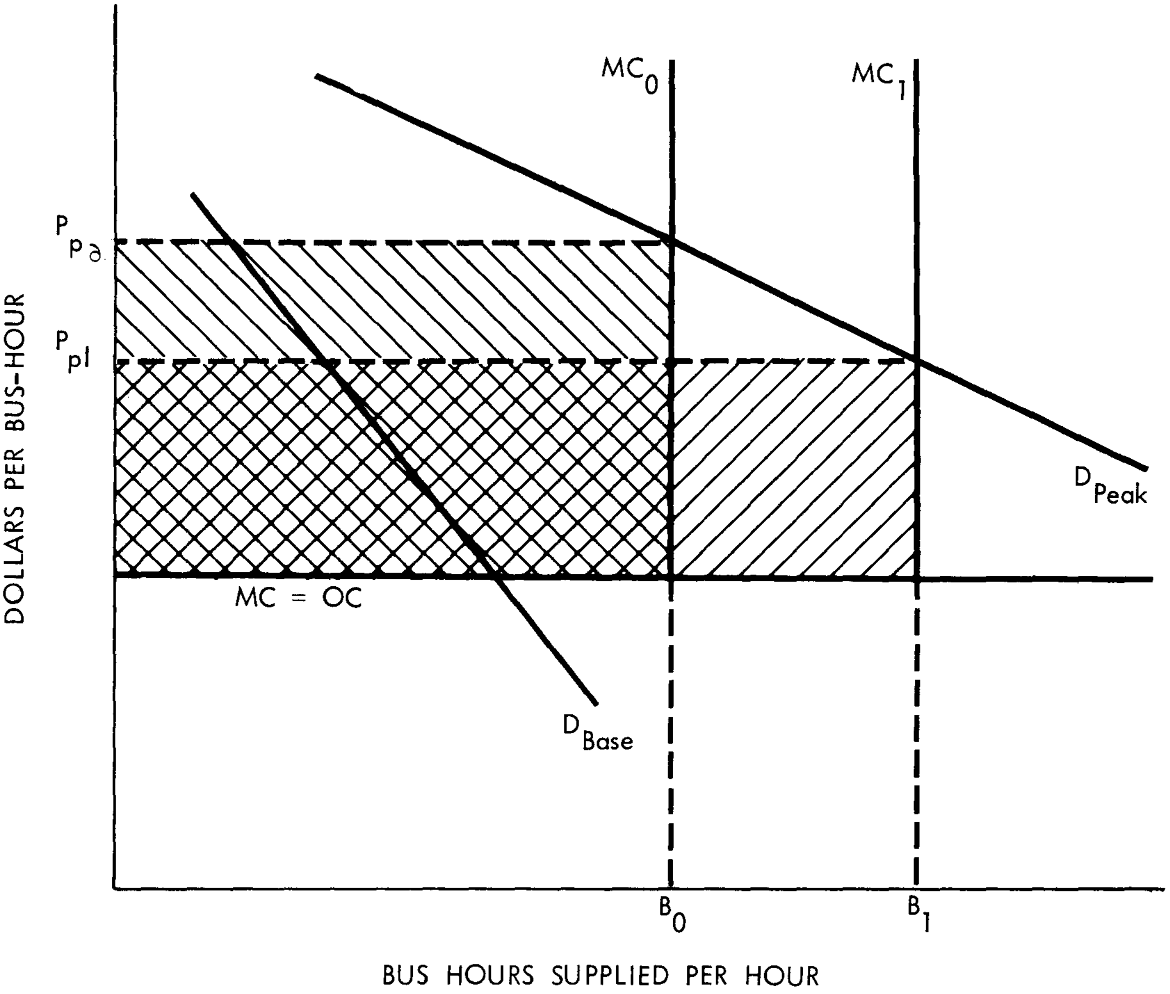

Figure B-1. EQUILIBRIA IN THE BUS-LEASING INDUSTRY WHEN ALL BUSES HAVE IDENTICAL OPERATING COSTS willingness of passengers to pay for various numbers of transit rides during the two periods. The peak demand for buses is higher because the peak demand for rides is also higher. During the peak period, given that the stock of buses is B_0, the competitive bus leasing industry would charge a price of P_{p0}. The competitive price would not fall below this amount, because then the demand for buses would exceed the amount that is capable of being supplied. The price cannot rise above this amount in equilibrium, because then there would be idle capacity and the firms in the competitive bus-leasing industry would compete against one another with lower prices until price fell to the equilibrium price. During the base period, the competitive price would fall to cover only operating costs. It would not fall below this price, because then firms in the industry would simply not supply buses--they would be worse off to do so. Firms trying to raise their price above this amount would be undercut by other firms until the price was driven back down to cover operating cost only. This pricing behavior would yield revenues in excess of operating costs only in the peak hours. This excess of revenues over operating costs, called quasi-rents in the economics literature, would be equal to the excess of price over unit operating costs times the number of hours per year at which this condition would be expected to prevail, in our example, 1,000 peak hours:

$$QR_0 = 1000B_0 \left(P_{p0} - OC\right). \tag{1}$$

If the bus fleet is expanded to an amount sufficient to offer B_1 bus-hours per hour of service, the price per bus-hour would fall to P_{p1} and the quasi-rents would be:

$$QR_1 = 1000B_1 \left(P_{p1} - OC\right). \tag{2}$$

Quasi-rents per bus would fall, although total quasi-rents may either fall or increase. Firms in the bus-leasing industry would find it profitable to expand their fleet to the point where the quasi-rent from the additional bus $\left[1,000\left(P_p - OC\right)\right]$ is equal to the annual depreciation and interest charge of holding that additional bus. Since the cost of owning and maintaining bus fleets is independent of the size of the bus fleet, that is to say, since owning and leasing buses is characterized by constant returns to scale, the cost of owning that marginal bus is equal to the average cost of owning all buses. Thus, competitive equilibrium in the industry is characterized by (1) an equality of price and short-run marginal cost in each demand period, and (2) an adjustment of capacity such that the marginal return from the last bus is equal to the cost of holding that bus, at which point total revenues from leasing buses is equal to total costs. In effect, this competitive behavior has "allocated" all costs of owning and holding the stock of buses to the peak time, and none to the off-peak time.

It is worth pointing out that these pricing and investment rules would be the same as those that would be followed by a benefit-maximizing public authority. Benefit maximization requires that price be equal to short-run marginal cost in each time period, since the additional sacrifice by society of supplying an additional bus-hour is equal to the value society receives from the bus-hour. Benefit maximization would also require that buses be purchased up to the point where the net value contributed by the marginal bus is equal to its cost. The contribution to welfare of the marginal bus is precisely the addition to quasi-rents, where the quasi-rents are evaluated at the equilibrium price.

To consider a slightly different case, assume that some buses are cheaper per hour to operate than other buses. Imagine that the buses are arranged in order of increasing cost per hour. If demand is very low, only those buses with the very lowest operating costs will be employed. If demand is somewhat higher, buses with slightly higher operating costs will be employed, and if demand is very high, those buses with the highest operating costs may be brought into play. Thus, the average cost per bus-hour is no longer independent of the number of bus-hours employed, but rises as a function of bus-hours per hour supplied. The average operating cost is, of course, below the marginal cost, since the average consists of not only the last bus employed but all of the previous buses which had, by hypothesis, lower operating cost per hour. The buses are priced in the same way as in Figure B-1, that is, equal to short run marginal cost in each time period. Quasi-rents per hour of operating are lower in the base period than in the peak period for two reasons. First, a larger number of buses are employed in the peak period and, second, the quasi-rents earned by each bus during the peak period is larger. Nevertheless, if the number of base hours during the year is appreciably larger than the number of peak hours, it is possible in this case that quasi-rents earned in the base period may be of comparable size to those earned by a fewer number of peak hours. In any case, the operations of competitive supply and demand would result in <u>ex post</u> allocation of a much higher <u>hourly</u> capital cost to peak services than to off-peak services.

Available evidence suggests that the model of Figure B-1 is a close approximation of reality. Costs of owning and operating buses seem to be largely proportional to bus-miles or bus-hours. The unit operating costs of buses seem to be largely independent of the average age of the fleet [31]. That is, bus fleets with a predominance of older buses experience no higher operating costs than do fleets with a preponderance of newer buses. Buses seem to be like the one horse shay, they keep going until they collapse. We are not trying to argue that Figure B-1 is an exact picture of reality, only that it is close enough for purposes of empirical allocation of costs.

These same results may be established more rigorously using an algebraic model, and can also be extended to the case where depreciation depends on utilization. The following variables are used in the algebraic model:

B_1 = peak bus-hours per hour
B_2 = off-peak bus-hours per hour

H_1 = peak hours per year

H_2 = off-peak hours per year
Y = lifetime of bus, in years
L = lifetime of bus, in hours of use
h = average hours of use per bus per year
C_B = initial cost of bus
R = capital recovery factor
i = interest rate
OC = operating cost per bus-hour
P_1 = price per peak bus-hour
P_2 = price per off-peak bus-hour
π = annual profits

The assumed goal of the competitive bus-leasing firms is to maximize annual profits:

$$\text{Max } \pi = \left(P_1 - OC\right)H_1B_1 + \left(P_2 - OC\right)H_2B_2 - C_BRB_1. \qquad (3)$$

The first term is net earnings from rentals during the peak period, the second term is earnings from off-peak rentals, and the last term is annual capital charges. H_1 and H_2 are given by market conditions. P_1 and P_2 are regarded as constants by a competitive firm. R is, for now, assumed independent of B_1 and B_2. The stock of buses, B_1, is assumed equal to peak demand. (For simplicity, we assume that operating costs are the same, peak and off-peak.) The firm thus has control over B_1 and B_2, or, equivalently, over the number of peak bus-hours supplied $\left(H_1B_1\right)$ and off-peak bus-hours supplied $\left(H_2B_2\right)$.

Differentiating with respect to peak bus-hours H, B, and off-peak bus-hours H_2B_2 and setting the resulting expressions equal to zero yields the following conditions for a profit maximum:

$$\left(P_1 - OC\right) = C_BR/H_1 \qquad (4)$$

$$\left(P_2 - OC\right) = 0 . \qquad (5)$$

Equations (4) and (5) are also conditions for a social welfare maximum. They imply that earnings from peak-hour service, $\left(P_1 - OC\right)$ per bus-hour, just cover the total capital charges $C_B R$ divided by the number of peak hours, and that off-peak price will be driven down to cover only operating costs. All of the capital costs have been "allocated," ex post, to peak services.

A different allocation should be used when depreciation depends on utilization rather than age. Assume that L = Yh if fixed, so that lifetime, Y, depends on hours of utilization, h, per year. Utilization is equal to

$$h = H_1 + H_2 B_2 / B_1 . \qquad (6)$$

The ratio B_2/B_1 is the probability that a bus is used during an off-peak hour. Thus, the lifetime depends on both B_1 and B_2:

$$Y = L \Big/ \left(H_1 + H_2 B_2 / B_1\right) . \qquad (7)$$

The capital recovery charge depends, in turn, on Y:

$$R = i / [1 - \exp(-iy)]^* . \qquad (8)$$

The profit equation is formally the same as before (equation above). The difference is that now the capital recovery factor R depends on B_1 and B_2, so that the optimum conditions will be different. Differentiating π with respect to $\left(H_1 B_1\right)$ and $\left(H_2 B_2\right)$, keeping in mind that now R is a function of B_1 and B_2 via equations (7)

---

* The expression exp(-iy) means $e^{-iy} = 1/e^{iy}$, where e is the base of the natural logarithms.

and (8), yields the following optimum conditions:

$$\left(P_1 - OC\right) = C_B \partial\left(RB_1\right) \Big/ \partial\left(H_1 B_1\right) \tag{9}$$

$$\left(P_2 - OC\right) = C_B \partial\left(RB_1\right) \Big/ \partial\left(H_1 B_2\right). \tag{10}$$

The partial derivatives $C_B \partial RB_i \Big/ \partial\left(H_i B_i\right)$ are the marginal capital costs of peak and off-peak bus-hours. The terms on the left $\left(P_1 - OC\right)$ are quasi-rents per bus-hour in peak and off-peak services.

The formal derivatives in equations (9) and (10) may be evaluated and manipulated to yield an ex post allocation of costs. Using equations (7) and (8), equations (9) and (10) can be written

$$\left(P_1 - OC\right) = \left(C_B \big/ H_1\right) \left[R - \frac{LH_2B_2}{h^2 B_1} R^2 \exp(-iy)\right] \tag{11}$$

$$\left(P_2 - OC\right) = C_B \left[LR^2 \exp(-iy) \big/ h^2\right]. \tag{12}$$

Total earnings in each of the two periods for each bus in the fleet are found by multiplying quasi-rents per peak bus-hour (equation 11) by H_1 and quasi-rents per off-peak bus-hour (equation 12) by $H_2B_2 \big/ B_1$. Thus, we have:

$$\text{Peak earnings} = H_1\left(P_1 - OC\right) = C_B \left[R - \frac{LH_2B_2}{h^2 B_1} R^2 \exp(-iy)\right] \tag{13}$$

$$\text{Off-peak earnings} = \left(H_2B_2 \big/ B_1\right)\left(P_2 - OC\right) = C_B \left[\frac{LH_2B_2}{h^2 B_1} R^2 \exp(-iy)\right]. \tag{14}$$

C_BR is total capital charges. The term $C_BLH_2B_2/h^2B_1$ which is subtracted in equation (13) and added in equation (14) captures the effect on the yearly capital charge. Adding a peak bus-hour (holding base-hours constant) not only increases the size of the fleet but lowers the base/peak ratio, lengthening the life of each bus and thus reducing the annual capital recovery charge. Adding a base bus-hour (holding peak utilization constant) raises the base/peak ratio, shortens the life of each bus, and increases the annual capital recovery factor.

