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Automated Mixed Traffic Transit Market Analysis

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16. Abstract

While automation of vehicle operator functions can result in significant operating cost savings, the high cost of the exclusive guideway and station structures associated with conventional automated guideway transit systems has limited their application. A need was perceived for an automated vehicle mode that could use existing rights-of-way with minor modification. The system concept has been called an Automated Mixed Traffic Transit (AMTT) system. Such a system can serve a variety of transit collection and distribution functions in urban areas. An examination of potential application areas indicates that AMTT would be less costly on a total annual cost basis than conventional bus transit in areas where fleet requirements are relatively low and high amount of service, as measured in vehicle kilometers, is desired.

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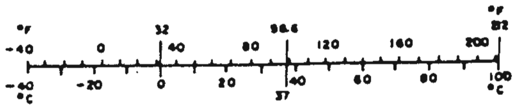
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

Approximate Conversions from Metric Measures

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



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1. INTRODUCTION

In the past few years, numerous efforts have been directed toward the development of the concept of small, driverless electric vehicles for mixed traffic use. Interest in such vehicles stems from the fact that the relatively high costs of operating conventional mass transit vehicles, such as buses, can be directly traced to the labor costs associated with the driver. These costs limit the ability of conventional public transit to serve many areas characterized by low trip volumes and short trip distances. Although automation of vehicle operator functions can result in significant operating cost savings, the high cost of the exclusive guideway and station structures associated with conventional automated guideway transit systems has limited their application. A need was thus perceived for a less capital-intensive automated vehicle mode that could utilize existing rights-of-way with relatively minor changes. The system also needed to have the ability to pick up or discharge passengers in the same way as does a conventional transit bus, thus eliminating the need for elaborate, expensive station facilities. In addition, the vehicle(s) should be able to move safely at low speed, over surfaces shared by pedestrians, or (possibly) move at higher speeds on a pedestrian-free path protected by suitable side barriers. The vehicle(s) should also be able to easily move from high-speed protected guideway to low-speed shared running surfaces in order to improve average speeds. This system concept has been called an "Automated Mixed Traffic Transit" (AMTT) system by its developers at the Jet Propulsion Laboratory (JPL), Pasadena, California.

To investigate the technical practicability of the AMTT concept, an experimental sensor and control test vehicle was built at JPL, using existing systems and control technology. The program was funded jointly by the National Aeronautics and Space Administration (NASA), Technology Utilization Office, and the Department of Transportation (DOT), Office of Technology Development and Deployment. Data generated on this prototype vehicle in operation on a test route at JPL was collected as part of the program. In addition, a preliminary effort to evaluate multiple vehicle scheduling algorithms and control schemes was carried out by JPL. These studies indicated the basic feasibility of the sensing and control techniques required for AMTT operation. (Further discussion of the JPL and other AMTT experimental systems is contained in Appendix A).

A wide selection of similar vehicles for goods movement are now commercially available and operational in dozens of plants and office buildings throughout the country. These systems, if properly equipped with proximity sensors, guidance sensors, and lateral and longitudinal control systems, appear to have the capability of operating in a mixed vehicle-pedestrian environment. These vehicles are capable of automatically following a path delineated by either a buried wire or a paint stripe. They are fitted with sensors that can see objects in their path, as well as with braking systems tied into these sensors that will stop the vehicle prior to collision. Some vehicles are also programmable; able to stop automatically at predetermined locations for loading of cargo. (See Appendixes B and C for information on these automated vehicles and their manufacturers).

The development of the AMTT has now reached the stage that, prior to commitment of further efforts for the development of the system, it has become desirable to examine and identify the potential market for this technology. This report examines the characteristics and associated costs of AMTT vis-a-vis its conventional transportation alternatives. A parametric analysis is performed between electrically powered driverless AMTT and internal combustion conventional bus transit to identify appropriate service and operating conditions for AMTT. Next a series of potential application areas for AMTT are examined and economic analyses performed. Finally, the results obtained for the application areas are used to give an estimate of the overall market penetration potential for AMTT.

2. CHARACTERISTICS OF AMTT AND ITS ALTERNATIVES

2.1 AMTT

2.1.1 System and Vehicle Characteristics

The "Automated Mixed Traffic Transit" (AMTT) concept refers to a system of driverless electric vehicles for mixed traffic use. These systems would significantly decrease the labor costs associated with transit operations. In addition, their ability to use existing rights-of-way with relatively minor changes indicates that system capital costs would also be relatively low compared to conventional modes.

AMTTs for moving goods have been in use for more than 20 years. Until recently their application has been limited to the low speed movement of cargo and mail in warehouses, factories, and offices. Systems available vary from simple closed loops with fixed stopping points to complex networks with on-board or centralized control to provide route selection and programmed stops. Vehicle load capacity can exceed 20 metric tons (44,100 lbs.). While cruise speeds are normally in the 3-5 km/hr range (2-3 mph), speeds as high as 16 km/hr (10 mph) have been achieved. Although normally intended for short distances, guidepaths up to 10 km. (6 mi.) in length have been installed.

For passenger operations, the AMTT vehicles will have the ability to pick up or discharge passengers in the same way as a conventional transit bus, eliminating the need for expensive station facilities. In addition, the vehicles will be able to move safely at low speeds over surfaces shared with pedestrians or move at higher speeds on a pedestrian-free path protected by suitable side barriers. Depending on the application area, several types of AMTT pathways may be required, as well as variations within types. To illustrate the concept, three possible pathway types--A, B, and C--are outlined here.

Type A pathways cross areas where other traffic has equal claim to the right-of-way. In such areas, the AMTT must be able to stop quickly enough to avoid striking a person or vehicle in its path. This is the condition under which AMTTs used for goods movement ordinarily operate. Pedestrians can approach the pathway an instant before the vehicle arrives. Vehicle mounted sensors must stop the vehicle without injuring the pedestrian. Therefore, speeds must be very low on Type A pathways. In fact, speeds of far below walking speeds--1.6 km/hr (1 mph) or less--are observed in factories.

Type B pathways are envisioned as having fences or other buffers to prevent access to the pathway from the sides. Pedestrians or other vehicles may walk on a Type B pathway but may not enter the pathway suddenly from either side. Vehicle mounted sensors, such as those employed by JPL, would be able to detect anything on the pathway at a considerable distance and would have time to decelerate from a moderate speed. For example, if the sensors have a range of 7.6 meters (25 feet), the vehicle may be able to operate safely at about 11.3 km/hr (7 mph). If an obstacle were detected, the vehicle would stop or slow to a safe speed.

Type C pathways are envisioned as segments of exclusive right-of-way protected by fences or other side buffers, automatically controlled gates at portals, and sensors that would detect the unauthorized presence of anyone or anything on the path. AMTTs on Type C pathways would not depend solely on vehicle mounted sensors and would be functionally equivalent to Automated Guideway Transit (AGTs). AMTTs on Type C pathways could operate at relatively high speeds (between 50 and 80 km/hr, or 30 and 50 mph).

An AMTT route could include any mix of A, B and C segments, and segments would vary in length. Generally, designers will want to achieve high average speeds and correspondingly high vehicle productivity. This would be done by using as much Type C and Type B pathway as possible. However, the desire for higher speed is not the designer's sole objective. The interests of pedestrians may be best served by maximizing a number of lengths of Type A segments. Actual designs will need to reflect a compromise of these conflicting goals.

To summarize the system and vehicle characteristics:

a. Vehicle Size - AMTT vehicle size is likely to vary within the range of 8 to 50 passengers. Since no driver is required, the vehicle size is more likely to be determined by the number of seats that must be provided to meet the capacity while providing frequent service, rather than by selecting the largest size of vehicle that can be operated by one person. For example, a peak capacity of 240 passengers per hour could be better met by 8-passenger vehicles operating at 2-minute headways rather than by 50-passenger vehicles operating at 12-minute headways.

b. Operating Speeds - A minimum of two operating speeds are likely to be required; a low speed for movement in close proximity to pedestrians and a higher speed for "line haul" operations where conflicting movements by pedestrians and other vehicles are prohibited.

c. Protected Guidepaths - Eventually it is likely that sensor technology will have advanced to the point where an AMTT vehicle can enjoy a high degree of protection from all conflicting movements while it is operating in a high speed mode on shared right-of-way. As an interim measure, it will be necessary to provide some degree of protection to both the AMTT vehicle and other objects (or people) whose paths could intersect during the high speed mode.

2.1.2 AMTT System Costs

Until operational people-moving AMTT systems are in existence, it is obviously impossible to present empirical cost information. However, some preliminary estimates are available and are summarized in Table 2-1.

AMTT vehicle cost estimates were based on studies of the JPL prototype vehicle and other electric vehicles currently in use.(1) Electric vehicles presently cost approximately twice as much as conventionally powered buses, although exact prices depend on the quantity of purchase and exact specifications such as horsepower requirements, seating capacity and type of control installed. AMTT vehicle cost was estimated by adding the cost of JPL prototype sensors and control to the cost of electric vehicles. The guidepath cost was estimated from a combination of the JPL prototype (costs of wire, layout, signs, magnets, exciter boxes, electronics, and related labor) and costs of cutting the desired trench and backfilling. The barrier cost was based on the "Jersey barrier" type of low concrete barrier used to avoid conflicting traffic. The AMTT operating and maintenance (O&M) cost was estimated from studies of the O&M costs of electric vehicles, conventional transit buses, and AGT systems (see Appendix D for details.)

One possible source of uncertainty in AMTT costs is the liability question. The question of liability as it affects AMTT manufacturers, operators and users must be viewed in the context of the current product liability crisis that is affecting all manufacturers, especially those of automated equipment and machinery. Changes in the tort law system, most notably in the concept of strict liability in tort, beginning back in the early 1960s, have driven up the cost of liability insurance for firms involved in this industry. The industry has started to study the problem and initial projections indicate that, by 1980, product liability costs borne by manufacturers will add 10-20% to the price of purchased equipment.(2)

TABLE 2-1 - AMTT UNIT COSTS

(1979 Dollars)

Capital Costs	
<u>Vehicles</u> (10-yr. life)*	
Small, 8 to 10 passengers	$ 50,000
Medium, 15 to 25 passengers	110,000
Large, 40 to 60 passengers	210,000
<u>Guidepath</u> (20 yr. life)**	$5,600/km. ($9,000/mi.)
<u>Barriers</u> (20 yr. life)***	$25,000/km. ($40,000/mi.)
O&M Cost****	$0.82/veh. km. ($1.32/veh. mi.)

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*Vehicle prices depend on quantity of purchase and exact specifications. Cost of JPL prototype sensors and control was added to the cost of electric vehicles. The U.S. Department of Energy reported that electric vehicles now cost about twice as much as conventionally powered buses (Ref. 1) and costs of conventional buses were based on data from "Characteristics of Urban Transportation Systems," by DeLeuw, Cather and Co., 1979 (see Table D-4 in Appendix D).

**Cost estimated from studies of JPL prototype and other industrial driverless vehicle systems.

***Low "Jersey barrier" type of concrete barrier.

****Estimated from studies of O&M costs of electric vehicles, conventional buses, and AGT systems (see Appendix D).

Currently, there is considerable ferment at both the state and federal levels on product liability reform. The groups involved in the political process of reforming the tort law system include individual manufacturers and their industry associations, consumer groups, and governmental agencies. A recent significant event was the release in April 1977 of a legal report by the U.S. Interagency Task Force on product liability law. Although the Task Force did not advocate the "major overhaul" of the tort system wanted by both manufacturers and insurers, it thought that modifications or "refinements" of the tort law would be most appropriate.

An approach to assessing the impact of liability on an AMTT system is to examine the current situation of industrial truck manufacturers, whose vehicles are often automatic and self-guided for hauling freight in controlled warehouse and factory environments, and small bus systems. Some of the industrial truck manufacturers have not had their insurance renewed because their insurers did not want exposure to the rapidly escalating liability claims. A few manufacturers have gone to what amounts to a self-insured position, with very large deductibles. Others are considering forming a captive insurer, to which several manufacturers would contribute. Although details are not given, entire associations are considering setting up insurance pools or captives to replace the present insurance system.

The current liability situation for small transit systems reflects the same ferment that manufacturers are facing. The cost of their insurance has been rising yearly, with some opting for high ($50,000) deductibles that amount to self-insuring. The cost of insurance varies widely across states because some states have a no-fault insurance system. Within states, individual counties can also vary greatly.