The average conditions for bus operations, cited above in the text, are sufficient to compute the allocations implied by equations (13) and (14).

Yearly compounding at 10 percent is equivalent to continuous compounding at about 9.53 percent. The lifetime of a bus is 15 years, so that R would be .1313 and $\exp(-.0953 \times 15) = .2393$. Buses run 29,400 miles per year at 12 miles per hour, or $h = 2{,}450$ hours per year and $L = 36{,}750$ hours over their lifetime. Off-peak hours per bus is $1{,}450 = H_2B_2/B_1$. This allows the evaluation of the expression

$$\frac{LH_2B_2}{h^2B_1} R^2 \exp(-iy) = \frac{36{,}750 \times 1{,}450}{2{,}450^2} \times .1313^2 \times .2393 = .0366.$$

Off-peak earnings are thus $.0366C_B$ compared with annual capital charges of $.1313C_B$, and the ratio of peak of total earnings per bus is

$$\frac{.1313 + .0366}{.1313} = 72 \text{ percent}.$$

Seventy-two percent of the costs are "allocated" ex post to peak service and 28 percent to base service.

This assumes that buses last 36,750 hours rather than 15 years. The contrary assumption allocates 100 percent of the capital charges to peak services. The truth is probably somewhere in between. Increasing annual utilization would probably shorten the life of the bus, but not in proportion. In the absence of better information, we allocate an intermediate percentage, 85 percent, to peak-hour services.

Even though rail rapid transit (and hence busway) patronage is slightly more "peaked" than conventional bus transit [5, p. 95], we have used the same allocation factor for rail and busway buses. The difference in peaking characteristics is not great, and in any event, no data is available comparable to the conventional bus data to allow a finer-grained calculation. Minibus costs were also allocated using the same factor, on the assumption that minibus operations would be similar to conventional bus operations.

APPENDIX C

CONGESTION COSTS OF OPERATING TRANSIT VEHICLES IN MIXED TRAFFIC

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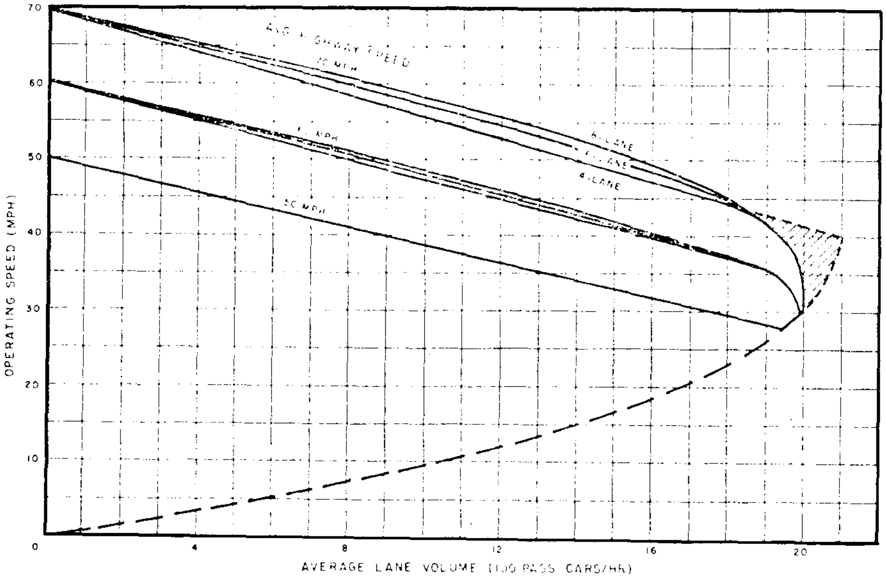
CONGESTION COSTS OF OPERATING TRANSIT VEHICLES IN MIXED TRAFFIC

The costs of street and road capacity and an allocation to transit vehicles operating in mixed traffic were derived in Chapter 3. In this Appendix, we compute estimates of the short-run opportunity costs of using the capacity of streets and roads for transit services. The opportunity cost of adding a transit vehicle to the traffic stream is the cost of delays caused to the other vehicles on the road. Equivalently, the opportunity cost of capacity used by any vehicle in the stream is the savings in time and operating costs that would be enjoyed by the other vehicles if the vehicle in question is removed from the stream. Figures C-1 and C-2 [12, pp. 62 and 320] indicate that the average speed declines as traffic volume along a given road is increased. Thus, adding a vehicle lowers average speed of the other vehicles, imposing a cost on them. It is this cost which we wish to estimate with respect to the delay caused by transit vehicles on other vehicles using the roads.

C.1 TYPES OF BUS OPERATION AND THEIR USE OF ROAD CAPACITY

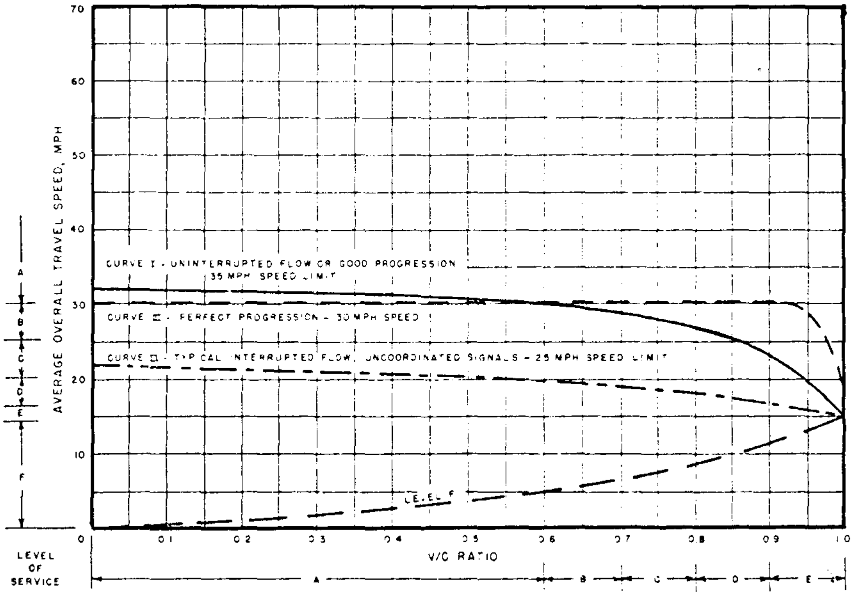
The Highway Capacity Manual [12] distinguishes between three different situations for conventional buses, depending on their utilization of capacity relative to private automobiles:

1. Buses operating nonstop on expressways and freeways, which we shall call expressway buses
2. Through buses, operating in express service without passenger stops on streets in mixed traffic
3. Local transit buses, operating on streets in mixed traffic and making stops to pick up and discharge passengers. Formulae are given to adjust highway capacity for each type; thus the auto equivalents can be computed.



Source: Highway Capacity Manual, Highway Research Board, Wash., D.C., 1965.

Figure C-1. TYPICAL RELATIONSHIPS BETWEEN VOLUME PER LANE AND OPERATING SPEED IN ONE DIRECTION OF TRAVEL UNDER IDEAL UNINTERRUPTED FLOW CONDITIONS ON FREEWAYS AND EXPRESSWAYS



Source: Highway Capacity Manual, Highway Research Board, Wash., D.C., 1965.

Figure C-2. TYPICAL RELATIONSHIPS BETWEEN V/C RATIO AND AVERAGE OVERALL TRAVEL SPEED, IN ONE DIRECTION OF TRAVEL, ON URBAN AND SUBURBAN ARTERIAL STREETS

Expressway buses use capacity equivalent to 1.6 automobiles. This applies both to mixed traffic and exclusive busway operations [12, pp. 342-345].

Auto equivalency factors are not given for through buses or local transit buses. Instead, traffic volume is expressed in total vehicles of all types and capacity is computed by multiplying nominal capacity by a "correction factor" to account for vehicles other than autos in the traffic stream. We have derived auto equivalencies from these capacity correction factors. The correction factor for through buses (and trucks, which have the same effect on traffic flow) depends on the percentage of trucks and through buses. The correction factor β [from 12, Table 6.6] is given by

$$\beta = 1.05 - \alpha,$$

where α is the proportion of trucks and through buses, T, to total traffic, including autos (T + A). The base case ($\beta = 1.0$) assumes $\alpha = .05$.

To illustrate, suppose there are 1,000 autos (A = 1,000 and T = 0) and the resulting volume/capacity ratio is R. Suppose we then add buses and subtract autos so that R (and average speed) is held constant up to 10 percent through buses. Capacity would then be

$$\frac{.95}{1.05} \cong .905$$

of the former capacity, so that the flow of total vehicles would be reduced to 905 if the same R is maintained: 90.5 buses and 814.5 autos. 90.5 buses have been added and 185.5 (1,000 - 814.5) autos have been subtracted, so that one bus displaces 185.5/90.5, or 2.05 autos.

It can be shown that the number of autos displaced per bus (holding R constant) is given by

$$\frac{(2.05 - \alpha)}{(1.05 - \alpha)}.^{*}$$

Thus, the auto equivalent of a through bus ranges from 1.95 for $\alpha = 0$ to 2.18 for $\alpha = .20$. We have used an auto equivalency factor of 2.0 autos per through bus for all computations in this chapter and in Chapter 3.

Figure C-3 from [12, p. 143], is a nomograph for calculating a street capacity correction factor for local transit buses. It assumes a near-side bus stop with no parking. Similar, but more complex, nomographs are given in the source document [12, pp. 143-145] for near-side stops <u>with</u> parking and for far-side stops with and without parking. Based on Figure C-3, the equivalent algebraic expression for the correction factor in fringe and outlying areas is

$$\beta_f = 1 - (.00417 - .00052L)B, \qquad (1a)$$

and in the CBD is

$$\beta_c = 1 - (.00556 - .00069L)B, \qquad (1b)$$

where L is the number of lanes ($2 \leq L \leq 4$) and B is the number of local buses ($0 \leq B \leq 120$ for fringe and outlying, and $0 \leq B \leq 90$) for CBD. Note that a bus in the CBD has one-third more effect on capacity than one in a frange or outlying area.

Intersection capacity (and thus street capacity) is expressed in vehicles per hour of green light time in the <u>Highway Capacity</u>

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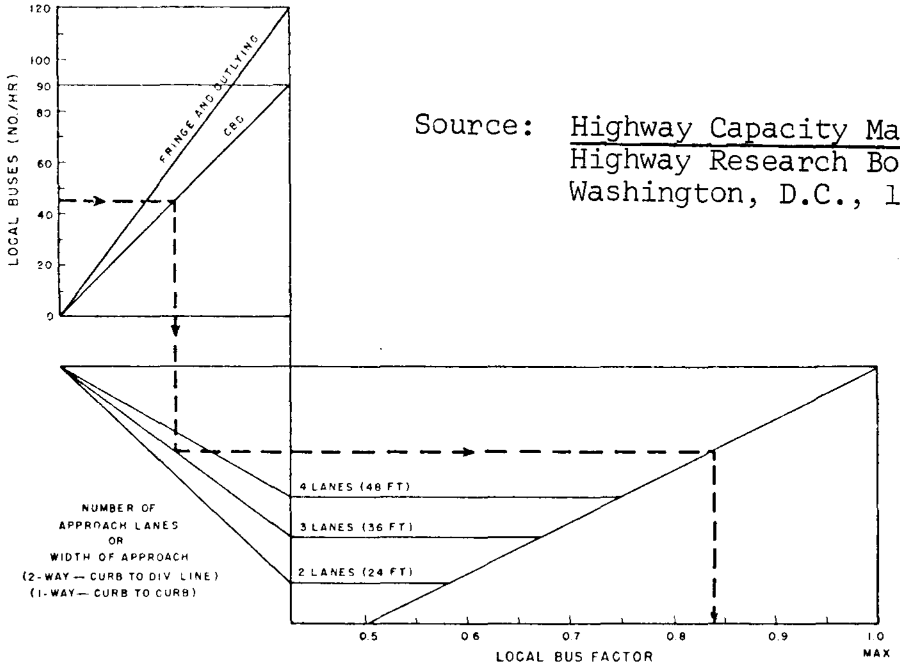
[*] Let R be the volume/capacity ratio (held constant) and K_o nominal capacity. With $T = 0$, $A' = 1.05RK_o$. The actual number of autos for some $T > 0$ is $A = (1 - \alpha) RK_o(1.05 - \alpha) = RK_o(1.05 - 2.05\alpha + \alpha^2)$; thus $A' - A = \alpha RK_o(2.05 - \alpha)$ autos are displaced. The number of through buses is $T = \alpha RK_o(1.05 - \alpha)$. Hence, $(A' - A)/T = (2.05 - \alpha)/(1.05 - \alpha)$.



Source: Highway Capacity Manual, Highway Research Board, Washington, D.C., 1965.

Figure C-3. LOCAL BUS FACTOR FOR NEAR-SIDE BUS STOP ON STREET WITH NO PARKING

Manual, while the local bus correction factor is expressed in buses per hour, independent of green light time. A measure of intersection capacity is needed to derive auto equivalencies for local buses.

C.2 STREET AND INTERSECTION CAPACITY

Capacity depends on such factors as the width of the approach to the intersection, whether the street is a one-way or a two-way street, parking conditions, the characteristics of the traffic, the amount of queueing at the traffic light, and the distribution of traffic over the peak hour. Intersections in large metropolitan areas have somewhat higher capacities than identical intersections in smaller metropolitan areas, perhaps because drivers are more experienced and more in a hurry. Location within the metropolitan area also influences intersection capacity. Traffic characteristics such as the percentage of turning movements, percentage of trucks and through buses, and percentage of local transit buses influence the capacity of the critical intersections [12, pp. 111-159].