A very careful experimental design plan will be required to assure that all the liability issues are addressed and evaluated in a system demonstration. All of the above could significantly affect system capital and operating costs.

2.2 Alternative Modes

AMTT systems may be regarded as alternatives to other existing modes of travel, or may, like the introduction and prompt exploitation of electric elevators (circa 1888) in tall buildings, open the way for new forms of urban design and new patterns of trip making. Modes of travel that AMTT systems may compete with include walking, pedestrian conveyors, small and medium-size conventional buses, electric buses, automated guideway transit (AGT) systems, and the private automobile. Walking, the most universal and most important alternative, pedestrian conveyors, buses, AGT systems, and the automobile are discussed in this section in terms of speeds, capacities, costs, route lengths, and typical applications.

2.2.1 Walking

Walking is the most common mode of travel. However, travelers exhibit a limited tolerance for walking because of the time and physical effort required. The willingness to walk appears to diminish at an increasing rate in a range of distance from about 80 meters (265 feet) (1 minute) to 800 meters (2,625 feet) (10 minutes). For example, in midtown Manhattan the observed walking distances for travelers entering or leaving two office buildings were studied.(3) The median walking distance for all trips was 326 meters (1,070 feet). Seventy-six percent of the trips were shorter than 610 meters (2,000 feet) and 94% walked less than 1,609 meters (1 mile). A study performed in Chicago showed median walking trips to be 315 meters (1,035 feet). Other studies show that shorter walking trips are the norm for smaller CBDs.

The length of the trip varies by trip purpose. Trips to eat had the shortest walking distance in midtown Manhattan, with a median of 247 meters (810 feet); business trips had the longest median walk--428 meters (1,405 feet). It appears that the differences depend on the availability of trip ends. That is, restaurants are plentiful in midtown, but business trip ends are likely to be more unique in character and, therefore, require greater travel distances. This phenomenon was also noted with respect to the length of walking distances to various transportation modes, with the shortest trip to taxis and the longest to commuter rail and bus terminals that are few and far between.

The midtown Manhattan study also showed that trip length correlated with age and sex. It was found that on the average, males walked over 100 meters (330 feet) more than women did. Not surprisingly, males and females over 50 years of age walked shorter distances than those between the ages of 25 and 50. To a great extent, this was found to be a function of speed. Indeed, when walking speeds of different groups were applied to their walking distances, it showed that most of the groups allocated a similar amount of time to their walking trips, with an average net time (exclusive of delays, waiting time, or window shopping) of 6 minutes.

2.2.2 Pedestrian Conveyors

As used here, pedestrian conveyors are synonymous with passenger conveyors, moving sidewalks, moving walks, moving ways, and various other names. Escalators, having discrete steps rather than continuous surfaces and primarily used for vertical travel, are considered a separate class of system. Pedestrian conveyors provide a continuous moving surface for pedestrians through the use of pallets or belts. Persons either stand or walk on the surface. Most installations are at grade, but ramp installations on grades up to 15% are feasible. An emerging pedestrian conveyor technology is the accelerating walkway. An accelerating walkway system (AWS) is an improved pedestrian conveyor system which provides line speeds twice that of normal walking speed. Users enter at speeds of 1.6 to 2.4 km/hr (1 to 1.5 mph) and are accelerated to line speeds of four to five times entry speed. Gradual deceleration occurs at the discharge end of the system, to provide a safe exit speed comparable to that of a conventional moving walkway. Several accelerating walkway systems are presently being advanced from prototype to commercial product status.(4,5,6)

Pedestrian conveyors can move large numbers of people over short distances in a short period of time. They are particularly helpful for persons encumbered with baggage, parcels, and small children. Consequently, pedestrian conveyors have been used extensively in airports. They have also been used in amusement parks and in other commercial applications.

Capacities of pedestrian conveyors are high. A 75 cm. (30 in.) wide 2.4 km/hr (1.5 mph) pedestrian conveyor (60 cm. or 24 in. treadboard) accommodates one adult and is theoretically capable of moving 4,800 persons per hour. A 105 cm. (42 in.) wide version (90 cm. or 36 in. treadboard) accommodates two adjacent adults or one adult with luggage and theoretically can move up to 9,600 people per hour. Nominal capacities are estimated at 75% of theoretical capacities, or 3,600 persons per hour for the narrower conveyor and 7,200 persons per hour for the wider one.

Pedestrian conveyors, usually operate at one-third to one-half walking speed--1.6-2.4 km/hr (1-1.5 mph). A pedestrian's overall speed, when walking on a belt, is usually between 6.5-7.3 km/hr (4-4.5 mph). Thus, a pedestrian can cover a greater distance in a given period of time than is normally achieved by walking without this aid. For those who choose not to walk on the belt, it takes two to three times longer to reach their destination than if they had walked at normal speed. Accelerating pedestrian conveyors permit operating speeds of up to five times higher than those of conventional conveyors.

Most installed pedestrian conveyors are less than 27 meters (90 feet) in length, although longer units have been engineered and developed. More recently, the market at airports is in the 45-150 meter (150-500 foot) range. It is possible to use a series of conveyors, to extend a pedestrian conveyor route to any desired length. For example, at Denver's Stapleton Airport, four pairs of conveyors are installed end-to-end. Accelerating walkway systems could have longer lengths.

Because each conveyor requires a driving mechanism and a return carriage, capital costs vary according to the length of the installation. Not surprisingly, the cost is also dependent on width, type of installation (pallet or belt), and other specifications such as how the structure is to be supported, the type of material to be used in the balustrades, etc. A 1973 study by SRI showed that the basic hardware--driving mechanism and return carriage--would cost $25,000. Based on the producer price index (previously called the wholesale price index) for machinery and motive products, this would cost approximately $42,740 in 1979 dollars. The cost per 30 cm. (linear foot) was given as $350 to $500, or $600 to $855 in 1979 dollars. Thus, a 1500-cm. (50 foot) installation would cost $1,500 to $1,750 per 30 cm. (linear foot), where as a 150-meter (500 foot) installation would cost approximately $690 to $940 per 30 cm. (linear foot). A 132-meter (440 foot) installation at San Francisco airport in 1976 cost $681 per 30 cm. ($850 in 1979 dollars). This falls within the range given.

2.2.3 Small- and Medium-Sized Conventional Buses

These are buses with seating capacity between 10 and 30 passengers. Most buses use gasoline or diesel fuel as their energy source, although some buses use butane fuel or electric power. Applications of such small- and medium-sized buses are most often used in serving small areas such as CBDs, universities, retirement communities, and airports. Route lengths are generally short. In the case studies presented, bus route lengths vary from 1.0-19.2 km. (0.65-12 miles).

Buses usually operate in mixed street traffic, but are sometimes provided their own rights-of-way. A lane reserved for bus use and curb loading can accommodate up to about 60 buses per hour per direction. Assuming no standees, this yields 900 passengers per hour per direction for 15-passenger buses to 1,800 passengers per hour per direction for 30-passenger buses.

Most buses are capable of cruise speeds of 50-95 km/hr (30-60 mph), but, like automobiles, are often constrained by traffic as well as speed limits, road, and weather conditions. However, buses have slower average speeds than automobiles because of their frequent stops to allow passengers to board and deboard. Buses in CBDs often have average speeds of 8 or 10 km/hr (5 or 6 mph). A study of bus lines in CBDs in seven large cities in the United States and Canada showed a range in bus speeds from 8-19 km/hr (5-11.5 mph) with a weighted average of 15 km/hr (9.4 mph).(7)

Capital costs of buses vary according to size, number of vehicles ordered, interior finish, engine specifications, and air conditioning capability. In terms of 1979 dollars, the price of minibuses ranged from $28,700 to $47,400. The default value of a minibus--a design value based on experience or study conclusions to be used for estimating--was given by one authority as $35,000. The cost range for medium-size buses was $42,400 to $72,400, with a default value of $55,000. (See Appendix D).

Buses are the only alternative mode considered in this report that incur driver costs. At least half of bus operating costs are those incurred for drivers' wages. As of July 1, 1976, the average hourly wage for operators of buses and surface cars was $6.53 ($8.15 in 1979 dollars).(8) If one adds fringe benefits of 28.4%--the average for transit employees--drivers cost approximately $8.40 per hour ($10.50 in 1979 dollars).(9)

Operating and maintenance costs vary with the terrain, speeds, and other variables such as driver and administrative salaries and the cost of fuel. In the case studies presented (Section 4.0), O&M costs of the buses employed varied from $0.55 per vehicle kilometer ($0.88 per vehicle mile) for the minibuses and vans employed at Detroit Airport to $1.29 per vehicle kilometer ($2.08 per vehicle mile) for the mix of larger buses in use at Rossmoor, California.

Total capital costs and O&M costs varied from $0.58 per vehicle kilometer ($0.94 per vehicle mile) for the small vehicles in use at Detroit Airport to $1.51 per vehicle kilometer ($2.43 per vehicle mile) for the mix of larger buses in use at Rossmoor. The GO-BART system, operating on the campus of the University of California, Berkeley, California, falls about in the middle of this range at $0.87 per vehicle kilometer ($1.40 per vehicle mile). This yields a cost of 3.1 cents per unit capacity kilometer of travel (5 cents per unit capacity mile). Nationally, the O&M cost of transit service buses is $1.66 per vehicle kilometer ($2.68/vehicle mile) in 1979 dollars. (Appendix D).

2.2.4 Electric Buses

Electric buses are battery-powered vehicles that emit few air pollutants and are relatively quiet compared with gasoline and diesel-powered buses. Most models are in the developmental prototype, or demonstration phase. Some are reported to be capable of handling grades up to 20%.

In terms of applications, small electric buses, like nonelectric minibuses and medium-size nonelectric buses, serve small areas such as CBDs or small towns. They are particularly popular with older people because of their low noise levels.

Electric buses have been built that will accommodate over 100 passengers, including standees.(10) However, U.S. manufacturers produce much smaller vehicles, and those in service in the United States tend to be smaller than their European and Japanese counterparts. Battronic Truck Corp., one of the few U.S. manufacturers of electric buses, sells buses that seat 12 passengers, 16 passengers, and 22 passengers. Standing room increases these capacities up to 50%. EVA/Chloride Electrobus Inc., produces an electric bus equipped with 29 seats and standing room for 12. Because electric buses can be made to accommodate the same number of passengers as minibuses and medium-size buses, the same number of passengers per hour per direction is assumed--900 to 1,800.

Cruise speeds up to 72 km/hr (45 mph) have been demonstrated under test conditions. Typical average speeds are in the 8-24 km/hr (5-15 mph) range and are suitable for activity center application. Route lengths may be limited by battery recharging requirements. A study of 15 suppliers indicated urban driving ranges up to 80 km. (50 miles). However, a survey of 17 transit systems in the United States and other parts of the world indicated the longest round trip route to be 46 km. (29 miles). The average was 14 km. (9 miles). Routes in activity centers are usually much shorter, and buses would ordinarily make several round trips before having to return for recharged batteries.

As is true of minibuses and medium-size nonelectric buses, capital costs of electric buses differ depending on the specifications and other variables. General estimates received from Battronic Truck Corporation for their small electric buses in 1977 were as follows:

	Dollars (1977)			
	Basic Vehicle	Two Batteries	Battery Charger	Total
12-seat	19,003	8,400	1,200	28,603
16-seat	21,753	8,400	1,200	31,353
22-seat	22,743	8,400	1,200	32,343

The prices quoted above do not include the expense of a manual-push type of battery lift truck, which was estimated to be about $1,200. Self-propelled battery lift trucks were quoted at about $2,500.

The City of Montevideo, Minnesota purchased, in 1977, a number of 20-seat electric buses for $40,388 each, including batteries, charger, lift truck, and freight charges. The larger electric buses, with 29 seats, are presently being quoted at $107,000. This includes one battery and a battery charger. In general, the U.S. Department of Energy reported that electric vehicles now cost approximately twice as much as conventionally powered buses.(1)

With the electric vehicles currently in operation, total O&M cost ranges between $0.12 and $1.09 per vehicle kilometer ($0.19 and $1.75 per vehicle mile) in 1979 dollars.(11) (Appendix D).

2.2.5 Private Automobile

Private automobiles are generally categorized by size as standard, compact, and subcompact. Automobiles provide the most convenient form of transportation for most travelers and most trips in urban areas. However, their usefulness and advantage over other modes decreases as population densities and vehicular traffic increase.