Intersection capacity is roughly proportional to approach width, where the width is measured curb-to-curb for one-way streets and curb-to-center-line for two-way streets. For one-way or two-way streets with no parking, 10 percent left turns and 10 percent right turns, 5 percent trucks and through buses, and no local transit, in cities of 750,000 population and for fringe and outlying business districts and residential districts, the relationship between capacity and approach width is approximately

$$K_g = 122W,^{*} \qquad (2)$$

where K_g is intersection capacity in vehicles per hour of green and W is the approach width in feet. The slope term would be 106 for one-way streets in the CBD and 98 for two-way streets in the CBD. For cities of over one million population, the capacity is about 3 to 6 percent greater than indicated by equation (2), while for cities with populations of approximately 100,000, the capacity is about 15 percent less, with capacities for intermediate sized cities roughly in proportion.

Assuming 12-foot lanes [12, p. 129], capacity would be approximately 1,500 vehicles per hour of green light time, while CBD street capacity would be approximately 1,200 vehicles per hour of green light time.

C.3 AUTO EQUIVALENCIES FOR LOCAL BUSES

If G is the proportion of green light time and K_g is basic capacity per hour of green, then GK_g is basic capacity per hour and $K = \beta GK_g$ is capacity adjusted for local buses. Substituting for β

[**] This relationship applies either to two-way or one-way streets without parking and was estimated from [12, Figures 6.5 and 6.8], assuming a peak-hour factor of .80 and load factor of 1.0. The peak-hour factor is the ratio of the volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour. The load factor is the ratio of the total number of green signal intervals that are fully utilized by traffic during the peak hour to the total number of green intervals for that approach during the same period.

in equations (1a) and (1b) and for K_g yields, for the fringe and outlying areas,

$$K = 1{,}500\ LG[1 - (.00417 - .00052L)B] \tag{3a}$$

and for the CBD,

$$K = 1{,}200\ LG[1 - (.00556 - .00069L)B]. \tag{3b}$$

Let A be the number of autos per hour and

$$R = \frac{(A + B)}{K}$$

the volume/capacity ratio. Then

$$A = RK - B,$$

and the marginal auto equivalent for a local bus in the fringe and outlying area is

$$E = -\partial A/\partial B = -R\partial K/\partial B + 1 = GR\left(6.26L - .78L^2\right) + 1,$$

and in the CBD is

$$E = GR\left(6.67L - .83L^2\right) + 1.$$

Auto equivalency depends on the number of lanes, the proportion of green light time and the volume/capacity ratio, and is roughly the same for CBD and outlying areas, other things being equal.

Table C-1 indicates the auto equivalencies for different combinations of GR and L. Surprisingly, the greater the number of lanes, the greater the number of autos that are displaced by local buses. For low GR (for example, low volume/capacity ratio and short green time), local buses are indistinguishable from through buses, which are equivalent to roughly two autos. For congested arterial streets with R in, say, the .90s and generous green light times,

Table C-1. RELATION BETWEEN GREEN LIGHT TIME, VOLUME/CAPACITY RATIO, NUMBER OF LANES, AND AUTO-EQUIVALENCY OF LOCAL TRANSIT BUSES

G x R	Number of Lanes (Each Direction)	Auto-Equivalency of Local Transit Buses
.10	2	1.9
	3	2.2
	4	2.3
.25	2	3.4
	3	3.9
	4	4.1
.50	2	5.7
	3	6.9
	4	7.3
.75	2	8.1
	3	9.8
	4	10.4

G = minutes of green light time per hour/60
R = traffic volume/intersection capacity

local buses can be equivalent to 10 or more autos. For congested CBD streets, with green proportion around .45 to .50, a bus would be equivalent to about six autos.

C.4 CONGESTION COST ESTIMATES

Mohring [7] has presented estimates of the opportunity costs of street and road capacity used by private automobiles. For two-way urban streets, the cost is approximately 7.4 cents per auto-mile for a volume/capacity ratio of .5 (perhaps typical of flows during the day outside the peak hour). For R equal to .9, typical of peak traffic conditions, the opportunity cost is about \$.29 per auto-mile. These computed values assume an average time value of \$3 per auto-hour. An "optimal congestion toll" would be equal to this opportunity cost of street capacity. (An actual toll would be somewhat lower, because the consequent reduction in traffic would result in a lower opportunity cost of capacity.)

Table 14 of Chapter 4 presents the results of our computations of bus costs, based on the auto equivalencies calculated above. We have assumed two types of street, an arterial street with long green light times and a CBD street with roughly equal green and red times. For base services, local buses on an arterial street cause congestion costs of \$.39 per bus-mile while express buses cost only \$.14 per mile. The differential widens in the peak to \$2.90 versus \$.58. In the CBD, base-hour costs are \$.28 per bus-mile and peak-hour costs are \$1.74.

These costs are two to three times the costs obtained in Chapter 3, which were derived by allocating road capital costs to the using vehicles. The \$.58 arterial street cost and the \$1.74 CBD street cost of Table 14 of Chapter 4 compare to Chapter 3 costs of \$.18 and \$.88, respectively. The costs of Chapter 3 are used in the commuter travel case study of Chapter 5.

Present auto road-user charges, consisting primarily of gasoline taxes, are something less than \$.015 per mile. This is far below the real cost of using the road in both peak (\$.29) and base (\$.07) periods. It is even lower than the \$.088 figure for peak capacity which results from the costing described in Chapter 3 (the .088 figure is obtained from the bus cost of \$.88 times the auto-to-bus equivalency factor of 1/10 used in Chapter 3). Clearly, peak-hour private auto travel is heavily subsidized. Charges sufficient to cover the true costs of auto travel in urban areas would surely cause a major restructuring of travel behavior and urban form.

Present transit operations pay low, if any, street user fees. Table 14 of Chapter 4 suggests that conventional local services that operate on arterial streets into the CBD receive a substantial implicit subsidy in that they do not pay for the opportunity costs of street capacity. There is even a substantial subsidy on the basis of allocated costs of Chapter 3. A greater emphasis on express services (not to mention exclusive busways) would not only save user time costs and some supplier costs (due to faster speeds and lower hourly costs per mile), but would economize as well on the use of scarce urban peak-hour street capacity.

APPENDIX D

RESIDENTIAL FEEDER COSTS

APPENDIX D

RESIDENTIAL FEEDER COSTS

Tables D-1 through D-8 present the residential feeder costs for the four vehicle types used in this service. The tables show costs for various combinations of time values, number of feeder routes and feeder route perpendicular distance from the line-haul route. Tables D-1 through D-4 and D-5 through D-8 for "low" and "high" time values, respectively, display the same comparative full costs as Figures 9 through 12 of Chapter 5, along with other information. Tables D-1, D-2, D-5 and D-6 are for 3-mile feeders, and two and four routes. Tables D-3, D-4, D-7, and D-8 are for 5-mile feeders. Time values are given for in-vehicle, waiting, and walking times.

Immediately under the name of the vehicle in the tables, six figures are given in the following order:

1. Vehicle speed (miles per hour)
2. Vehicle hourly costs (dollars per vehicle-hour)
3. Vehicle mileage costs (dollars per vehicle-mile)
4. Beta = vehicle operating cost (dollars per vehicle-mile)
5. Alpha = average vehicle cost per round-trip (dollars)
6. Time per vehicle round-trip (hours)

The time per round trip (as well as α) includes five minutes per hour layover time between trips.

Each panel consists of six columns in the following order:

1. PDEN = passengers per square mile generated per hour
2. SUPPL COST = supplier cost (dollars per passenger)
3. U TIME = user time cost (dollars per passenger)
4. TOTAL = sum of supplier plus user time costs (dollars per passenger)
5. FREQ = vehicle frequency on each route (vehicles per hour)
6. LOAD = average number of passengers carried per vehicle-trip (passengers per vehicle).

Results are presented for 9-passenger generation densities (PDEN), expressed as passengers per square mile per hour. In each panel, total full costs are underlined to indicate minimum-cost route spacing for each vehicle type as a function of PDEN. The minimum-cost vehicle type and route spacing is marked with an asterisk.

Table D-1. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $1.20, $3.00, $3.00; 2 FEEDER ROUTES; 3 MILES)

	JITNEY						BUS WAGON					
	SPEED	HR COSTS	MI	BETA	ALPHA	TIME	SPEED	HR COSTS	MI	BETA	ALPHA	TIME
	20.	3.66	0.134	0.332	2.13	0.35	19.	3.88	0.141	0.362	2.32	0.37

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.426	0.427	0.854	7.50	5.0	0.305	0.538	0.843*	4.92	7.6
50.	0.426	0.327	0.754	15.00	5.0	0.290	0.393	0.683*	9.38	8.0
75.	0.426	0.294	0.720	22.50	5.0	0.290	0.340	0.630*	14.06	8.0
100.	0.426	0.277	0.704	30.00	5.0	0.290	0.313	0.603*	18.75	8.0
150.	0.426	0.261	0.687	45.00	5.0	0.290	0.286	0.577	28.13	8.0
200.	0.426	0.252	0.679	60.00	5.0	0.290	0.273	0.563	37.50	8.0
300.	0.426	0.244	0.670	90.00	5.0	0.290	0.260	0.550	56.25	8.0
500.	0.426	0.237	0.664	150.00	5.0	0.290	0.249	0.539	93.75	8.0
700.	0.426	0.235	0.661	210.00	5.0	0.290	0.244	0.535	131.25	8.0

	MINIBUS						BUS					
	SPEED	HR COSTS	MI	BETA	ALPHA	TIME	SPEED	HR COSTS	MI	BETA	ALPHA	TIME
	17.	9.22	0.261	0.848	5.44	0.41	15.	13.69	0.325	1.313	8.43	0.46

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.467	0.712	1.179	3.21	11.7	0.581	0.842	1.423	2.58	14.5
50.	0.330	0.576	0.905	4.55	16.5	0.411	0.672	1.083	3.65	20.5
75.	0.286	0.499	0.785	5.92	19.0	0.335	0.597	0.932	4.47	25.1
100.	0.286	0.436	0.722	7.89	19.0	0.290	0.552	0.842	5.17	29.0
150.	0.286	0.372	0.659	11.84	19.0	0.237	0.499	0.736	6.33	35.6
200.	0.286	0.341	0.627	15.79	19.0	0.205	0.467	0.672	7.31	41.1
300.	0.286	0.309	0.595	23.68	19.0	0.169	0.428	0.597	9.00	50.0
500.	0.286	0.234	0.570	39.47	19.0	0.169	0.362	0.530	15.00	50.0
700.	0.286	0.273	0.559	55.26	19.0	0.169	0.333	0.502	21.00	50.0

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-2. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $1.20, $3.00, $3.00; 4 FEEDER ROUTES; 3 MILES)

	JITNEY						BUS WAGON					
	SPEED	HR COSTS	MI	BETA	ALPHA	TIME	SPEED	HR COSTS	MI	BETA	ALPHA	TIME
	20.	3.66	0.134	0.332	2.16	0.35	19.	3.88	0.141	0.362	2.35	0.37

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.432	0.561	0.992	3.75	5.0	0.434	0.600	1.034	3.46	5.4
50.	0.432	0.361	0.792	7.50	5.0	0.307	0.473	0.780	4.89	7.7
75.	0.432	0.294	0.726	11.25	5.0	0.294	0.379	0.674	7.03	8.0
100.	0.432	0.261	0.692	15.00	5.0	0.294	0.326	0.620	9.38	8.0
150.	0.432	0.227	0.659	22.50	5.0	0.294	0.273	0.567*	14.06	8.0
200.	0.432	0.211	0.642	30.00	5.0	0.294	0.246	0.540*	18.75	8.0
300.	0.432	0.194	0.626	45.00	5.0	0.294	0.219	0.514*	28.13	8.0
500.	0.432	0.181	0.612	75.00	5.0	0.294	0.198	0.492*	46.88	8.0
700.	0.432	0.175	0.607	105.00	5.0	0.294	0.189	0.483*	65.63	8.0

	MINIBUS						BUS					
	SPEED	HR COSTS	MI	BETA	ALPHA	TIME	SPEED	HR COSTS	MI	BETA	ALPHA	TIME
	17.	9.22	0.261	0.348	5.51	0.41	15.	13.69	0.325	1.313	8.54	0.47

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.664	0.843	1.508	2.26	8.3	0.826	1.022	1.848	1.82	10.3
50.	0.470	0.649	1.118	3.19	11.7	0.584	0.780	1.364	2.57	14.6
75.	0.383	0.563	0.946	3.91	14.4	0.477	0.673	1.150	3.14	17.9
100.	0.332	0.511	0.843	4.52	16.6	0.413	0.609	1.022	3.63	20.7
150.	0.290	0.432	0.723	5.92	19.0	0.337	0.533	0.870	4.45	25.3
200.	0.290	0.369	0.659	7.89	19.0	0.292	0.488	0.780	5.13	29.2
300.	0.290	0.306	0.596	11.84	19.0	0.239	0.434	0.673	6.29	35.8
500.	0.290	0.255	0.545	19.74	19.0	0.185	0.380	0.565	8.12	46.2
700.	0.290	0.233	0.524	27.63	19.0	0.171	0.338	0.509	10.50	50.0

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-3. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $1.20, $3.00, $3.00; 2 FEEDER ROUTES; 5 MILES)