Standard full-sized automobiles seat up to six people comfortably, whereas compact cars seat only four adults in reasonable comfort. Subcompacts usually accommodate only two adults comfortably, although rear seats can accommodate children with ease. Average actual vehicle occupancy varies by type of trip. The range is from 1.4 persons for a commute trip, with an overall average of 1.9 for all trip purposes.(12) Street lane capacity is about 600 automobiles per hour, if turn delays and other obstructions are infrequent.(13)

Although automobiles are capable of traveling up to (and over) the present U.S. speed limit of 90 km/hr (55 mph) actual average speeds are usually slower. In urban areas speed limits are often 40-55 km/hr (25-35 mph), and traffic, road, or weather conditions often hamper vehicle movements. Central business districts are generally the most congested, with automobiles often slowed to average speeds between 8-16 km/hr (5-10 mph).

The typical person trip via automobile is less than 8 km. (5 miles) in length. The length of automobile trips varies by trip purpose, and the average ranges from 7 km. (4.4 miles) for a shopping trip to 256 km. (160 miles) for a vacation trip.(12)

Average estimated costs for the assumed lifetime of the vehicle--10 years--are 11.2 cents/km. (17.88 cents/mile) for a standard size automobile, 9.1 cents/km. (14.56 cents/mile) for a compact, and 7.9 cents/km. (12.64 cents/mile) for a subcompact.(15) The cost per unit capacity kilometer of travel equals 1.86 cents for a full-sized automobile (2.98 cents/mile), 2.28 cents for a compact (3.64 cents/mile), and 2.63 cents for the subcompact (4.21 cents/mile).

2.2.6 Automated Guideway Transit

Automated Guideway Transit (AGT) systems, also called peoplemovers, are a class of transportation systems in which automated vehicles are operated on fixed guideways along an exclusive right-of-way. There are three major categories of AGT systems.(14) Single line transit (SLT) is the simplest type. Vehicles move along fixed paths with few or no switches. The vehicles of a simple shuttle system move back and forth on a single guideway. They may or may not make intermediate stops. Vehicles in a loop system move around a closed path, stopping at any number of stations. The vehicles may vary considerably in size. Group Rapid Transit (GRT) serves groups of people with similar origins and destinations. GRT tends to have shorter headways and uses switching more extensively than SLT. Vehicles with a capacity of 10 to 50 passengers may be operated singly or in trains. Headways range from 3 to 60 seconds. Personal Rapid Transit (PRT) is restricted to systems with small vehicles carrying groups of up to six usually traveling together by choice. Plans for PRT systems typically include off-line stations connected by an extensive guideway network. Under computer control, vehicles switch at guideway intersections so as to follow the shortest uncongested path from origin to destination without intermediate stops. Most proposed PRT systems call for vehicles to be operated at headways of two seconds or less. There are approximately 20 AGT systems in operational service to date. These are located primarily in airports or amusement parks, although other applications include mixed use developments, university campuses, and hospital complexes.

AGT vehicles have been designed using a variety of technical and design approaches. They are of varying sizes with differing passenger capacities and differing accommodations for entry and exit, and comfort or convenience, while riding. They run on fixed guideways, usually constructed of steel or reinforced concrete sections. Control systems for existing AGT systems vary as to the functions they are required to perform. Typical functions performed by control systems include: regulation of speed and position, response to emergency conditions, system status, checks, etc.

New AGT systems are under construction at Duke University, Durham, North Carolina; at the Bronx Zoo, Brooklyn, New York; the Miami International Airport, Miami, Florida; Atlanta Airport, Georgia; Orlando Airport, Florida; and a few other locations. Other potential sites include CBDs, where funds have been appropriated for engineering, design and environmental impact studies in a number of cities.(16)

The capacity of vehicles currently in use ranges from a low of four, for the Walt Disney World "WEDway People Mover System," to a nominal high of 100 for the Tampa Airport system. The lane capacity of operational AGT systems varies between 500 and 7,600 passengers per hour.(17,18,19)

All the systems built to date have short route lengths. The longest route is 20.8 lane kilometers (13 lane miles) for the "Airtrans" system at the Dallas/Fort Worth Airport. Maximum speeds of present systems vary from about 16 to 48 km/hr (10 to 30 mph). Average speeds including stops, however, are frequently less than 16 km/hr (10 mph).

Because of the great variation in types and complexity of AGT systems, capital costs vary considerably. These costs are also dependent on whether the systems are installed at grade, tunnelled, or elevated. The loop and shuttle systems, not surprisingly, are less capital expensive than the more complex group rapid transit systems.

Total O&M costs for the four systems studied varied between 31 cents and 87 cents per vehicle kilometer (49 cents and $1.39 per vehicle mile) of travel in 1979 dollars. (Appendix D).

2.3 Comparison of AMTT and Alternative Modes

As can be seen in the previous sections, AMTT and its alternatives each have their own strengths and regimes of applicability. For example, the automobile is a nearly ideal mode in low density areas but its usefulness and advantage over other modes decrease as densities increase. In addition, automobiles are not available to everyone, either because of their cost or a person's lack of driver skills and/or license. Others share an automobile, so that at times they are dependent on alternative modes or must forego a trip. It has been estimated that about 40% of the population old enough to need independent mobility--10 years of age or older--does not drive, does not own an automobile, or must share an automobile with other drivers.

The potential of AMTT technology might best be assessed by comparing its capabilities to satisfy specific application criteria with those of other transportation modes. The higher the level and quality of service afforded the user by AMTT technology, compared with existing, conventional systems, the greater are its chances for acceptance. As an example, the trip time costs of AMTT vis-a-vis alternative transportation systems are compared in the following paragraphs.

Walking is a basic alternative to AMTTs. A median walking trip of 0.3 km. (0.2 miles) requires about 4 minutes at 4.8 km/hr (3 mph), but entails no delay in the beginning of the trip. Riding an AMTT would require 2 minutes plus waiting time to board. With headways of 1 minute--probably the shortest interval easily attainable--waiting time will average 0.5 minutes. In this comparison, the AMTT provides two advantages, a 1.5 minute reduction in travel time, and reduced effort. If headways were four minutes, AMTTs would provide no time advantage. Generally the advantages of AMTT systems versus walking tend to decrease as trip lengths are shortened and/or headways increase, and to increase with longer trips and/or shorter headways.

Looked at another way, AMTT systems need to have average speeds somewhat above 5 km/hr (3 mph), perhaps 8 km/hr (5 mph), if riders are to save both time and effort. The added speed above 5 km/hr is needed to achieve total trip times equal to walking. Total distance traveled is likely to be greater when an AMTT rather than walking is the mode of travel. Travelers must walk to the AMTT line, wait for a vehicle, ride, and walk again to the final destination. If average AMTT speeds were only 5 km/hr travelers would have to sacrifice some time to save effort.

Pedestrian conveyors are slow, but like walking they do not require travelers to wait at the start of a trip. Almost all pedestrian conveyors are less than 152 meters (500 feet) in length. Conveyor speeds range from about 1.6-2.4 km/hr (1.0-1.5 mph). Based on the higher speed, a trip of 160 meters (528 feet) by a person standing on the conveyor will take 4 minutes. If the traveler walks on the conveyor, the trip will require about 1.3 minutes. An AMTT system with an average speed of 9.6 km/hr (6 mph) and with 1-minute headways would require a 0.5-minute wait and a 1-minute ride or a total of 1.5 minutes for the entire trip. This suggest that AMTTs could save time and effort even for the short lengths that are typical of pedestrian fixed speed conveyor installations.(20)

Electric buses generally operate in the 8-24 km/hr (5-15 mph) range, and it is believed that small conventional buses in activity centers also typically operate at about those speeds, although they have higher speed capabilities. (The case studies presented bear this out). In CBD applications, bus speeds often average 8-9.6 km/hr (5-6 mph), equal to the speed of the present JPL-AMTT prototype. Although the current JPL vehicle has not been experimentally demonstrated at speeds considerably greater than 8-11 km/hr, service equivalent to electric buses by AMTTs can be readily envisioned.

The maximum and average speeds of AGTs in existence are mostly slower than buses. Slower average speeds including wait times are in evidence at Walt Disney World (8.3 km/hr, 5.2 mph) and King's Dominion (9.9 km/hr, 6.2 mph), both theme parks. Average trip speeds at Tampa International Airport and the Seattle-Tacoma International Airport are about 14.4 km/hr (9 mph). Busch Gardens, a 2.4 km. (1.5 mile) loop with two stations, has an average speed of 29 km/hr (18 mph). AMTTs would be speed competitive at parks that contain many attractions where lower speeds are desirable.

Of course, it has to be recognized that the comparisons of AMTT with alternative modes assume certain levels of performance and reliability. The capabilities of AMTT technology, as first exemplified by JPL's experimental test vehicle, require further development prior to its implementation in revenue service. Improved sensor systems, able to detect objects in the vehicle's path, as well as paths oblique to the vehicle's guidepath, must still be developed.

To be competitive with buses and other transportation modes, the AMTT system must be designed to be not only safe, but attractive and comfortable as well. To be cost competitive with buses, for example, the savings realized in driver labor will have to be greater than any increase in capital, maintenance, and operating cost required by the AMTTs. As labor costs over the next decade can be expected to continue their escalation, it would appear that the move to automated vehicles will gain increasing interest and acceptance.

To summarize some of the main characteristics of AMTT and its operating environment which might help facilitate its introduction, the following are noted:

a. Urban areas of certain types (established CBDs, for example) are poorly served by existing modes of transportation and might obtain attractive new services from AMTT systems. Such systems could be installed to supplement existing bus or transit routes, or to add a feeder/distributor mode to currently existing systems.

b. Limitations and deficiencies that are inherent in existing modes of transportation might be avoided or rectified by use of AMTT systems. The AMTT's potential capability of offering a low-cost guidepath, coupled with a vehicle capacity equivalent to that offered by most minibuses and medium-sized buses, and a line capacity equivalent to, or greater than, such buses at a potentially lower overall cost (annualized capital cost plus O&M cost), make the AMTT appear to be an attractive alternative to such buses. The same appears true with AGT systems where capital costs and the requirements of construction of new transportation facilities in established areas (CBDs) make AMTT potentially attractive.

c. The use of AMTT systems as feeder/distributor lines to increase the use and usefulness of existing mass transportation systems represents an especially interesting application of this technology.

d. AMTTs may represent a vital, short-range transportation link for the elderly and handicapped in shopping centers, hospitals, etc. This segment of the community, now poorly served by existing transportation modes, may experience significantly increased mobility by means of specifically designed AMTT systems meeting the requirements of this ridership.

The results presented in this chapter indicate the need for a more detailed analysis and a closer examination of specific application areas. The parametric analysis and a series of case studies are presented in the following chapters.

3. PARAMETRIC ANALYSIS

A parametric analysis is performed between Automated Mixed Traffic Transit and conventional bus transit. The purpose of the parametric analysis is to identify potential urban applications, and service and operating conditions for AMTT. Parametric curves are presented here as a result of the parametric analysis. These charts can be used by transportation planners and transit system operators in evaluating the application potential of specific AMTT systems.

3.1 Approach

The parametric analysis undertaken in this study evaluates the cost-competitiveness of AMTT and conventional bus over a range of selected parametric values. The annualized total cost, which consists of the annualized capital cost and annual operating and maintenance (O&M) cost, is calculated for each mode under varying sets of conditions.

Parameters selected to be varied in the analysis include total vehicle kilometers operated per year, fleet size and total route length. These parameters were chosen because the annual O&M cost is directly proportional to the total vehicle kilometers operated per year, and the system capital cost is determined jointly by the fleet size and the total route length.

The parametric analysis involves:

a. calculation of annualized total costs for both AMTT and bus over a range of fleet size and yearly vehicle kilometer values for several preselected route lengths,

b. development of cost lines showing equal annualized total cost for both AMTT and bus, and

c. development of isocost lines showing areas where AMTT becomes more cost-competitive than bus under different sets of conditions.

3.2 Development of Equal Cost Lines

Two major cost components of the annualized total cost are annualized capital cost and annual O&M cost. The annualized capital cost is composed of the cost of the vehicles and the cost of the guidepath for AMTT. For a certain route length within each mode, it is possible to determine the different combinations of fleet size and vehicle kilometers operated per year that produce equal annualized total cost.

The unit capital and O&M costs used in the parametric analysis for both AMTT and conventional bus are summarized in Table 3-1. To calculate the annualized capital cost, the service lives are assumed to be 10 years for the vehicles and 20 years for the guidepath and barriers needed for the AMTT. A discount rate of 10 percent is used to derive capital recovery factors of 0.16 and 0.12 for vehicles and fixed facilities, respectively. The following equations represent the relationship between the annualized total cost and various parameters:

$$\text{Annualized total cost} = \text{annualized capital cost} + \text{annual O\&M cost}$$

$$\text{Annualized capital cost} = RF1 \times RL \times (GUNIT + BUNIT) + RF2 \times FS \times VUNIT$$

$$\text{Annual O\&M cost} = VKM \times OM$$

$$\text{Annualized total cost} = RF1 \times RL \times (GUNIT + BUNIT) + RF2 \times FS \times VUNIT + VKM \times OM$$

where:
RF1 = capital recovery factor for fixed facilities (including guidepath and barriers),
RF2 = capital recovery factor for vehicles,
RL = route length,
GUNIT = unit cost of the guidepath,
BUNIT = unit cost of the barrier,
VUNIT = unit cost of the vehicle,
FS = fleet size (no. of vehicles),
VKM = annual vehicle kilometers, and
OM = unit O&M cost.

Three vehicle sizes are used in the analysis to meet the transportation requirements of different urban applications. Small vehicles have a capacity of 8 to 10 passengers, medium 15 to 25 passengers, and large 40 to 60 passengers. Four different route lengths are investigated: 2 km., 5 km., 10 km., and 30 km. (1.2 mi., 3.1 mi., 6.2 mi. and 18.6 mi.).

A set of four charts is developed for each vehicle size. Each chart is for a specific route length and depicts for AMTT and bus the equal cost lines showing annualized total cost ranges. Figures 3.1.a through 3.1.d are developed for small vehicles, Figures 3.2.a through 3.2.d for medium vehicles, and Figures 3.3.a through 3.3.d for large vehicles.

TABLE 3-1 - UNIT CAPITAL AND O&M COSTS

(1979 Dollars)

I. AMTT	
Vehicles (10-yr. service life)	
Small, 8 to 10 passengers	$ 50,000
Medium, 15 to 25 passengers	110,000
Large, 40 to 60 passengers	210,000
Guidepath (20-yr. service life)	$5,600/km. ($9,000/mi.)
Barriers (20-yr. service life)	$25,000/km. ($40,000/mi.)
O&M Cost	$0.82/veh. km. ($1.32/veh. mi.)
II. Bus	
Vehicles (10-yr. service life)	
Small, 8 to 10 passengers	$ 20,000
Medium, 15 to 25 passengers	55,000
Large, 40 to 60 passengers	100,000
O&M Cost	$1.66/veh. km. ($2.68/veh. mi.)

Source: Section 2.

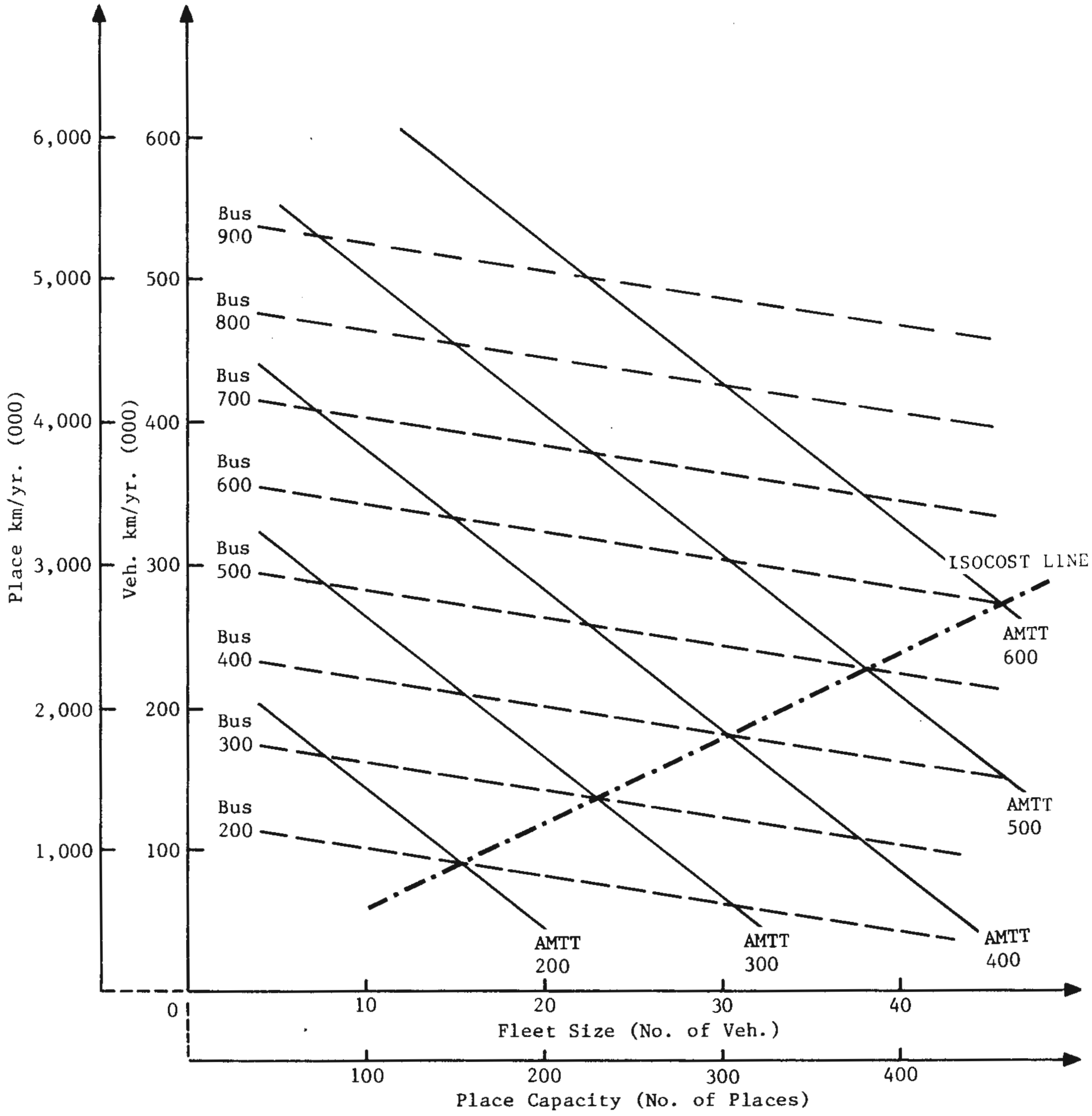

FIGURE 3.1.A EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —SMALL VEHICLES, 2 KM ROUTE LENGTH.

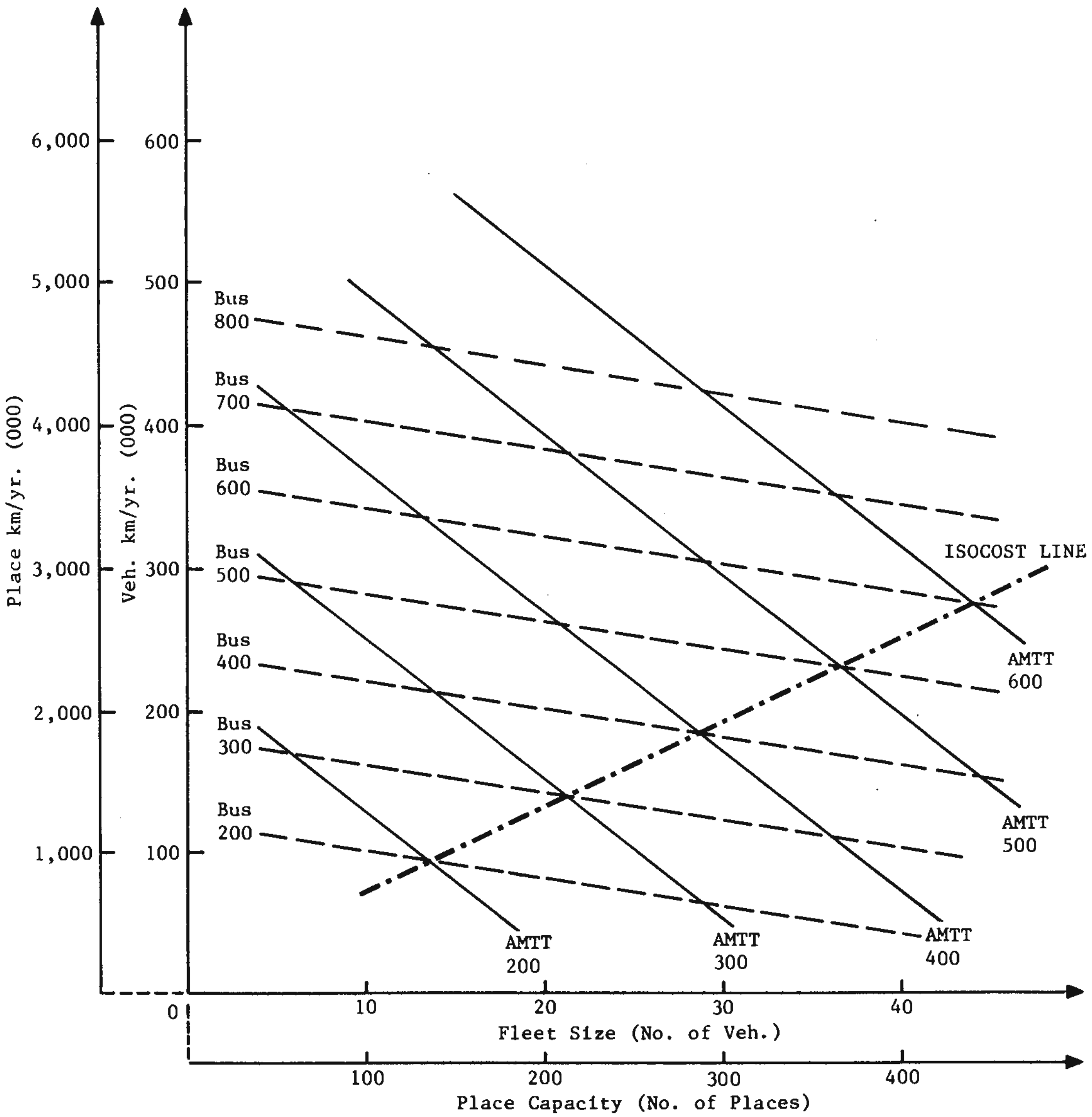

FIGURE 3.1.B EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —SMALL VEHICLES, 5 KM ROUTE LENGTH.