JITNEY

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
20.	3.66	0.134	0.332	3.46	0.56

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.692	0.407	1.099	12.50	5.0
50.	0.692	0.347	1.039	25.00	5.0
75.	0.692	0.327	1.019	37.50	5.0
100.	0.692	0.317	1.009	50.00	5.0
150.	0.692	0.307	0.999	75.00	5.0
200.	0.692	0.302	0.994	100.00	5.0
300.	0.692	0.297	0.989	150.00	5.0
500.	0.692	0.293	0.985	250.00	5.0
700.	0.692	0.292	0.984	350.00	5.0

BUS WAGON

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
19.	3.88	0.141	0.362	3.77	0.59

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.472	0.488	0.960*	7.81	8.0
50.	0.472	0.392	0.864*	15.63	8.0
75.	0.472	0.360	0.832*	23.44	8.0
100.	0.472	0.344	0.816	31.25	8.0
150.	0.472	0.328	0.800	46.88	8.0
200.	0.472	0.320	0.792	62.50	8.0
300.	0.472	0.312	0.784	93.75	8.0
500.	0.472	0.306	0.777	156.25	8.0
700.	0.472	0.303	0.774	218.75	8.0

MINIBUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
17.	9.22	0.261	0.848	8.84	0.66

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.465	0.772	1.237	3.29	19.0
50.	0.465	0.544	1.009	6.58	19.0
75.	0.465	0.468	0.933	9.37	19.0
100.	0.465	0.430	0.895	13.16	19.0
150.	0.465	0.392	0.857	19.74	19.0
200.	0.465	0.373	0.838	26.32	19.0
300.	0.465	0.354	0.819	39.47	19.0
500.	0.465	0.339	0.804	65.79	19.0
700.	0.465	0.332	0.798	92.11	19.0

BUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
15.	13.69	0.325	1.313	13.68	0.75

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.573	0.915	1.488	2.62	23.9
50.	0.405	0.747	1.152	3.70	33.8
75.	0.331	0.672	1.003	4.53	41.4
100.	0.287	0.628	0.915	5.24	47.8
150.	0.274	0.542	0.815	7.50	50.0
200.	0.274	0.492	0.765	10.00	50.0
300.	0.274	0.442	0.715*	15.00	50.0
500.	0.274	0.402	0.675	25.00	50.0
700.	0.274	0.384	0.658	35.00	50.0

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-4. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $1.20, $3.00, $3.00; 4 FEEDER ROUTES; 5 MILES)

JITNEY

SPEED	HR COSTS MI		BETA	ALPHA	TIME
20.	3.66	0.134	0.332	3.49	0.57

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.693	0.461	1.158	6.25	5.0
50.	0.693	0.341	1.038	12.50	5.0
75.	0.698	0.301	0.998	18.75	5.0
100.	0.698	0.281	0.978	25.00	5.0
150.	0.693	0.261	0.958	37.50	5.0
200.	0.693	0.251	0.948	50.00	5.0
300.	0.698	0.241	0.938	75.00	5.0
500.	0.698	0.233	0.930	125.00	5.0
700.	0.693	0.229	0.927	175.00	5.0

BUS WAGON

SPEED	HR COSTS MI		BETA	ALPHA	TIME
19.	3.88	0.141	0.362	3.80	0.60

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.475	0.613	1.089	3.91	8.0
50.	0.475	0.421	0.897	7.81	8.0
75.	0.475	0.357	0.833	11.72	8.0
100.	0.475	0.325	0.801*	15.63	8.0
150.	0.475	0.293	0.769*	23.44	8.0
200.	0.475	0.277	0.753*	31.25	8.0
300.	0.475	0.261	0.737	46.88	8.0
500.	0.475	0.248	0.724	78.13	8.0
700.	0.475	0.243	0.718	109.38	8.0

MINIBUS

SPEED	HR COSTS MI		BETA	ALPHA	TIME
17.	9.22	0.261	0.848	8.91	0.67

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.654	0.904	1.558	2.29	13.6
50.	0.469	0.706	1.175	3.29	19.0
75.	0.469	0.554	1.023	4.93	19.0
100.	0.469	0.473	0.947	6.58	19.0
150.	0.469	0.402	0.871	9.87	19.0
200.	0.469	0.364	0.833	13.16	19.0
300.	0.469	0.326	0.795	19.74	19.0
500.	0.469	0.295	0.764	32.89	19.0
700.	0.469	0.282	0.751	46.05	19.0

BUS

SPEED	HR COSTS MI		BETA	ALPHA	TIME
15.	13.69	0.325	1.313	13.79	0.76

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.814	1.089	1.903	1.84	17.0
50.	0.575	0.851	1.426	2.61	24.0
75.	0.470	0.745	1.215	3.19	29.4
100.	0.407	0.682	1.089	3.69	33.9
150.	0.332	0.603	0.940	4.52	41.5
200.	0.288	0.563	0.851	5.21	47.9
300.	0.276	0.476	0.751	7.50	50.0
500.	0.276	0.396	0.671*	12.50	50.0
700.	0.276	0.361	0.637*	17.50	50.0

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-5. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $3.00, $7.50, $7.50; 2 FEEDER ROUTES; 3 MILES)

	JITNEY						BUS WAGON				
	SPEED	HR COSTS	MI	BETA	ALPHA	TIME	SPEED	HR COSTS	MI	BETA	ALPHA	TIME
	20.	3.66	0.134	0.332	2.13	0.35	19.	3.88	0.141	0.362	2.32	0.37

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.462	1.030	1.492*	8.12	4.6	0.482	1.064	1.546	7.78	4.8
50.	0.426	0.819	1.245*	15.00	5.0	0.341	0.923	1.264	11.00	6.8
75.	0.426	0.735	1.162	22.50	5.0	0.290	0.849	1.139*	14.06	8.0
100.	0.426	0.694	1.120	30.00	5.0	0.290	0.782	1.073*	18.75	8.0
150.	0.426	0.652	1.078	45.00	5.0	0.290	0.716	1.006	28.13	8.0
200.	0.426	0.631	1.057	60.00	5.0	0.290	0.682	0.973	37.50	8.0
300.	0.426	0.610	1.037	90.00	5.0	0.290	0.649	0.939	56.25	8.0
500.	0.426	0.594	1.020	150.00	5.0	0.290	0.622	0.913	93.75	8.0
700.	0.426	0.587	1.013	210.00	5.0	0.290	0.611	0.901	131.25	8.0

	MINIBUS						BUS				
	SPEED	HR COSTS	MI	BETA	ALPHA	TIME	SPEED	HR COSTS	MI	BETA	ALPHA	TIME
	17.	9.22	0.261	0.848	5.44	0.41	15.	13.69	0.325	1.313	8.43	0.46

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.738	1.352	2.089	5.08	7.4	0.918	1.572	2.490	4.09	9.2
50.	0.522	1.136	1.657	7.19	10.4	0.649	1.303	1.952	5.78	13.0
75.	0.426	1.040	1.466	8.80	12.8	0.530	1.184	1.714	7.08	15.9
100.	0.369	0.983	1.352	10.17	14.8	0.459	1.113	1.572	8.17	18.4
150.	0.301	0.915	1.216	12.45	18.1	0.375	1.029	1.404	10.01	22.5
200.	0.236	0.851	1.138	15.79	19.0	0.325	0.979	1.303	11.55	26.0
300.	0.236	0.772	1.059	23.68	19.0	0.265	0.919	1.184	14.15	31.8
500.	0.236	0.709	0.995	39.47	19.0	0.205	0.859	1.065	18.27	41.1
700.	0.236	0.682	0.968	55.26	19.0	0.173	0.828	1.001	21.62	48.6

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-6. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $3.00, $7.50, $7.50; 4 FEEDER ROUTES, 3 MILES)

JITNEY

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
20.	3.66	0.134	0.332	2.16	0.35

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.657	1.059	1.716	5.71	3.3
50.	0.465	0.865	1.331	8.07	4.6
75.	0.432	0.735	1.167	11.25	5.0
100.	0.432	0.651	1.083	15.00	5.0
150.	0.432	0.568	1.000	22.50	5.0
200.	0.432	0.526	0.958	30.00	5.0
300.	0.432	0.485	0.917	45.00	5.0
500.	0.432	0.451	0.883	75.00	5.0
700.	0.432	0.437	0.869	105.00	5.0

BUS WAGON

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
19.	3.88	0.141	0.362	2.35	0.37

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.686	1.101	1.788	5.47	3.4
50.	0.485	0.900	1.386	7.73	4.9
75.	0.396	0.811	1.208	9.47	5.9
100.	0.343	0.758	1.101	10.93	6.9
150.	0.294	0.682	0.976*	14.06	8.0
200.	0.294	0.615	0.910*	18.75	8.0
300.	0.294	0.549	0.843*	28.13	8.0
500.	0.294	0.495	0.790*	46.88	8.0
700.	0.294	0.472	0.767*	65.63	8.0

MINIBUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
17.	9.22	0.261	0.843	5.51	0.41

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	1.050	1.493	2.548	3.57	5.3
50.	0.743	1.190	1.933	5.05	7.4
75.	0.606	1.054	1.660	6.18	9.1
100.	0.525	0.973	1.498	7.14	10.5
150.	0.429	0.877	1.305	8.75	12.9
200.	0.371	0.819	1.190	10.10	14.9
300.	0.303	0.751	1.054	12.37	18.2
500.	0.290	0.633	0.928	19.74	19.0
700.	0.290	0.584	0.874	27.63	19.0

BUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
15.	13.69	0.325	1.313	8.54	0.47

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	1.307	1.796	3.102	2.87	6.5
50.	0.924	1.413	2.337	4.06	9.2
75.	0.754	1.243	1.998	4.97	11.3
100.	0.653	1.142	1.796	5.74	13.1
150.	0.533	1.022	1.556	7.03	16.0
200.	0.462	0.951	1.413	8.12	18.5
300.	0.377	0.866	1.243	9.94	22.6
500.	0.292	0.781	1.073	12.83	29.2
700.	0.247	0.736	0.983	15.19	34.6

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-7. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $3.00, $7.50, $7.50; 2 FEEDER ROUTES; 5 MILES)

JITNEY

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
20.	3.66	0.134	0.332	3.46	0.56

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.692	1.019	1.711	12.50	5.0
50.	0.692	0.869	1.561	25.00	5.0
75.	0.692	0.819	1.511	37.50	5.0
100.	0.692	0.794	1.486	50.00	5.0
150.	0.692	0.769	1.461	75.00	5.0
200.	0.692	0.756	1.448	100.00	5.0
300.	0.692	0.744	1.436	150.00	5.0
500.	0.692	0.734	1.426	250.00	5.0
700.	0.692	0.729	1.421	350.00	5.0

BUS WAGON

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
19.	3.88	0.141	0.362	3.77	0.59

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.476	1.216	1.692*	7.88	7.9
50.	0.472	0.980	1.452*	15.63	8.0
75.	0.472	0.900	1.372	23.44	8.0
100.	0.472	0.860	1.332	31.25	8.0
150.	0.472	0.820	1.292	46.88	8.0
200.	0.472	0.800	1.272	62.50	8.0
300.	0.472	0.780	1.252	93.75	8.0
500.	0.472	0.764	1.236	156.25	8.0
700.	0.472	0.757	1.229	218.75	8.0

MINIBUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
17.	9.22	0.261	0.843	8.84	0.66

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.728	1.519	2.247	5.15	12.1
50.	0.515	1.305	1.320	7.28	17.2
75.	0.465	1.170	1.635	9.87	19.0
100.	0.465	1.075	1.540	13.16	19.0
150.	0.465	0.980	1.445	19.74	19.0
200.	0.465	0.933	1.398	26.32	19.0
300.	0.465	0.835	1.350	39.47	19.0
500.	0.465	0.847	1.312	65.79	19.0
700.	0.465	0.831	1.296	92.11	19.0

BUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
15.	13.69	0.325	1.313	13.68	0.75

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.906	1.760	2.666	4.14	15.1
50.	0.641	1.495	2.135	5.85	21.4
75.	0.523	1.377	1.900	7.17	26.2
100.	0.453	1.307	1.760	8.28	30.2
150.	0.370	1.224	1.594	10.14	37.0
200.	0.320	1.174	1.495	11.71	42.7
300.	0.274	1.104	1.378	15.00	50.0
500.	0.274	1.004	1.278	25.00	50.0
700.	0.274	0.961	1.235	35.00	50.0

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

Table D-8. RESIDENTIAL FEEDER COSTS
(TIME VALUES = $3.00, $7.50, $7.50; 4 FEEDER ROUTES; 5 MILES)

JITNEY

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
20.	3.66	0.134	0.332	3.49	0.57

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.693	1.151	1.849	6.25	5.0
50.	0.693	0.851	1.549	12.50	5.0
75.	0.693	0.751	1.449	18.75	5.0
100.	0.693	0.701	1.399	25.00	5.0
150.	0.693	0.651	1.349	37.50	5.0
200.	0.693	0.626	1.324	50.00	5.0
300.	0.693	0.601	1.299	75.00	5.0
500.	0.693	0.581	1.279	125.00	5.0
700.	0.698	0.573	1.271	175.00	5.0

BUS WAGON

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
19.	3.88	0.141	0.362	3.80	0.60

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	0.676	1.249	1.924	5.55	5.6
50.	0.478	1.051	1.529	7.85	8.0
75.	0.475	0.893	1.369*	11.72	8.0
100.	0.475	0.813	1.289*	15.63	8.0
150.	0.475	0.733	1.209*	23.44	8.0
200.	0.475	0.693	1.169*	31.25	8.0
300.	0.475	0.653	1.129*	46.88	8.0
500.	0.475	0.621	1.097*	78.13	8.0
700.	0.475	0.607	1.093*	109.38	8.0

MINIBUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
17.	9.22	0.261	0.848	8.91	0.67

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	1.034	1.658	2.692	3.63	8.6
50.	0.731	1.355	2.086	5.13	12.2
75.	0.597	1.221	1.818	6.28	14.9
100.	0.517	1.141	1.658	7.25	17.2
150.	0.469	1.004	1.473	9.87	19.0
200.	0.469	0.909	1.378	13.16	19.0
300.	0.469	0.814	1.283	19.74	19.0
500.	0.469	0.738	1.207	32.89	19.0
700.	0.469	0.706	1.175	46.05	19.0

BUS

SPEED	HR COSTS	MI	BETA	ALPHA	TIME
15.	13.69	0.325	1.313	13.79	0.76

PDEN	SUPPL COST	U TIME	TOTAL	FREQ	LOAD
25.	1.286	1.975	3.262	2.92	10.7
50.	0.910	1.599	2.508	4.12	15.2
75.	0.743	1.432	2.174	5.05	18.6
100.	0.643	1.332	1.975	5.83	21.4
150.	0.525	1.214	1.739	7.14	26.3
200.	0.455	1.144	1.599	8.24	30.3
300.	0.371	1.060	1.432	10.10	37.1
500.	0.288	0.977	1.264	13.04	47.9
700.	0.276	0.903	1.179	17.50	50.0

0.XXX = Minimum cost route spacing for this vehicle type and PDEN

0.XXX* = Minimum cost route spacing and vehicle type for this PDEN

APPENDIX E

RAIL RAPID TRANSIT LINE HAUL COSTS

APPENDIX E

RAIL RAPID TRANSIT LINE HAUL COSTS

The three panels of Tables E-1 and E-2 are for 6-, 10-, and 14-mile line-haul routes, respectively. Line-haul speed and CBD distribution speeds are, respectively, 35 and 18 miles per hour. Maximum frequency is 40 trains per hour and car capacity is 79 seated passengers. Operating cost is \$1.87 per car-mile plus \$7.27 per train-hour, and car capital cost is \$37.80 per car-hour. The way and structures cost is \$1,785 per route-mile-hour.

For passenger volumes ranging from 1,000 to 30,000 passengers per hour, the tables give train frequency in trains per hour, train length in cars, and train load in number of passengers. The last five columns show costs in dollars per passenger for supplier cost both without way and including way, user time cost, and full cost without way and including way.

Table E-1. RAIL RAPID TRANSIT COSTS
(TIME VALUES = $1.20, $3.00, $3.00)

CBD= 1. LINE SPEED= 35. CBD SPEED= 18. MAX FREQ= 40.
CAR CAP= 79. OP COST= 1.87/CAR MI, 7.27/TR HR CAR K COST= 37.80 WAY COST= 1785.

ROUTE LENGTH = 6.

				SUPPL COST			TOTAL	
PASS/HR	FREQ	TR LEN	TR LOAD	W/O WAY	INCL WAY	U TIME CST	W/O WAY	INCL WAY
1000.	6.3	2.	158.0	0.534	12.137	0.723	1.257	12.860
2000.	12.7	2.	158.0	0.534	6.335	0.605	1.139	6.940
4000.	25.3	2.	158.0	0.534	3.435	0.545	1.079	3.980
7000.	22.2	4.	316.0	0.524	2.182	0.554	1.078	2.736
10000.	31.6	4.	316.0	0.524	1.684	0.534	1.058	2.218
15000.	31.6	6.	474.0	0.521	1.294	0.534	1.054	1.828
20000.	31.6	8.	632.0	0.519	1.099	0.534	1.053	1.633
30000.	38.0	10.	790.0	0.518	0.905	0.526	1.044	1.431

ROUTE LENGTH =10.

				SUPPL COST			TOTAL	
PASS/HR	FREQ	TR LEN	TR LOAD	W/O WAY	INCL WAY	U TIME CST	W/O WAY	INCL WAY
1000.	6.3	2.	158.0	0.853	19.596	0.792	1.645	20.387
2000.	12.7	2.	158.0	0.853	10.224	0.673	1.526	10.898
4000.	25.3	2.	158.0	0.853	5.539	0.614	1.467	6.153
7000.	22.2	4.	316.0	0.838	3.515	0.622	1.460	4.138
10000.	31.6	4.	316.0	0.838	2.712	0.602	1.440	3.314
15000.	31.6	6.	474.0	0.832	2.082	0.602	1.435	2.684
20000.	31.6	8.	632.0	0.830	1.767	0.602	1.432	2.369
30000.	38.0	10.	790.0	0.828	1.453	0.594	1.422	2.047

ROUTE LENGTH =14.

				SUPPL COST			TOTAL	
PASS/HR	FREQ	TR LEN	TR LOAD	W/O WAY	INCL WAY	U TIME CST	W/O WAY	INCL WAY
1000.	6.3	2.	158.0	1.172	27.055	0.860	2.033	27.915
2000.	12.7	2.	158.0	1.172	14.114	0.742	1.914	14.856
4000.	25.3	2.	158.0	1.172	7.643	0.683	1.855	8.326
7000.	22.2	4.	316.0	1.151	4.849	0.691	1.842	5.540
10000.	31.6	4.	316.0	1.151	3.739	0.671	1.822	4.410
15000.	31.6	6.	474.0	1.144	2.870	0.671	1.815	3.540
20000.	31.6	8.	632.0	1.140	2.435	0.671	1.811	3.105
30000.	38.0	10.	790.0	1.138	2.001	0.663	1.801	2.664

Table E-2. RAIL RAPID TRANSIT COSTS
(TIME VALUES = $3.00, $7.50, $7.50)

```
CBD= 1.      LINE SPEED= 35.      CBD SPEED= 18.      MAX FREQ= 40.
CAR CAP= 79.      OP COST= 1.87/CAR MI, 7.27/TR HR      CAR K COST= 37.80      WAY COST= 1785.


ROUTE LENGTH = 6.

                                            SUPPL COST                               TOTAL
PASS/HR    FREQ    TR LEN    TR LOAD    W/O WAY    INCL WAY    U TIME CST    W/O WAY    INCL WAY

  1000.     6.7      2.       158.0      0.563      12.165        1.778        2.340      13.943
  2000.    12.7      2.       158.0      0.534       6.335        1.512        2.046       7.847
  4000.    25.3      2.       158.0      0.534       3.435        1.364        1.898       4.798
  7000.    22.2      4.       316.0      0.524       2.182        1.385        1.909       3.566
 10000.    31.6      4.       316.0      0.524       1.684        1.334        1.858       3.018
 15000.    31.6      6.       474.0      0.521       1.294        1.334        1.855       2.628
 20000.    31.6      8.       632.0      0.519       1.099        1.334        1.853       2.433
 30000.    38.0     10.       790.0      0.518       0.905        1.314        1.832       2.219

ROUTE LENGTH =10.

                                            SUPPL COST                               TOTAL
PASS/HR    FREQ    TR LEN    TR LOAD    W/O WAY    INCL WAY    U TIME CST    W/O WAY    INCL WAY

  1000.     6.3      2.       158.0      0.853      19.596        1.979        2.833      21.575
  2000.    12.7      2.       158.0      0.853      10.224        1.683        2.536      11.908
  4000.    25.3      2.       158.0      0.853       5.539        1.535        2.388       7.074
  7000.    22.2      4.       316.0      0.838       3.515        1.556        2.394       5.071
 10000.    31.6      4.       316.0      0.838       2.712        1.505        2.343       4.217
 15000.    31.6      6.       474.0      0.832       2.082        1.505        2.338       3.587
 20000.    31.6      8.       632.0      0.830       1.767        1.505        2.335       3.272
 30000.    38.0     10.       790.0      0.828       1.453        1.486        2.314       2.939

ROUTE LENGTH =14.

                                            SUPPL COST                               TOTAL
PASS/HR    FREQ    TR LEN    TR LOAD    W/O WAY    INCL WAY    U TIME CST    W/O WAY    INCL WAY

  1000.     6.3      2.       158.0      1.172      27.055        2.151        3.323      29.206
  2000.    12.7      2.       158.0      1.172      14.114        1.855        3.027      15.968
  4000.    25.3      2.       158.0      1.172       7.643        1.706        2.879       9.350
  7000.    22.2      4.       316.0      1.151       4.849        1.728        2.879       6.576
 10000.    31.6      4.       316.0      1.151       3.739        1.677        2.828       5.416
 15000.    31.6      6.       474.0      1.144       2.870        1.677        2.821       4.546
 20000.    31.6      8.       632.0      1.140       2.435        1.677        2.817       4.111
 30000.    38.0     10.       790.0      1.136       2.001        1.657        2.795       3.658
```

APPENDIX F

INTEGRATED COMMUTER BUS COSTS

APPENDIX F

INTEGRATED COMMUTER BUS COSTS

Tables F-1 through F-8 present the complete calculations for integrated bus for "low" and "high" time values, respectively.

Tables F-1, F-2, F-5, and F-6 are for a 3-mile feeder (arterial and busway line-haul), and Tables F-3, F-4, F-7, and F-8 are for a 5-mile feeder. Note that each page contains calculations for four and two feeder routes, arranged left to right and for 3-, 5-, and 7-mile passenger average line-haul distances, corresponding to total line-haul distances of 6, 10, and 14 miles. At the top of each page are time values (in-vehicle, waiting, and walking) in dollars per hour; speeds; vehicle costs per mile for the collection, line-haul, and CBD portions; and way costs. The CBD and arterial way costs are in dollars per vehicle-mile, and the busway cost is in dollars per route-mile-hour. (Arterial costs are zero when the busway alternative is being analyzed, and busway costs are zero when the arterial alternative is being examined.)

For each passenger generation density, the table contains the corresponding number of passengers per hour for each feeder route; supplier, user time, and full costs (dollars per passenger); frequency; and load. The full costs corresponding to the minimum cost feeder route spacing are underlined, and the minimum cost line-haul way type (arterial street or busway) are designated by asterisks.

Table F-1. INTEGRATED COMMUTER BUS COSTS, ARTERIAL
(Dollars per Passenger)

```
TIME VALUES 1.20 3.00 3.00      3. MI FEEDER     SPEEDS  15.0   20.0    9.0      VEH MILE COSTS 1.313 1.066 1.972
WAY COSTS  ART 0.176  XWAY    0.  CBD 0.878

DISTANCE =  3. MILES
                    4 ROUTES  ALPHA = 18.84                                  2 ROUTES  ALPHA = 18.73

P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ    LOAD       P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ    LOAD
    25.     19.   1.223   1.920    3.148     1.22    15.35   **    25.      38.   0.866   1.624    2.489*    1.73    21.64
    50.     38.   0.868   1.560    2.429     1.73    21.70   **    50.      75.   0.612   1.370    1.982*    2.45    30.60
    75.     56.   0.709   1.401    2.110     2.12    26.58   **    75.     113.   0.500   1.258    1.758*    3.00    37.48
   100.     75.   0.614   1.306    1.920     2.44    30.69   **   100.     150.   0.433   1.191    1.624*    3.47    43.28
   150.    113.   0.501   1.193    1.695     2.99    37.59   **   150.     225.   0.375   1.092    1.466*    4.50    50.00
   200.    150.   0.434   1.126    1.560     3.46    43.41   **   200.     300.   0.375   1.008    1.383*    6.00    50.00
   300.    225.   0.377   1.026    1.402     4.50    50.00   **   300.     450.   0.375   0.925    1.300     9.00    50.00
   500.    375.   0.377   0.892    1.269     7.50    50.00   **   500.     750.   0.375   0.858    1.233    15.00    50.00
   700.    525.   0.377   0.835    1.212    10.50    50.00   **   700.    1050.   0.375   0.830    1.204    21.00    50.00

DISTANCE =  5. MILES
                    4 ROUTES  ALPHA = 23.81                                  2 ROUTES  ALPHA = 23.70

P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ    LOAD       P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ    LOAD
    25.     19.   1.380   2.192    3.573     1.09    17.25   **    25.      38.   0.974   1.852    2.826*    1.54    24.34
    50.     38.   0.976   1.788    2.764     1.54    24.40   **    50.      75.   0.688   1.567    2.255*    2.18    34.42
    75.     56.   0.797   1.609    2.406     1.88    29.88   **    75.     113.   0.562   1.440    2.003*    2.67    42.16
   100.     75.   0.690   1.502    2.192     2.17    34.50   **   100.     150.   0.487   1.365    1.852*    3.08    48.68
   150.    113.   0.563   1.376    1.939     2.66    42.26   **   150.     225.   0.474   1.212    1.686*    4.50    50.00
   200.    150.   0.488   1.300    1.788     3.07    48.80   **   200.     300.   0.474   1.128    1.602     6.00    50.00
   300.    225.   0.476   1.146    1.622     4.50    50.00   **   300.     450.   0.474   1.045    1.519     9.00    50.00
   500.    375.   0.476   1.012    1.488     7.50    50.00   **   500.     750.   0.474   0.978    1.452    15.00    50.00
   700.    525.   0.476   0.955    1.431    10.50    50.00   **   700.    1050.   0.474   0.950    1.424    21.00    50.00

DISTANCE =  7. MILES
                    4 ROUTES  ALPHA = 28.78                                  2 ROUTES  ALPHA = 28.67

P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ    LOAD       P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ    LOAD
    25.     19.   1.517   2.450    3.967     0.99    18.97   **    25.      38.   1.071   2.069    3.140*    1.40    26.77
    50.     38.   1.073   2.005    3.078     1.40    26.82   **    50.      75.   0.757   1.756    2.513*    1.98    37.86
    75.     56.   0.876   1.808    2.684     1.71    32.85   **    75.     113.   0.618   1.617    2.235*    2.43    46.37
   100.     75.   0.759   1.691    2.450     1.98    37.93   **   100.     150.   0.573   1.498    2.072*    3.00    50.00
   150.    113.   0.619   1.552    2.171     2.42    46.46   **   150.     225.   0.573   1.332    1.905     4.50    50.00
   200.    150.   0.576   1.432    2.008     3.00    50.00   **   200.     300.   0.573   1.248    1.822     6.00    50.00
   300.    225.   0.576   1.266    1.841     4.50    50.00   **   300.     450.   0.573   1.165    1.738     9.00    50.00
   500.    375.   0.576   1.132    1.708     7.50    50.00   **   500.     750.   0.573   1.098    1.672    15.00    50.00
   700.    525.   0.576   1.075    1.651    10.50    50.00   **   700.    1050.   0.573   1.070    1.643    21.00    50.00
```