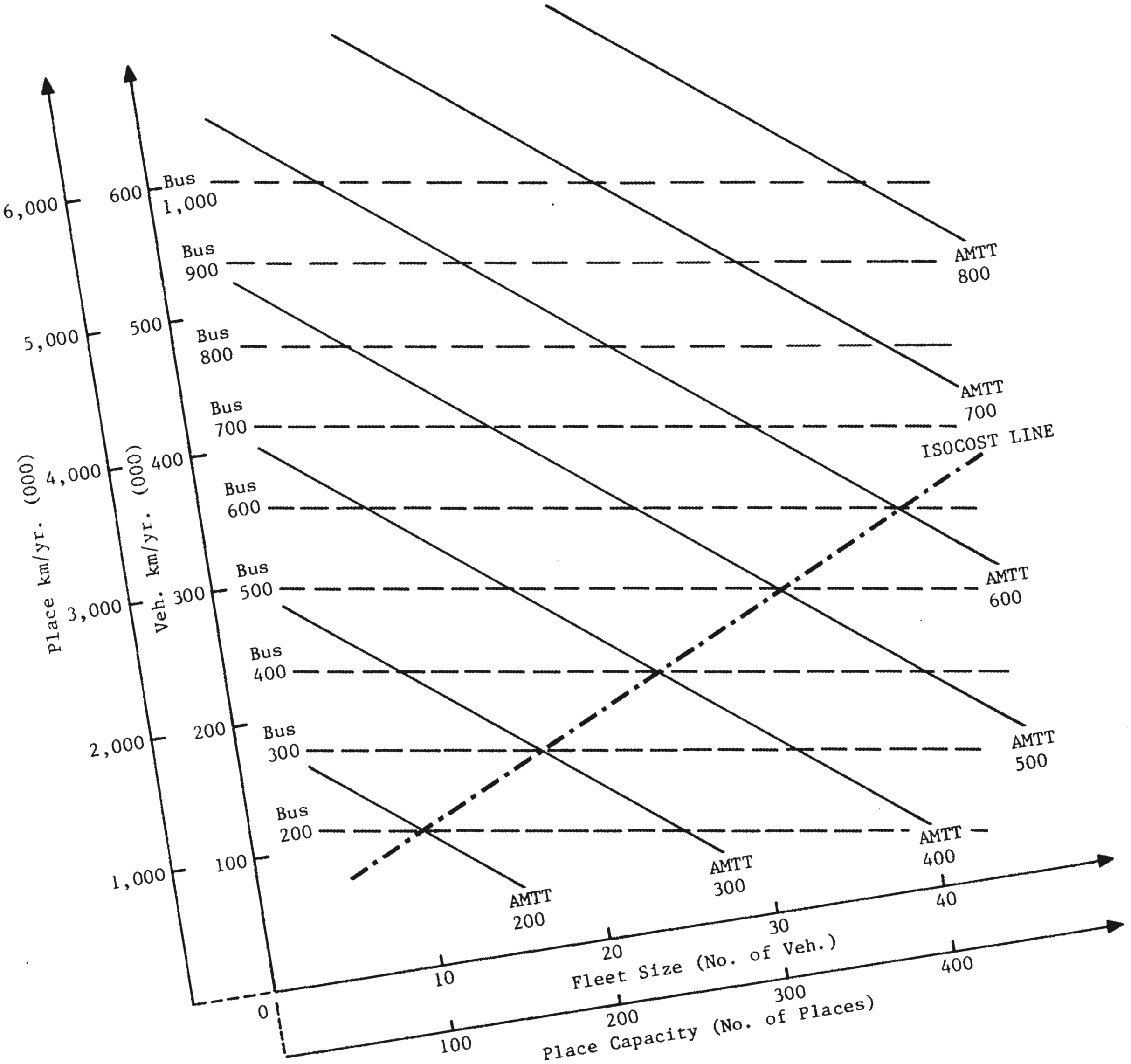

FIGURE 3.1.C EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —SMALL VEHICLES, 10 KM ROUTE LENGTH.

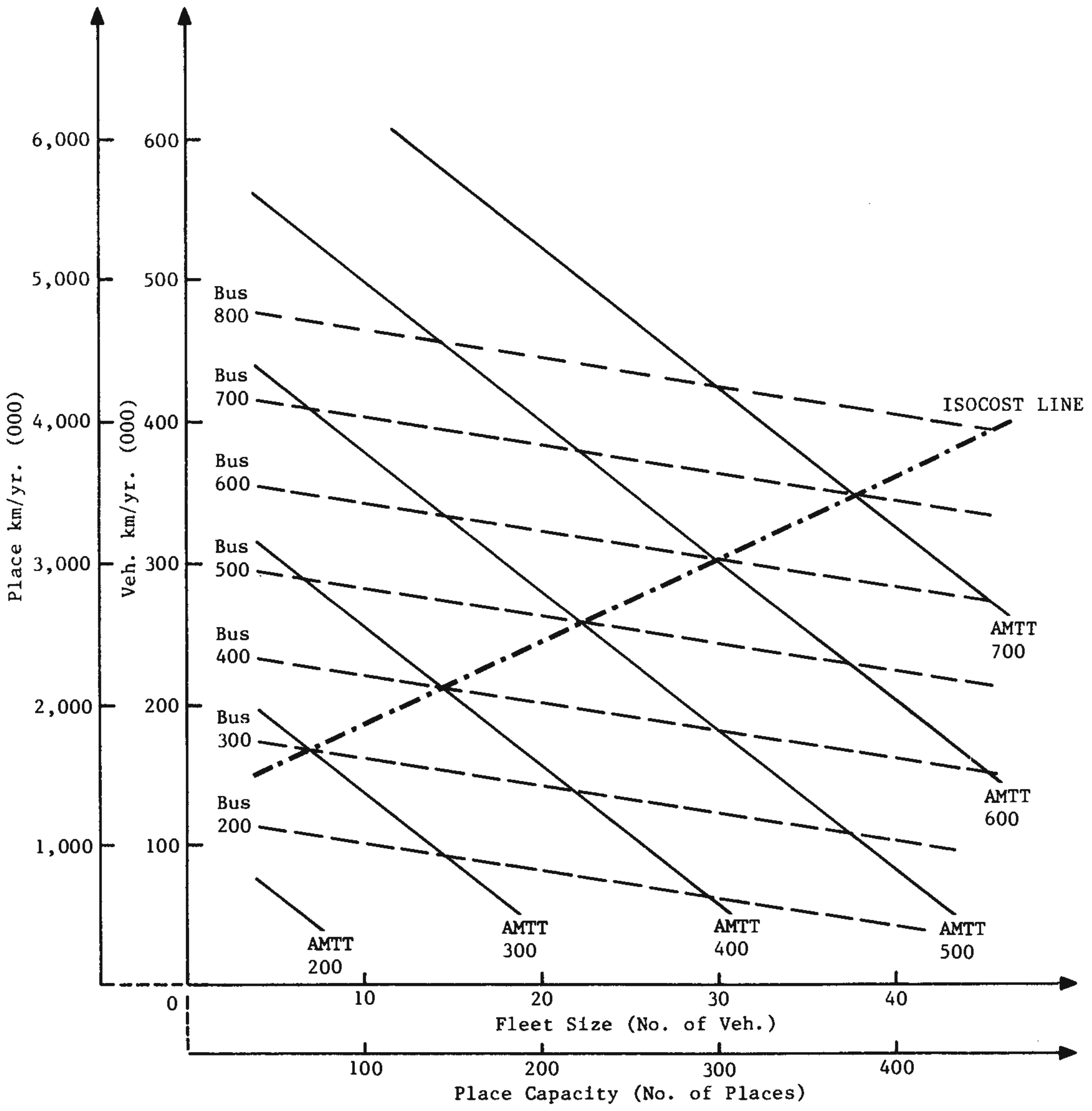

FIGURE 3.1.D EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —SMALL VEHICLES, 30 KM ROUTE LENGTH.

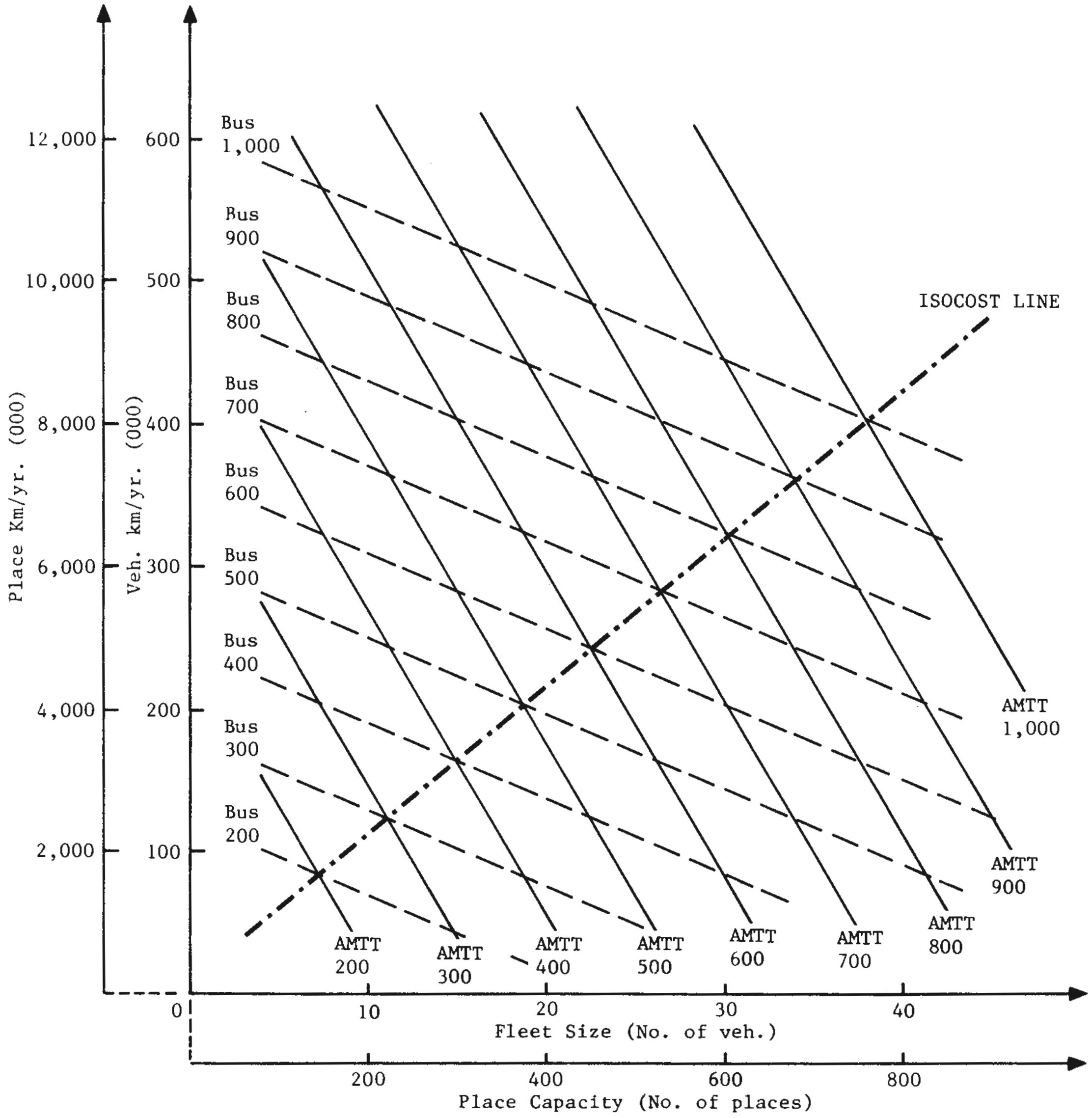

FIGURE 3.2.A EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —MEDIUM VEHICLES, 2 KM ROUTE LENGTH.