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-2. INTEGRATED COMMUTER BUS COSTS, BUSWAY
(Dollars per Passenger)

TIME VALUES 1.20 3.00 3.00 3. MI FEEDER SPEEDS 15.0 45.0 9.0 VEH MILE COSTS 1.388 0.674 2.103
WAY COSTS ART 0.0 XWAY 275. CBD 0.878

DISTANCE = 3. MILES

4 ROUTES ALPHA = 16.05								2 ROUTES ALPHA = 15.93						
P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	19.	2.966	1.725	4.692	1.32	14.16	**	25.	38.	2.632	1.457	4.088	1.88	19.96
50.	38.	1.713	1.394	3.111	1.87	20.03	**	50.	75.	1.481	1.223	2.704	2.66	28.23
75.	56.	1.265	1.246	2.512	2.29	24.53	**	75.	113.	1.072	1.119	2.191	3.25	34.57
100.	75.	1.025	1.159	2.184	2.65	28.33	**	100.	150.	0.858	1.057	1.915	3.76	39.92
150.	113.	0.768	1.055	1.823	3.24	34.70	**	150.	225.	0.631	0.984	1.616	4.60	48.89
200.	150.	0.630	0.993	1.623	3.74	40.06	**	200.	300.	0.548	0.908	1.456	6.00	50.00
300.	225.	0.480	0.919	1.399	4.59	49.07	**	300.	450.	0.471	0.825	1.296*	9.00	50.00
500.	375.	0.413	0.792	1.205	7.50	50.00	**	500.	750.	0.410	0.758	1.169*	15.00	50.00
700.	525.	0.386	0.735	1.122	10.50	50.00	**	700.	1050.	0.384	0.730	1.114*	21.00	50.00

DISTANCE = 5. MILES

4 ROUTES ALPHA = 18.75								2 ROUTES ALPHA = 18.63						
P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	19.	3.058	1.870	4.928	1.22	15.31	**	25.	38.	2.697	1.575	4.271	1.74	21.58
50.	38.	1.783	1.512	3.294	1.73	21.65	**	50.	75.	1.527	1.322	2.849	2.46	30.52
75.	56.	1.318	1.353	2.671	2.12	26.51	**	75.	113.	1.110	1.210	2.320	3.01	37.38
100.	75.	1.071	1.258	2.329	2.45	30.62	**	100.	150.	0.890	1.143	2.033	3.48	43.16
150.	113.	0.806	1.146	1.951	3.00	37.50	**	150.	225.	0.678	1.045	1.723	4.50	50.00
200.	150.	0.662	1.079	1.741	3.46	43.30	**	200.	300.	0.602	0.962	1.563*	6.00	50.00
300.	225.	0.528	0.979	1.507	4.50	50.00	**	300.	450.	0.525	0.878	1.404*	9.00	50.00
500.	375.	0.467	0.846	1.312	7.50	50.00	**	500.	750.	0.464	0.812	1.276*	15.00	50.00
700.	525.	0.440	0.788	1.229	10.50	50.00	**	700.	1050.	0.438	0.783	1.221*	21.00	50.00

DISTANCE = 7. MILES

4 ROUTES ALPHA = 21.44								2 ROUTES ALPHA = 21.33						
P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	19.	3.143	2.009	5.152	1.15	16.37	**	25.	38.	2.757	1.689	4.446	1.62	23.09
50.	38.	1.843	1.625	3.468	1.62	23.15	**	50.	75.	1.570	1.418	2.988	2.30	32.66
75.	56.	1.367	1.455	2.822	1.98	28.36	**	75.	113.	1.144	1.298	2.443	2.81	39.99
100.	75.	1.113	1.354	2.467	2.29	32.74	**	100.	150.	0.920	1.227	2.147	3.25	46.18
150.	113.	0.840	1.234	2.074	2.81	40.10	**	150.	225.	0.732	1.098	1.830*	4.50	50.00
200.	150.	0.692	1.162	1.854	3.24	46.31	**	200.	300.	0.656	1.015	1.671*	6.00	50.00
300.	225.	0.582	1.032	1.614	4.50	50.00	**	300.	450.	0.579	0.932	1.511*	9.00	50.00
500.	375.	0.521	0.899	1.419	7.50	50.00	**	500.	750.	0.518	0.865	1.383*	15.00	50.00
700.	525.	0.494	0.842	1.336	10.50	50.00	**	700.	1050.	0.492	0.836	1.328*	21.00	50.00

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-3. INTEGRATED COMMUTER BUS COSTS, ARTERIAL
(Dollars per Passenger)

TIME VALUES 1.20 3.00 3.00   5. MI FEEDER   SPEEDS 15.0 20.0 9.0   VEH MILE COSTS 1.313 1.066 1.972
WAY COSTS ART 0.176 XWAY 0. CBD 0.878

DISTANCE = 3. MILES

4 ROUTES ALPHA = 24.10   2 ROUTES ALPHA = 23.98

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	1.075	1.848	2.923	1.39	22.40	**	25.	63.	0.759	1.597	2.356*	1.98	31.61
50.	63.	0.760	1.533	2.293	1.97	31.69	**	50.	125.	0.536	1.375	1.911*	2.80	44.71
75.	94.	0.621	1.393	2.014	2.42	38.81	**	75.	188.	0.480	1.238	1.718*	3.75	50.00
100.	125.	0.533	1.310	1.848	2.79	44.81	**	100.	250.	0.480	1.138	1.618*	5.00	50.00
150.	188.	0.482	1.172	1.654	3.75	50.00	**	150.	375.	0.480	1.038	1.518*	7.50	50.00
200.	250.	0.482	1.072	1.554	5.00	50.00	**	200.	500.	0.480	0.988	1.468	10.00	50.00
300.	375.	0.482	0.972	1.454	7.50	50.00	**	300.	750.	0.480	0.938	1.418	15.00	50.00
500.	625.	0.482	0.892	1.374	12.50	50.00	**	500.	1250.	0.480	0.898	1.378	25.00	50.00
700.	875.	0.482	0.858	1.340	17.50	50.00	**	700.	1750.	0.480	0.881	1.361	35.00	50.00

DISTANCE = 5. MILES

4 ROUTES ALPHA = 29.06   2 ROUTES ALPHA = 28.95

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	1.181	2.073	3.255	1.27	24.61	**	25.	63.	0.834	1.792	2.626*	1.80	34.73
50.	63.	0.835	1.727	2.563	1.80	34.80	**	50.	125.	0.589	1.548	2.137*	2.54	49.12
75.	94.	0.682	1.574	2.256	2.20	42.62	**	75.	188.	0.579	1.358	1.937*	3.75	50.00
100.	125.	0.591	1.483	2.073	2.54	49.21	**	100.	250.	0.579	1.258	1.837*	5.00	50.00
150.	188.	0.581	1.292	1.874	3.75	50.00	**	150.	375.	0.579	1.158	1.737	7.50	50.00
200.	250.	0.581	1.192	1.774	5.00	50.00	**	200.	500.	0.579	1.108	1.687	10.00	50.00
300.	375.	0.581	1.092	1.674	7.50	50.00	**	300.	750.	0.579	1.058	1.637	15.00	50.00
500.	625.	0.581	1.012	1.594	12.50	50.00	**	500.	1250.	0.579	1.018	1.597	25.00	50.00
700.	875.	0.581	0.978	1.559	17.50	50.00	**	700.	1750.	0.579	1.001	1.580	35.00	50.00

DISTANCE = 7. MILES

4 ROUTES ALPHA = 34.03   2 ROUTES ALPHA = 33.92

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	1.273	2.290	3.569	1.17	26.63	**	25.	63.	0.902	1.981	2.883*	1.66	37.60
50.	63.	0.904	1.916	2.820	1.66	37.66	**	50.	125.	0.678	1.678	2.357*	2.50	50.00
75.	94.	0.738	1.750	2.488	2.03	46.12	**	75.	188.	0.678	1.478	2.157	3.75	50.00
100.	125.	0.681	1.612	2.293	2.50	50.00	**	100.	250.	0.678	1.378	2.057	5.00	50.00
150.	188.	0.681	1.412	2.093	3.75	50.00	**	150.	375.	0.678	1.278	1.957	7.50	50.00
200.	250.	0.681	1.312	1.993	5.00	50.00	**	200.	500.	0.678	1.228	1.907	10.00	50.00
300.	375.	0.681	1.212	1.893	7.50	50.00	**	300.	750.	0.678	1.178	1.857	15.00	50.00
500.	625.	0.681	1.132	1.813	12.50	50.00	**	500.	1250.	0.678	1.138	1.817	25.00	50.00
700.	875.	0.681	1.098	1.779	17.50	50.00	**	700.	1750.	0.678	1.121	1.800	35.00	50.00

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-4. INTEGRATED COMMUTER BUS COSTS, BUSWAY
(Dollars per Passenger)

TIME VALUES 1.20 3.00 3.00 5. MI FEEDER SPEEDS 15.0 45.0 9.0 VEH MILE COSTS 1.388 0.674 2.103
WAY COSTS ART 0.0 XWAY 275. CBD 0.878

DISTANCE = 3. MILES

4 ROUTES ALPHA = 21.60 | 2 ROUTES ALPHA = 21.49

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.118	1.691	3.809	1.47	21.22	**	25.	63.	1.818	1.456	3.275	2.09	29.92
50.	63.	1.270	1.392	2.662	2.08	30.00	**	50.	125.	1.058	1.246	2.304	2.95	42.32
75.	94.	0.955	1.260	2.215	2.55	36.75	**	75.	188.	0.796	1.138	1.935	3.75	50.00
100.	125.	0.784	1.181	1.966	2.95	42.43	**	100.	250.	0.705	1.038	1.743	5.00	50.00
150.	188.	0.615	1.072	1.688	3.75	50.00	**	150.	375.	0.613	0.938	1.551	7.50	50.00
200.	250.	0.570	0.972	1.542	5.00	50.00	**	200.	500.	0.567	0.888	1.456*	10.00	50.00
300.	375.	0.524	0.872	1.396	7.50	50.00	**	300.	750.	0.521	0.838	1.360*	15.00	50.00
500.	625.	0.487	0.792	1.279*	12.50	50.00	**	500.	1250.	0.485	0.798	1.283	25.00	50.00
700.	875.	0.471	0.758	1.229*	17.50	50.00	**	700.	1750.	0.469	0.781	1.250	35.00	50.00

DISTANCE = 5. MILES

4 ROUTES ALPHA = 24.30 | 2 ROUTES ALPHA = 24.18

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.180	1.806	3.986	1.39	22.50	**	25.	63.	1.862	1.553	3.415	1.97	31.74
50.	63.	1.314	1.489	2.803	1.96	31.82	**	50.	125.	1.089	1.330	2.419	2.78	44.89
75.	94.	0.990	1.349	2.339	2.41	38.97	**	75.	188.	0.850	1.192	2.042	3.75	50.00
100.	125.	0.815	1.266	2.081	2.78	45.00	**	100.	250.	0.759	1.092	1.850	5.00	50.00
150.	188.	0.669	1.126	1.795	3.75	50.00	**	150.	375.	0.667	0.992	1.659*	7.50	50.00
200.	250.	0.624	1.026	1.649	5.00	50.00	**	200.	500.	0.621	0.942	1.563*	10.00	50.00
300.	375.	0.578	0.926	1.503	7.50	50.00	**	300.	750.	0.575	0.892	1.467*	15.00	50.00
500.	625.	0.541	0.846	1.387*	12.50	50.00	**	500.	1250.	0.539	0.852	1.390	25.00	50.00
700.	875.	0.525	0.811	1.337*	17.50	50.00	**	700.	1750.	0.523	0.834	1.357	35.00	50.00

DISTANCE = 7. MILES

4 ROUTES ALPHA = 27.00 | 2 ROUTES ALPHA = 26.88

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.238	1.917	4.156	1.32	23.72	**	25.	63.	1.903	1.648	3.551	1.87	33.47
50.	63.	1.355	1.584	2.939	1.86	33.54	**	50.	125.	1.118	1.413	2.531	2.64	47.33
75.	94.	1.024	1.436	2.460	2.28	41.08	**	75.	188.	0.904	1.245	2.149*	3.75	50.00
100.	125.	0.844	1.348	2.192	2.64	47.43	**	100.	250.	0.813	1.145	1.958*	5.00	50.00
150.	188.	0.723	1.179	1.902	3.75	50.00	**	150.	375.	0.721	1.045	1.766*	7.50	50.00
200.	250.	0.677	1.079	1.756	5.00	50.00	**	200.	500.	0.675	0.995	1.670*	10.00	50.00
300.	375.	0.632	0.979	1.611	7.50	50.00	**	300.	750.	0.629	0.945	1.574*	15.00	50.00
500.	625.	0.595	0.899	1.494*	12.50	50.00	**	500.	1250.	0.593	0.905	1.498	25.00	50.00
700.	875.	0.579	0.865	1.444*	17.50	50.00	**	700.	1750.	0.577	0.888	1.465	35.00	50.00