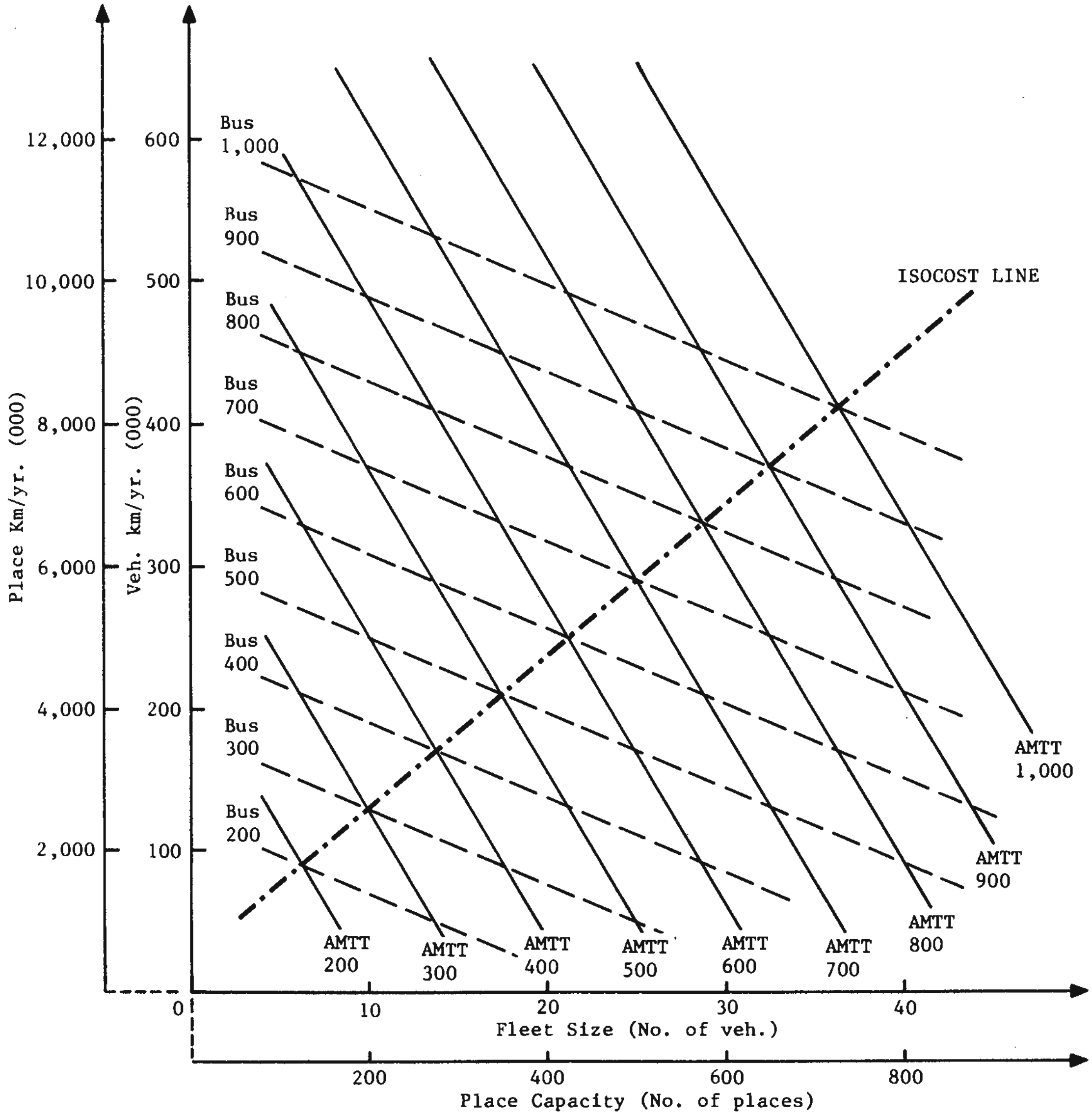

FIGURE 3.2.B EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —MEDIUM VEHICLES, 5 KM ROUTE LENGTH.

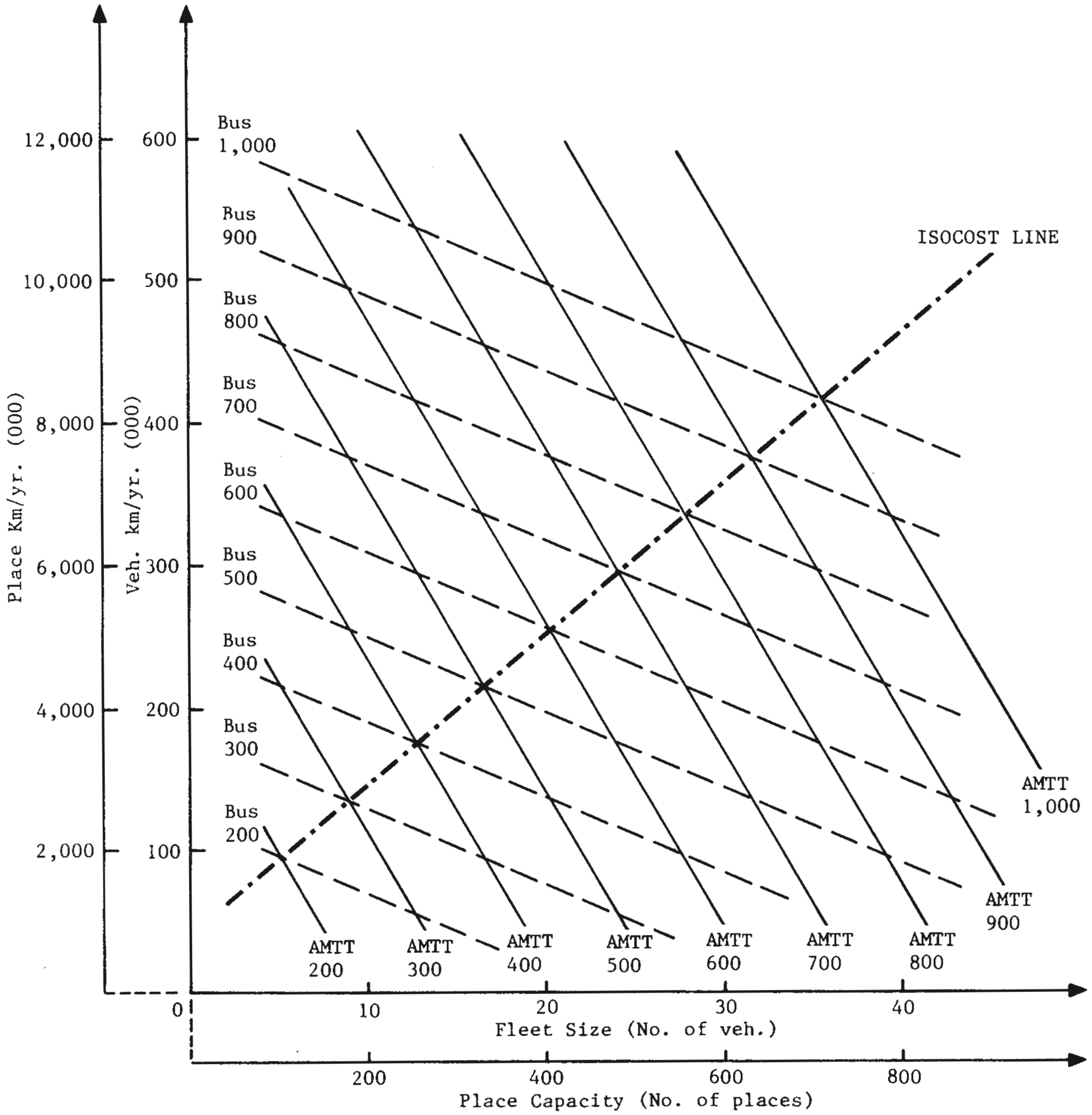

FIGURE 3.2.C EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —MEDIUM VEHICLES, 10 KM ROUTE LENGTH.

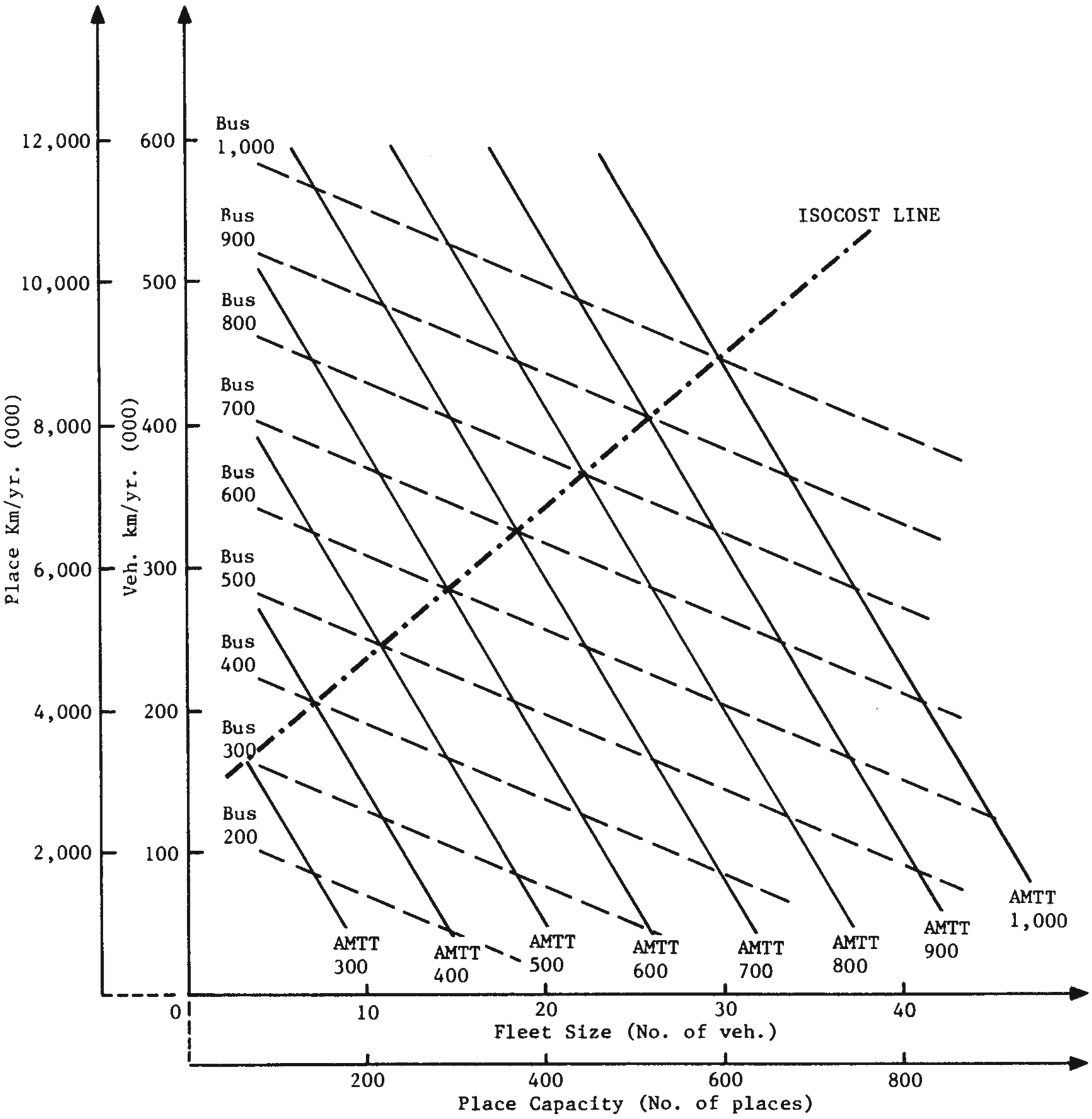

FIGURE 3.2.D EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —MEDIUM VEHICLES, 30 KM ROUTE LENGTH.

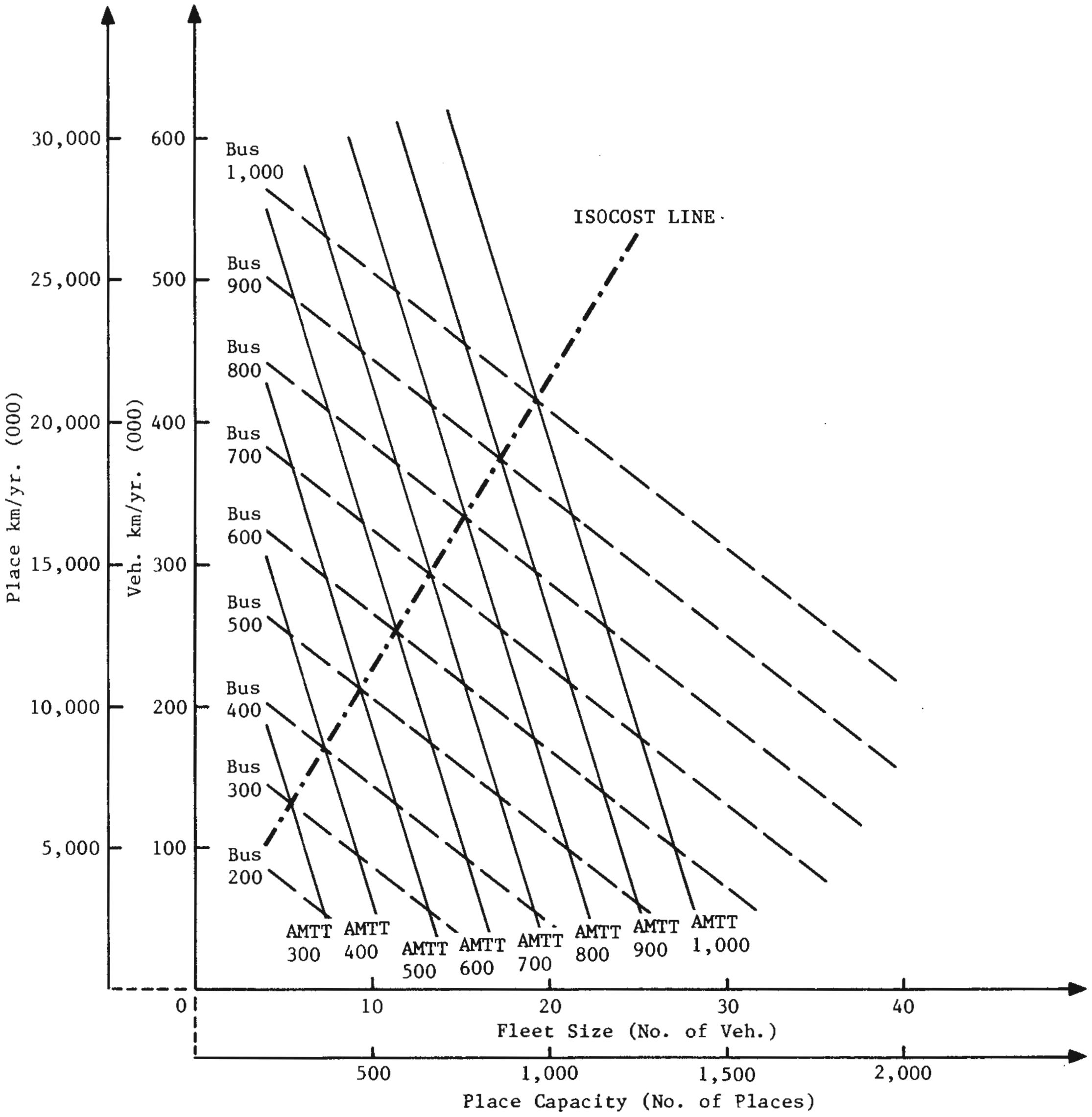

FIGURE 3.3.A EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —LARGE VEHICLES, 2 KM ROUTE LENGTH.