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-5. INTEGRATED COMMUTER BUS COSTS, ARTERIAL
(Dollars per Passenger)

TIME VALUES 3.00 7.50 7.50   3. MI FEEDER   SPEEDS 15.0 20.0 9.0   VEH MILE COSTS 1.313 1.066 1.972
WAY COSTS ART 0.175 XWAY 0. CBD 0.878

DISTANCE = 3. MILES

4 ROUTES ALPHA = 18.84 | 2 ROUTES ALPHA = 18.73

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	19.	1.941	3.672	5.613	1.93	9.71	**	25.	38.	1.369	3.264	4.633*	2.74	13.69
50.	38.	1.373	3.103	4.476	2.73	13.73	**	50.	75.	0.968	2.864	3.831*	3.87	19.36
75.	56.	1.121	2.851	3.972	3.35	16.81	**	75.	113.	0.790	2.686	3.476*	4.75	23.71
100.	75.	0.971	2.701	3.672	3.86	19.41	**	100.	150.	0.684	2.580	3.264*	5.48	27.37
150.	113.	0.792	2.523	3.316	4.73	23.77	**	150.	225.	0.559	2.455	3.013	6.71	33.52
200.	150.	0.686	2.417	3.103	5.46	27.45	**	200.	300.	0.484	2.380	2.864	7.75	38.71
300.	225.	0.560	2.291	2.851	6.69	33.62	**	300.	450.	0.395	2.291	2.686	9.49	47.41
500.	375.	0.434	2.165	2.599	8.64	43.41	**	500.	750.	0.375	2.146	2.520	15.00	50.00
700.	525.	0.377	2.088	2.465	10.50	50.00	**	700.	1050.	0.375	2.074	2.449	21.00	50.00

DISTANCE = 5. MILES

4 ROUTES ALPHA = 23.81 | 2 ROUTES ALPHA = 23.70

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	19.	2.182	4.213	6.395	1.72	10.91	**	25.	38.	1.539	3.735	5.275*	2.44	15.39
50.	38.	1.543	3.574	5.117	2.43	15.43	**	50.	75.	1.089	3.284	4.373*	3.44	21.77
75.	56.	1.260	3.291	4.550	2.98	18.90	**	75.	113.	0.889	3.085	3.973	4.22	26.66
100.	75.	1.091	3.122	4.213	3.44	21.82	**	100.	150.	0.770	2.966	3.735	4.87	30.79
150.	113.	0.891	2.922	3.812	4.21	26.73	**	150.	225.	0.628	2.824	3.453	5.97	37.71
200.	150.	0.772	2.802	3.574	4.86	30.86	**	200.	300.	0.544	2.740	3.284	6.89	43.54
300.	225.	0.630	2.661	3.291	5.95	37.80	**	300.	450.	0.474	2.612	3.086	9.00	50.00
500.	375.	0.488	2.519	3.007	7.69	48.80	**	500.	750.	0.474	2.446	2.920	15.00	50.00
700.	525.	0.476	2.388	2.864	10.50	50.00	**	700.	1050.	0.474	2.374	2.848	21.00	50.00

DISTANCE = 7. MILES

4 ROUTES ALPHA = 28.78 | 2 ROUTES ALPHA = 28.67

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	19.	2.399	4.730	7.129	1.56	12.00	**	25.	38.	1.693	4.189	5.882*	2.21	16.93
50.	38.	1.696	4.027	5.724	2.21	16.96	**	50.	75.	1.197	3.693	4.890*	3.13	23.95
75.	56.	1.385	3.716	5.101	2.71	20.78	**	75.	113.	0.978	3.473	4.451	3.84	29.33
100.	75.	1.200	3.530	4.730	3.13	23.99	**	100.	150.	0.847	3.342	4.189	4.43	33.86
150.	113.	0.979	3.310	4.290	3.83	29.38	**	150.	225.	0.691	3.187	3.878	5.42	41.48
200.	150.	0.848	3.179	4.027	4.42	33.93	**	200.	300.	0.599	3.094	3.693	6.26	47.89
300.	225.	0.693	3.023	3.716	5.41	41.55	**	300.	450.	0.573	2.912	3.486	9.00	50.00
500.	375.	0.575	2.831	3.406	7.50	50.00	**	500.	750.	0.573	2.746	3.319	15.00	50.00
700.	525.	0.575	2.688	3.263	10.50	50.00	**	700.	1050.	0.573	2.674	3.248	21.00	50.00

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-6. INTEGRATED COMMUTER BUS COSTS, BUSWAY
(Dollars per Passenger)

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 TIME VALUES 3.00 7.50 7.50      3. MI FEEDER      SPEEDS  15.0  45.0   9.0      VEH MILE COSTS 1.388 0.674 2.103
 WAY COSTS  ART 0.0     XWAY  275.  CBD 0.878

DISTANCE =  3. MILES
                         4 ROUTES  ALPHA = 16.05                                              2 ROUTES  ALPHA = 15.93

P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL      FREQ     LOAD        P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ     LOAD
    25.     19.   3.625   3.272    6.897      2.09      8.96  **     25.       38.   3.096   2.908    6.004     2.97    12.62
    50.     38.   2.164   2.748    4.931      2.96     12.67  **     50.       75.   1.809   2.538    4.348     4.20    17.85
    75.     56.   1.645   2.515    4.161      3.63     15.52  **     75.      113.   1.340   2.375    3.714     5.15    21.86
   100.     75.   1.354   2.377    3.731      4.19     17.92  **    100.      150.   1.089   2.277    3.366     5.94    25.25
   150.    113.   1.037   2.212    3.249      5.13     21.94  **    150.      225.   0.821   2.161    2.982*    7.28    30.92
   200.    150.   0.863   2.114    2.977      5.92     25.34  **    200.      300.   0.675   2.092    2.768*    8.40    35.70
   300.    225.   0.670   1.998    2.668      7.25     31.03  **    300.      450.   0.517   2.010    2.527*   10.29    43.73
   500.    375.   0.492   1.881    2.374      9.36     40.06  **    500.      750.   0.410   1.896    2.306*   15.00    50.00
   700.    525.   0.404   1.819    2.223     11.08     47.40  **    700.     1050.   0.384   1.824    2.208*   21.00    50.00

DISTANCE =  5. MILES
                         4 ROUTES  ALPHA = 18.75                                              2 ROUTES  ALPHA = 18.63

P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL      FREQ     LOAD        P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ     LOAD
    25.     19.   3.770   3.550    7.320      1.94      9.68  **     25.       38.   3.198   3.144    6.342     2.75    13.65
    50.     38.   2.286   2.983    5.269      2.74     13.69  **     50.       75.   1.882   2.744    4.626     3.89    19.30
    75.     56.   1.729   2.732    4.461      3.35     16.77  **     75.      113.   1.399   2.567    3.966*    4.76    23.64
   100.     75.   1.427   2.582    4.009      3.87     19.36  **    100.      150.   1.141   2.462    3.602*    5.49    27.30
   150.    113.   1.095   2.405    3.501      4.74     23.72  **    150.      225.   0.863   2.336    3.199*    6.73    33.43
   200.    150.   0.914   2.299    3.212      5.48     27.38  **    200.      300.   0.712   2.262    2.973*    7.77    38.61
   300.    225.   0.712   2.173    2.885      6.71     33.54  **    300.      450.   0.547   2.173    2.720*    9.52    47.28
   500.    375.   0.525   2.047    2.572      8.66     43.30  **    500.      750.   0.464   2.029    2.493*   15.00    50.00
   700.    525.   0.440   1.971    2.412     10.50     50.00  **    700.     1050.   0.438   1.958    2.396*   21.00    50.00

DISTANCE =  7. MILES
                         4 ROUTES  ALPHA = 21.44                                              2 ROUTES  ALPHA = 21.33