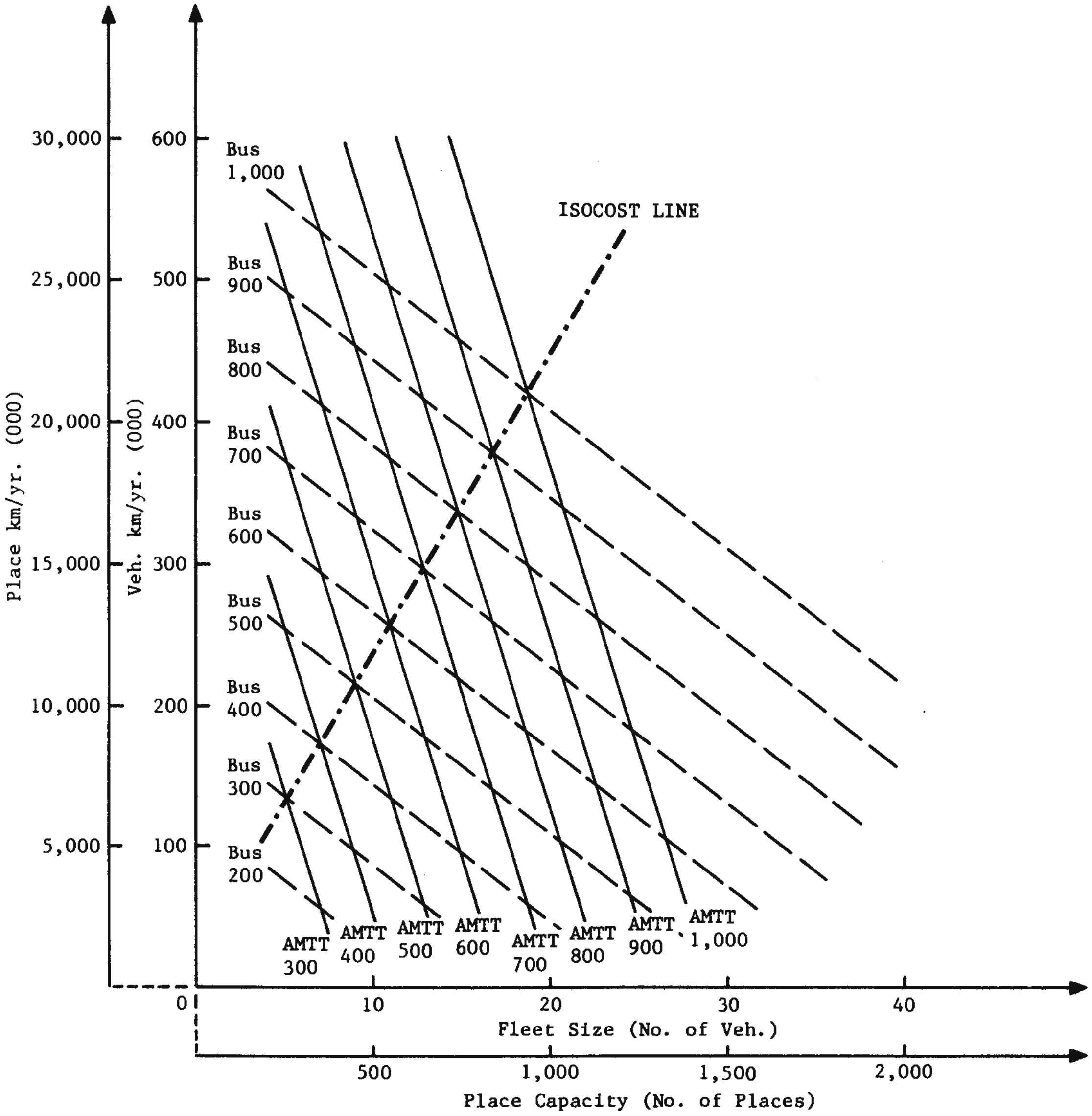

FIGURE 3.3.B EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —LARGE VEHICLES, 5 KM ROUTE LENGTH.

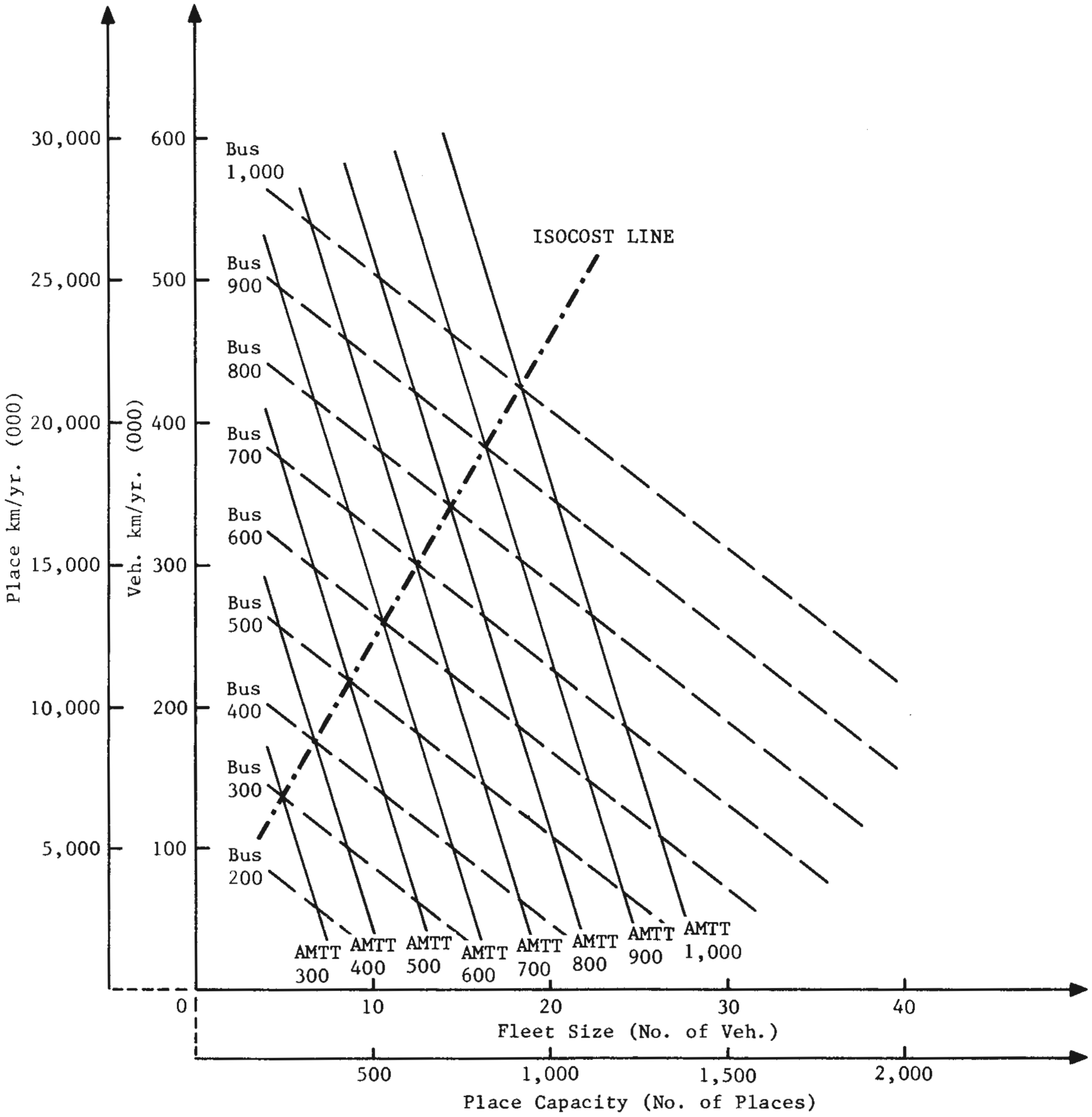

FIGURE 3.3.C EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —LARGE VEHICLES, 10 KM ROUTE LENGTH .

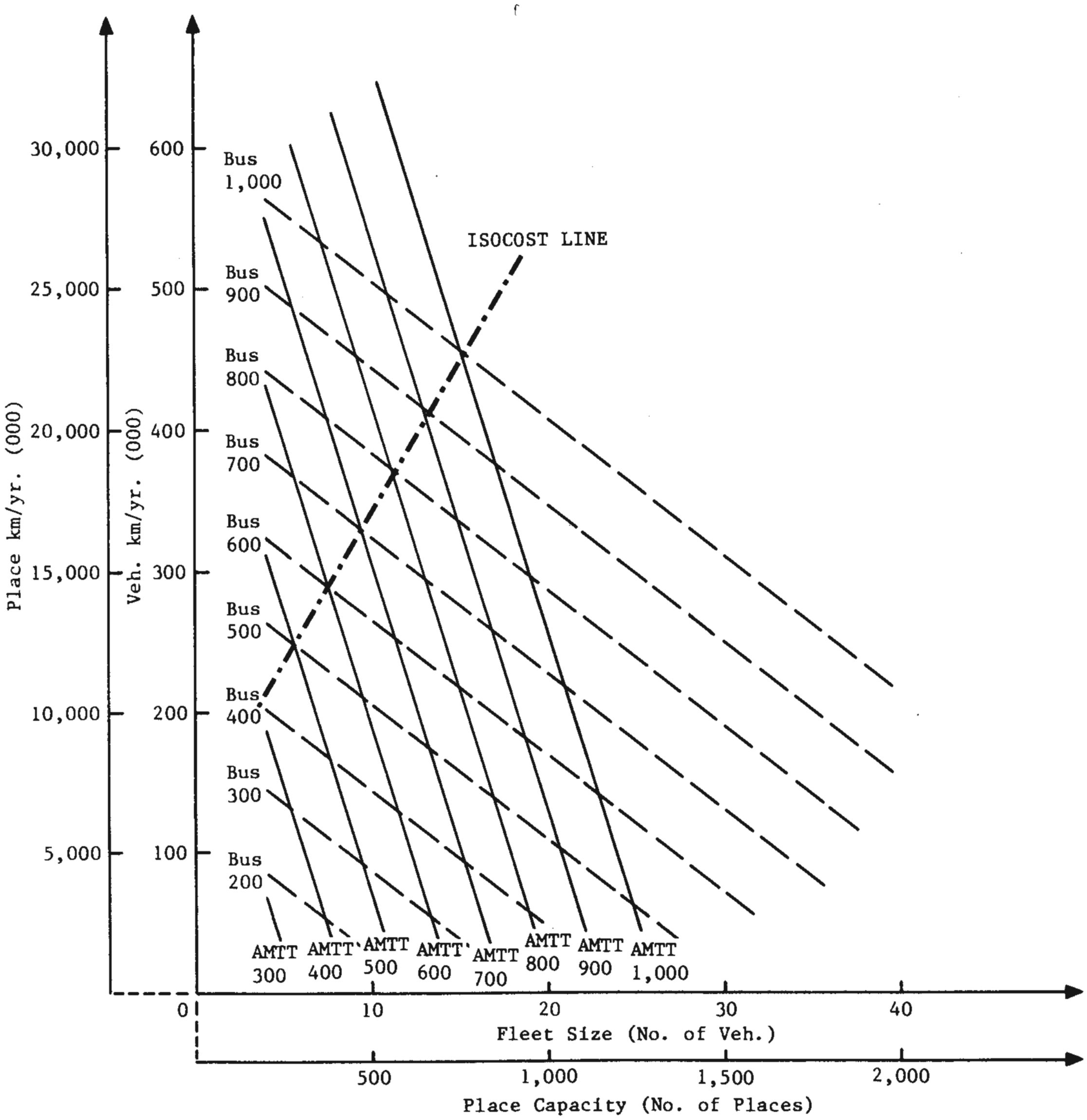

FIGURE 3.3.D EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) —LARGE VEHICLES, 30 KM ROUTE LENGTH.