P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL      FREQ     LOAD        P/SQMIHR  P/RTHR  SUPPL   U TIME   TOTAL     FREQ     LOAD
    25.     19.   3.904   3.318    7.723      1.81     10.35  **     25.       38.   3.294   3.373    6.667     2.57    14.60
    50.     38.   2.381   3.212    5.593      2.56     14.64  **     50.       75.   1.949   2.945    4.894     3.63    20.65
    75.     56.   1.807   2.943    4.750      3.14     17.93  **     75.      113.   1.454   2.756    4.210*    4.45    25.29
   100.     75.   1.494   2.783    4.277      3.62     20.71  **    100.      150.   1.189   2.643    3.831*    5.14    29.21
   150.    113.   1.151   2.593    3.744      4.44     25.36  **    150.      225.   0.902   2.509    3.410*    6.29    35.77
   200.    150.   0.961   2.480    3.441      5.12     29.29  **    200.      300.   0.745   2.429    3.174*    7.26    41.31
   300.    225.   0.751   2.345    3.096      6.27     35.87  **    300.      450.   0.579   2.329    2.908*    9.00    50.00
   500.    375.   0.555   2.210    2.765      8.10     46.31  **    500.      750.   0.518   2.162    2.681*   15.00    50.00
   700.    525.   0.494   2.104    2.599     10.50     50.00  **    700.     1050.   0.492   2.091    2.583*   21.00    50.00
```

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-7. INTEGRATED COMMUTER BUS COSTS, ARTERIAL
(Dollars per Passenger)

TIME VALUES 3.00 7.50 7.50   5. MI FEEDER   SPEEDS 15.0 20.0 9.0   VEH MILE COSTS 1.313 1.066 1.972
WAY COSTS ART 0.176 XWAY 0. CBD 0.878

DISTANCE = 3. MILES

4 ROUTES ALPHA = 24.10								2 ROUTES ALPHA = 23.98						
P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	1.700	3.631	5.331	2.21	14.17	**	25.	63.	1.200	3.295	4.495*	3.13	19.99
50.	63.	1.202	3.133	4.335	3.12	20.04	**	50.	125.	0.848	2.944	3.792*	4.42	28.28
75.	94.	0.982	2.912	3.894	3.62	24.54	**	75.	188.	0.693	2.788	3.481*	5.41	34.63
100.	125.	0.850	2.781	3.631	4.41	28.34	**	100.	250.	0.600	2.696	3.295	6.25	39.99
150.	188.	0.694	2.625	3.319	5.40	34.71	**	150.	375.	0.490	2.586	3.075	7.66	48.97
200.	250.	0.601	2.532	3.133	6.24	40.08	**	200.	500.	0.480	2.471	2.950	10.00	50.00
300.	375.	0.491	2.422	2.912	7.64	49.09	**	300.	750.	0.480	2.346	2.825	15.00	50.00
500.	625.	0.482	2.231	2.713	12.50	50.00	**	500.	1250.	0.480	2.246	2.725	25.00	50.00
700.	875.	0.482	2.145	2.627	17.50	50.00	**	700.	1750.	0.480	2.203	2.683	35.00	50.00

DISTANCE = 5. MILES

4 ROUTES ALPHA = 29.06								2 ROUTES ALPHA = 28.95						
P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	1.868	4.098	5.966	2.01	15.56	**	25.	63.	1.318	3.714	5.032*	2.85	21.97
50.	63.	1.321	3.551	4.872	2.84	22.01	**	50.	125.	0.932	3.328	4.260	4.02	31.07
75.	94.	1.078	3.309	4.387	3.48	26.96	**	75.	188.	0.761	3.157	3.918	4.93	38.05
100.	125.	0.934	3.164	4.098	4.02	31.13	**	100.	250.	0.659	3.055	3.714	5.69	43.93
150.	188.	0.762	2.993	3.756	4.92	38.12	**	150.	375.	0.579	2.896	3.475	7.50	50.00
200.	250.	0.660	2.891	3.551	5.68	44.02	**	200.	500.	0.579	2.771	3.350	10.00	50.00
300.	375.	0.581	2.731	3.312	7.50	50.00	**	300.	750.	0.579	2.646	3.225	15.00	50.00
500.	625.	0.581	2.531	3.112	12.50	50.00	**	500.	1250.	0.579	2.546	3.125	25.00	50.00
700.	875.	0.581	2.445	3.026	17.50	50.00	**	700.	1750.	0.579	2.503	3.082	35.00	50.00

DISTANCE = 7. MILES

4 ROUTES ALPHA = 34.03								2 ROUTES ALPHA = 33.92						
P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.021	4.552	6.572	1.86	16.84	**	25.	63.	1.427	4.122	5.549*	2.63	23.78
50.	63.	1.429	3.960	5.389	2.62	23.82	**	50.	125.	1.009	3.705	4.713	3.72	33.63
75.	94.	1.167	3.697	4.864	3.21	29.17	**	75.	188.	0.824	3.519	4.343	4.55	41.18
100.	125.	1.010	3.541	4.552	3.71	33.68	**	100.	250.	0.713	3.409	4.122	5.26	47.56
150.	188.	0.825	3.356	4.181	4.55	41.25	**	150.	375.	0.678	3.196	3.874	7.50	50.00
200.	250.	0.714	3.245	3.960	5.25	47.63	**	200.	500.	0.678	3.071	3.749	10.00	50.00
300.	375.	0.681	3.031	3.711	7.50	50.00	**	300.	750.	0.678	2.946	3.624	15.00	50.00
500.	625.	0.681	2.831	3.511	12.50	50.00	**	500.	1250.	0.678	2.846	3.524	25.00	50.00
700.	875.	0.681	2.745	3.426	17.50	50.00	**	700.	1750.	0.678	2.803	3.481	35.00	50.00

0.XXX = Minimum cost feeder route spacing for this PDEN.
0.XXX* = Minimum cost line haul type (arterial or busway) for this PDEN.

Table F-8. INTEGRATED COMMUTER BUS COSTS, BUSWAY (Dollars per Passenger)

TIME VALUES 3.00 7.50 7.50 5. MI FEEDER SPEEDS 15.0 45.0 9.0 VEH MILE COSTS 1.388 0.674 2.103
WAY COSTS ART 0.0 XWAY 275. CBD 0.878

DISTANCE = 3. MILES

4 ROUTES ALPHA = 21.60 — 2 ROUTES ALPHA = 21.49

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.710	3.291	6.001	2.33	13.42	**	25.	63.	2.235	2.981	5.217	3.30	18.92
50.	63.	1.689	2.819	4.508	3.29	18.98	**	50.	125.	1.353	2.649	4.002	4.67	26.76
75.	94.	1.296	2.610	3.907	4.03	23.24	**	75.	188.	1.022	2.501	3.524	5.72	32.78
100.	125.	1.080	2.486	3.566	4.66	26.84	**	100.	250.	0.843	2.413	3.256*	6.61	37.85
150.	188.	0.841	2.338	3.179	5.70	32.87	**	150.	375.	0.647	2.309	2.956*	8.09	46.35
200.	250.	0.707	2.250	2.957	6.59	37.95	**	200.	500.	0.567	2.221	2.788*	10.00	50.00
300.	375.	0.556	2.145	2.702	8.07	46.48	**	300.	750.	0.521	2.096	2.617*	15.00	50.00
500.	625.	0.537	1.931	2.468*	12.50	50.00	**	500.	1250.	0.485	1.996	2.481	25.00	50.00
700.	875.	0.471	1.895	2.366*	17.50	50.00	**	700.	1750.	0.469	1.953	2.422	35.00	50.00

DISTANCE = 5. MILES

4 ROUTES ALPHA = 24.30 — 2 ROUTES ALPHA = 24.18

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.808	3.522	6.329	2.20	14.23	**	25.	63.	2.305	3.184	5.488	3.11	20.08
50.	63.	1.757	3.021	4.779	3.11	20.12	**	50.	125.	1.402	2.831	4.233*	4.40	28.39
75.	94.	1.353	2.800	4.153	3.80	24.65	**	75.	188.	1.062	2.675	3.737*	5.39	34.77
100.	125.	1.129	2.668	3.797	4.39	28.46	**	100.	250.	0.877	2.581	3.459*	6.23	40.15
150.	188.	0.880	2.511	3.392	5.38	34.86	**	150.	375.	0.675	2.471	3.146*	7.63	49.18
200.	250.	0.741	2.418	3.159	6.21	40.25	**	200.	500.	0.621	2.354	2.975*	10.00	50.00
300.	375.	0.585	2.307	2.892	7.61	49.30	**	300.	750.	0.575	2.229	2.804*	15.00	50.00
500.	625.	0.541	2.114	2.655*	12.50	50.00	**	500.	1250.	0.539	2.129	2.668	25.00	50.00
700.	875.	0.525	2.028	2.554*	17.50	50.00	**	700.	1750.	0.523	2.086	2.609	35.00	50.00

DISTANCE = 7. MILES

4 ROUTES ALPHA = 27.00 — 2 ROUTES ALPHA = 26.88

P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD		P/SQMIHR	P/RTHR	SUPPL	U TIME	TOTAL	FREQ	LOAD
25.	31.	2.900	3.747	6.647	2.08	15.00	**	25.	63.	2.370	3.382	5.752	2.95	21.17
50.	63.	1.823	3.220	5.043	2.95	21.21	**	50.	125.	1.448	3.010	4.458*	4.18	29.93
75.	94.	1.405	2.987	4.392	3.61	25.98	**	75.	188.	1.100	2.846	3.946*	5.11	36.66
100.	125.	1.175	2.847	4.022	4.17	30.00	**	100.	250.	0.910	2.747	3.657*	5.91	42.33
150.	188.	0.918	2.682	3.600	5.10	36.74	**	150.	375.	0.721	2.612	3.333*	7.50	50.00
200.	250.	0.774	2.584	3.358	5.89	42.42	**	200.	500.	0.675	2.487	3.163*	10.00	50.00
300.	375.	0.632	2.447	3.079	7.50	50.00	**	300.	750.	0.629	2.362	2.992*	15.00	50.00
500.	625.	0.595	2.247	2.842*	12.50	50.00	**	500.	1250.	0.593	2.262	2.855	25.00	50.00
700.	875.	0.579	2.162	2.741*	17.50	50.00	**	700.	1750.	0.577	2.220	2.796	35.00	50.00

0.XXX* = Minimum cost feeder route spacing for this PDEN.
0.XXX = Minimum cost line haul type (arterial or busway) for this PDEN.

APPENDIX G

RAIL LINE-HAUL PLUS FEEDER COSTS

APPENDIX G

RAIL LINE-HAUL PLUS FEEDER COSTS

Tables G-1 through G-4 show the calculation of rail line-haul plus feeder costs. For a given passenger density, the passengers per hour in a corridor increase with feeder route perpendicular distance and line-haul route length. The area served by the corridor is

2 x feeder length perpendicular distance
x line-haul route length.

Hence, if 500 passengers per square mile are generated per hour, and if the feeder route perpendicular distance is 3 miles and the line-haul route length is 10 miles, the passengers per hour in corridor are

$$2 \times 3 \times 10 \times 500 = 30{,}000.$$

These are the conditions for the bottom row of the middle panel, Table G-1.

The rail line-haul cost per passenger for the appropriate passengers per hour in corridor is read from the last column of the tables of Appendix E. The residential feeder costs for the appropriate passenger density are read from Figures 9 through 12. In each case, the minimum cost feeder vehicle type is selected and is noted in the next to last column of Tables G-1 through G-4. The final column shows the total of the rail line-haul plus residential feeder costs.

Table G-1. RAIL LINE HAUL PLUS FEEDER COSTS

Route Length (Miles)	Passengers per Hour in Corridor	Passenger Density (Passengers per sq. mi. per Hour)	Rail Line-Haul Cost (Dollars per Passenger)	Residential Feeder Cost (Dollars per Passenger)	Total Rail Plus Feeder Costs (Dollars per Passenger)
6	1,000	27.8	12.86	.80 BW	13.66
	2,000	55.6	6.94	.67 BW	7.61
	4,000	111.2	3.98	.60 BW	4.58
	7,000	194.7	2.74	.54 BW	3.38
	10,000	278	2.22	.52 BW	2.74
	15,000	417	1.83	.50 BW	2.33
	20,000	556	1.63	.49 BW	2.12
	30,000	834	1.43	.48 BW	1.91
10	1,000	16.7	20.39	--	--
	2,000	33.4	10.90	.75 BW	11.65
	4,000	66.7	6.15	.65 BW	6.80
	7,000	116.8	4.14	.60 BW	4.74
	10,000	167	3.31	.56 BW	3.87
	15,000	250	2.68	.53 BW	3.21
	20,000	334	2.37	.51 BW	2.88
	30,000	500	2.05	.49 BW	2.54
14	1,000	11.9	27.92	--	--
	2,000	23.8	14.86	.86 BW	15.72
	4,000	47.7	8.33	.69 BW	9.02
	7,000	83.4	5.54	.62 BW	6.16
	10,000	119	4.41	.60 BW	5.01
	15,000	179	3.54	.55 BW	4.09
	20,000	238	3.11	.53 BW	3.64
	30,000	357	2.66	.51 BW	3.17

NOTES:

Time Value { \$1.20 per hour in-vehicle
\$3.00 per hour walking and waiting
Feeder Route Perpendicular Distance = 3 Miles
BW = Bus-wagon

Table G-2. RAIL LINE HAUL PLUS FEEDER COSTS

Route Length (Miles)	Passengers per Hour in Corridor	Passenger Density (Passengers per sq. mi. per Hour)	Rail Line-Haul Cost (Dollars per Passenger)	Residential Feeder Costs (Dollars per Passenger)	Total Rail Plus Feeder Costs (Dollars per Passenger)
6	1,000	16.7	12.86	--	--
	2,000	33.4	6.94	.92 BW	7.86
	4,000	66.7	3.98	.84 BW	4.82
	7,000	116.8	2.74	.79 BW	3.53
	10,000	167	2.22	.76 BW	2.98
	15,000	250	1.83	.73 B	2.56
	20,000	334	1.63	.71 B	2.34
	30,000	500	1.43	.67 B	2.10
10	1,000	10.0	20.39	--	--
	2,000	20.0	10.90	1.02 BW	11.92
	4,000	40.0	6.15	.90 BW	7.05
	7,000	70.0	4.14	.83 BW	4.97
	10,000	100	3.31	.80 BW	4.11
	15,000	150	2.68	.77 BW	3.45
	20,000	200	2.37	.75 BW	3.12
	30,000	300	2.05	.71 B	2.76
14	1,000	7.2	27.92	--	--
	2,000	14.3	14.86	1.10 BW	15.96
	4,000	28.6	8.33	.95 BW	9.28
	7,000	50.0	5.54	.87 BW	6.41
	10,000	72	4.41	.83 BW	5.24
	15,000	107	3.54	.79 BW	4.33
	20,000	143	3.11	.77 BW	3.88
	30,000	214	2.66	.75 BW	3.41

NOTES:

Time Value $\begin{cases}\$1.20 \text{ per hour in-vehicle} \\ \$3.00 \text{ per hour walking and waiting}\end{cases}$

Feeder Route Perpendicular Distance = 5 Miles

BW = Bus-wagon

B = 50-Passenger Bus

Table G-3. RAIL LINE HAUL PLUS FEEDER COSTS

Route Length (Miles)	Passengers per Hour in Corridor	Passenger Density (Passengers per sq. mi. per Hour)	Rail Line-Haul Cost (Dollars per Passenger)	Residential Feeder Costs (Dollars per Passenger)	Total Rail Plus Feeder Costs (Dollars per Passenger)
6	1,000	27.8	13.94	1.43 J	15.37
	2,000	55.6	7.85	1.22 J	9.07
	4,000	111.2	4.80	1.04 BW	5.84
	7,000	194.7	3.57	.91 BW	4.48
	10,000	278	3.02	.86 BW	3.88
	15,000	417	2.63	.81 BW	3.44
	20,000	556	2.43	.78 BW	3.21
	30,000	834	2.22	.76 BW	2.98
10	1,000	16.7	21.58	--	--
	2,000	33.4	11.91	1.35 J	13.26
	4,000	66.7	7.07	1.17 BW	8.24
	7,000	116.8	5.07	1.03 BW	6.10
	10,000	167	4.22	.95 BW	5.17
	15,000	250	3.59	.87 BW	4.46
	20,000	334	3.27	.83 BW	4.10
	30,000	500	2.94	.79 BW	3.73
14	1,000	11.9	29.21	--	--
	2,000	23.8	15.97	1.52 J	17.49
	4,000	47.7	9.35	1.26 J	10.61
	7,000	83.4	6.58	1.11 BW	7.69
	10,000	119	5.42	1.03 BW	6.45
	15,000	179	4.55	.93 BW	5.49
	20,000	238	4.11	.88 BW	4.99
	30,000	357	3.66	.82 BW	4.48

NOTES:

Time Value { $3.00 per hour in-vehicle
$7.50 per hour walking and waiting
Feeder Route Perpendicular Distance = 3 Miles
BW = Bus-wagon
J = Jitney

Table G-4. RAIL LINE HAUL PLUS FEEDER COSTS

Route Length (Miles)	Passengers per Hour in Corridor	Passenger Density (Passengers per sq. mi. per Hour)	Rail Line-Haul Cost (Dollars per Passenger)	Residential Feeder Costs (Dollars per Passenger)	Total Rail Plus Feeder Costs (Dollars per Passenger)
6	1,000	16.7	13.94	--	--
	2,000	33.4	7.85	1.57 BW	9.42
	4,000	66.7	4.80	1.39 BW	6.19
	7,000	116.8	3.57	1.26 BW	4.83
	10,000	167	3.02	1.19 BW	4.21
	15,000	250	2.63	1.15 BW	3.78
	20,000	334	2.43	1.12 BW	3.55
	30,000	500	2.22	1.10 BW	3.32
10	1,000	10.0	21.58	--	--
	2,000	20.0	11.91	1.90 BW	13.81
	4,000	40.0	7.07	1.52 BW	8.59
	7,000	70.0	5.07	1.38 BW	6.45
	10,000	100	4.22	1.29 BW	5.51
	15,000	150	3.59	1.21 BW	4.80
	20,000	200	3.27	1.17 BW	4.44
	30,000	300	2.94	1.13 BW	4.07
14	1,000	7.2	29.21	--	--
	2,000	14.3	15.97	--	--
	4,000	28.6	9.35	1.64 BW	10.99
	7,000	50.0	6.58	1.45 BW	8.03
	10,000	72	5.42	1.38 BW	6.80
	15,000	107	4.55	1.27 BW	5.82
	20,000	143	4.11	1.22 BW	5.33
	30,000	214	3.66	1.16 BW	4.82

NOTES:

Time Value { $3.00 per hour in-vehicle
$7.50 per hour walking and waiting
Feeder Route Perpendicular Distance = 5 Miles
BW = Bus-wagon

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