The horizontal axes on these diagrams indicate the fleet size in terms of number of vehicles and the total place capacity provided by the system expressed in number of places. The vertical axes indicate total vehicles kilometers and total place kilometers operated per year.

3.3 Isocost Lines

Isocost lines between the AMTT and conventional bus transit modes can be drawn from the families of equal cost lines developed previously. This is done by connecting the intersecting points of AMTT and bus equal cost lines having the same annualized total cost values. Isocost lines are shown on each chart from Figure 3.1 through 3.3.

Combinations of fleet size and annual vehicle kilometers indicated by points on the isocost line give AMTT and conventional bus systems that cost the same to own and operate. In the area above the isocost line, AMTT is less costly than bus. Below the isocost line, conventional bus is less costly than AMTT.

3.4 Major Characteristics and Uses of Equal Cost Lines and Isocost Lines

3.4.1 Equal Cost Lines

The equal cost lines for the AMTT mode generally have steeper slopes than those of the conventional bus. Two major reasons are that the AMTT has a higher vehicle cost and a lower O&M cost per vehicle kilometer than the bus. As the fleet size increases, the annualized total cost increases much faster for the AMTT than for the bus because of AMTT's higher unit vehicle cost. As the annual vehicle kilometers increase along the vertical axis, on the other hand, the annualized total cost for bus increases much faster than that for AMTT because bus has a higher unit O&M cost than AMTT.

Within the same vehicle size, the equal cost lines for the bus mode remain constant as the route length changes because there is no guideway cost for the conventional bus. For the AMTT, however, the equal cost lines move to the lower left hand corner as the route length increases because of higher fixed guidepath cost.

As the vehicle size increases, the slopes of all equal cost lines for both AMTT and bus become steeper. This is because of the higher vehicle costs per unit for larger vehicles.

The individual equal cost line diagrams can be used by a transportation planner or a transit operator in planning a new transit system or in evaluating the possible deployment of a new AMTT system. With specific information on the level of service to be provided, vehicle size desired, and system route length, the fleet size needed, and annual vehicle kilometers to be operated, can be determined. The specific system on the appropriate equal cost line chart can be plotted. The annualized total cost of the AMTT or the bus mode can be determined and the less costly mode can be selected. With these sets of equal cost line charts, planning parameters, as mentioned above, of a system can easily be changed to select the more cost-competitive conditions. Similar charts can be developed between AMTT and other appropriate alternative modes.

3.4.2 Isocost Lines

The isocost line displaces to the upper left hand corner as the route length increases within a specific vehicle size (Figure 3.4.a through 3.4.c). Increased route length, thus, reduces the domain where the AMTT is less costly than bus. This is because longer route length increases the fixed cost of the AMTT and makes the AMTT relatively less attractive when compared with the conventional bus which does not require any guidepath.

The slope of the isocost cost lines also becomes steeper as the vehicle size increases (Figure 3.5). The reason is that larger vehicles have higher unit cost and in order for the AMTT to have the same annualized total cost as the bus, more vehicle kilometers must be operated per year. The area where AMTT is less costly than bus (AMTT zone to the upper left hand side of the isocost line) for small vehicles is greater than that for larger vehicles. When annualized total cost scales are indicated on these isocost lines (as shown in Figure 3.5), it can be seen that the annualized total cost increases faster along the isocost line for large vehicles than on the ones for smaller vehicles.

Isocost lines can also be developed between the AMTT and other alternative modes. These lines can be used in two types of analysis. The first type is in evaluating individual transit systems to determine whether the AMTT is less costly than other alternative modes. This is done by plotting the specific transit system on the appropriate diagram. If the system falls in the AMTT zone, i.e., on the upper left hand side of the isocost line, AMTT could be less costly for the system than its

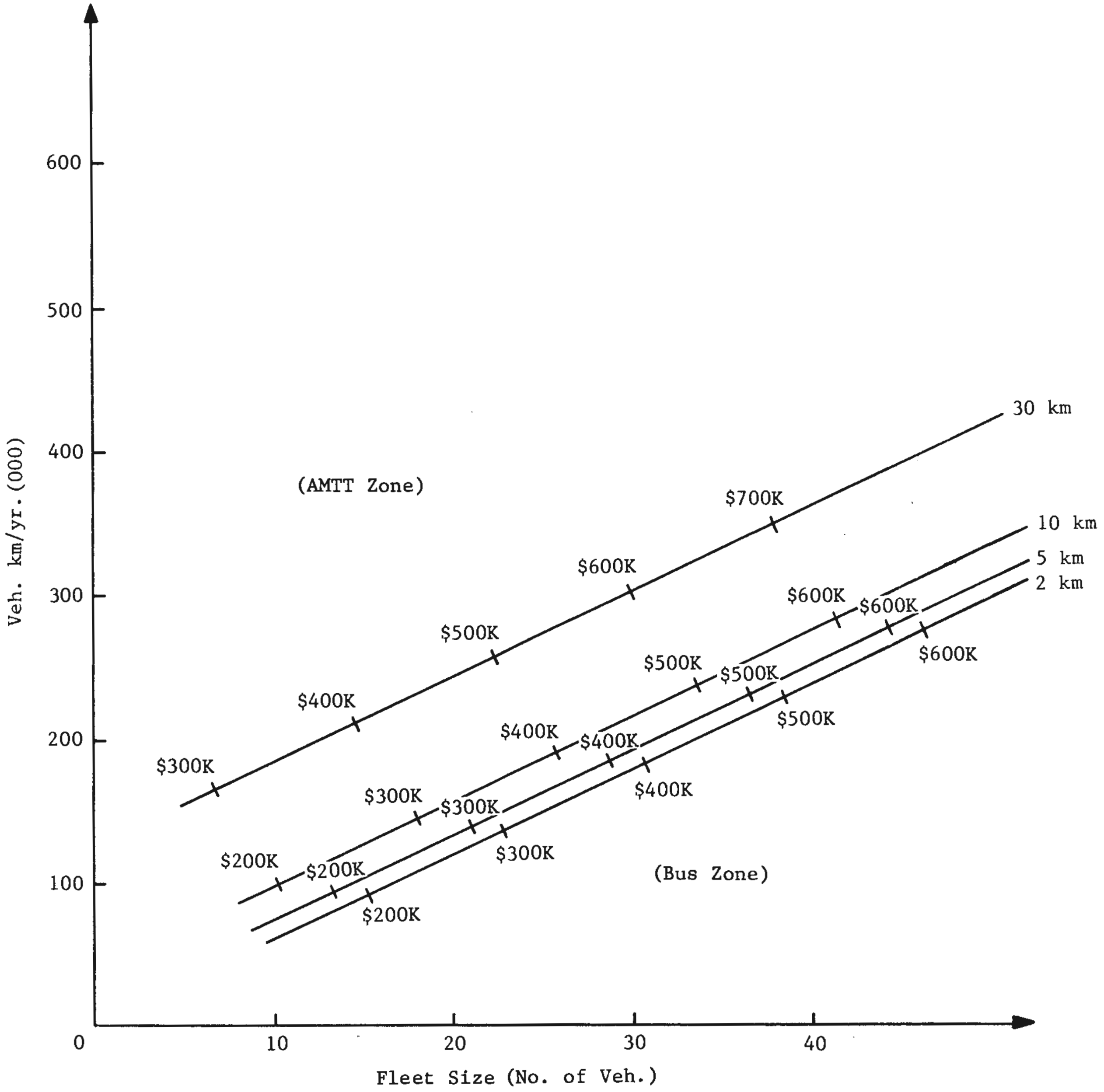

FIGURE 3.4.A ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (SMALL-SIZED VEHICLES).

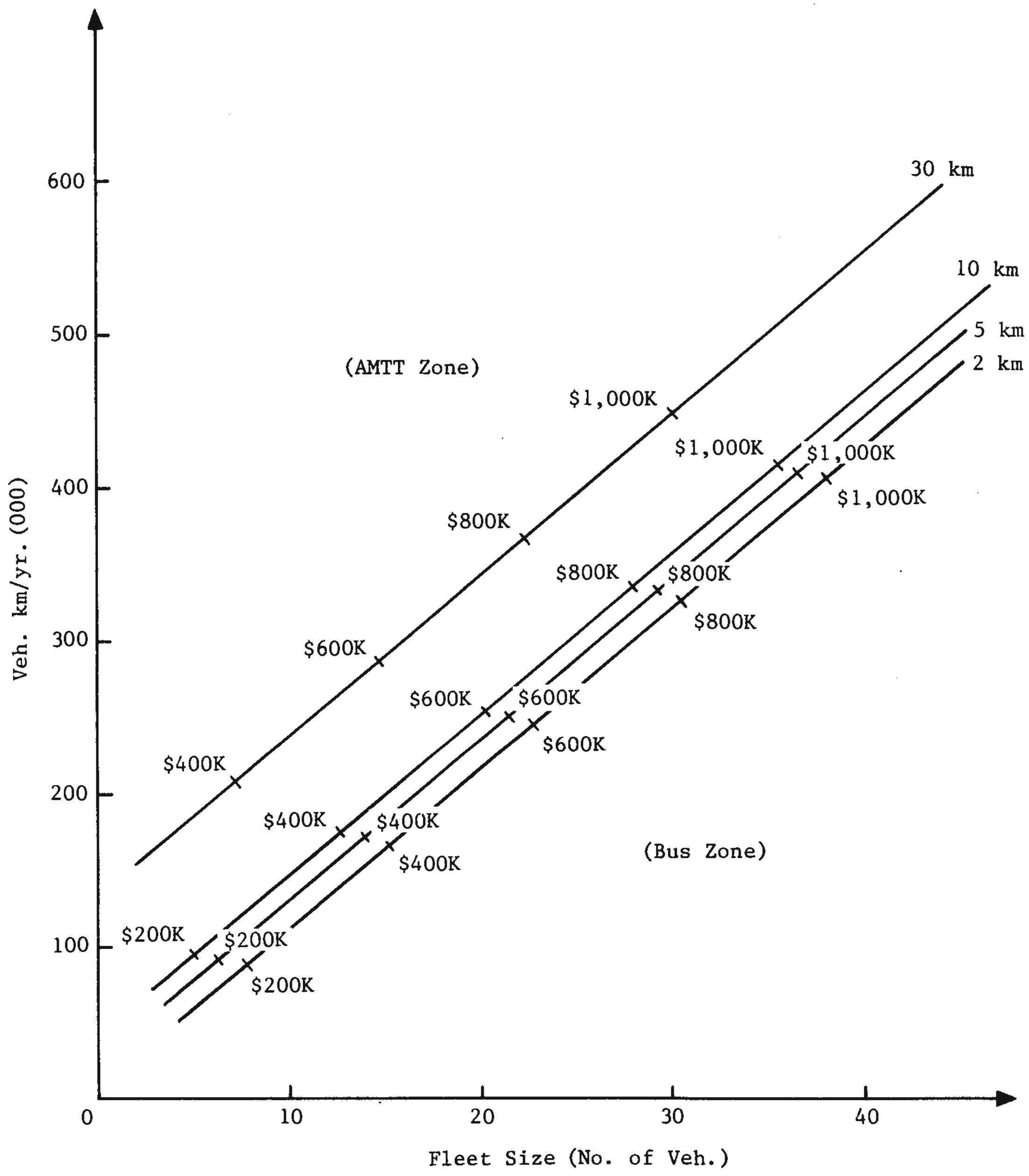

FIGURE 3.4.B ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (MEDIUM-SIZED VEHICLES).

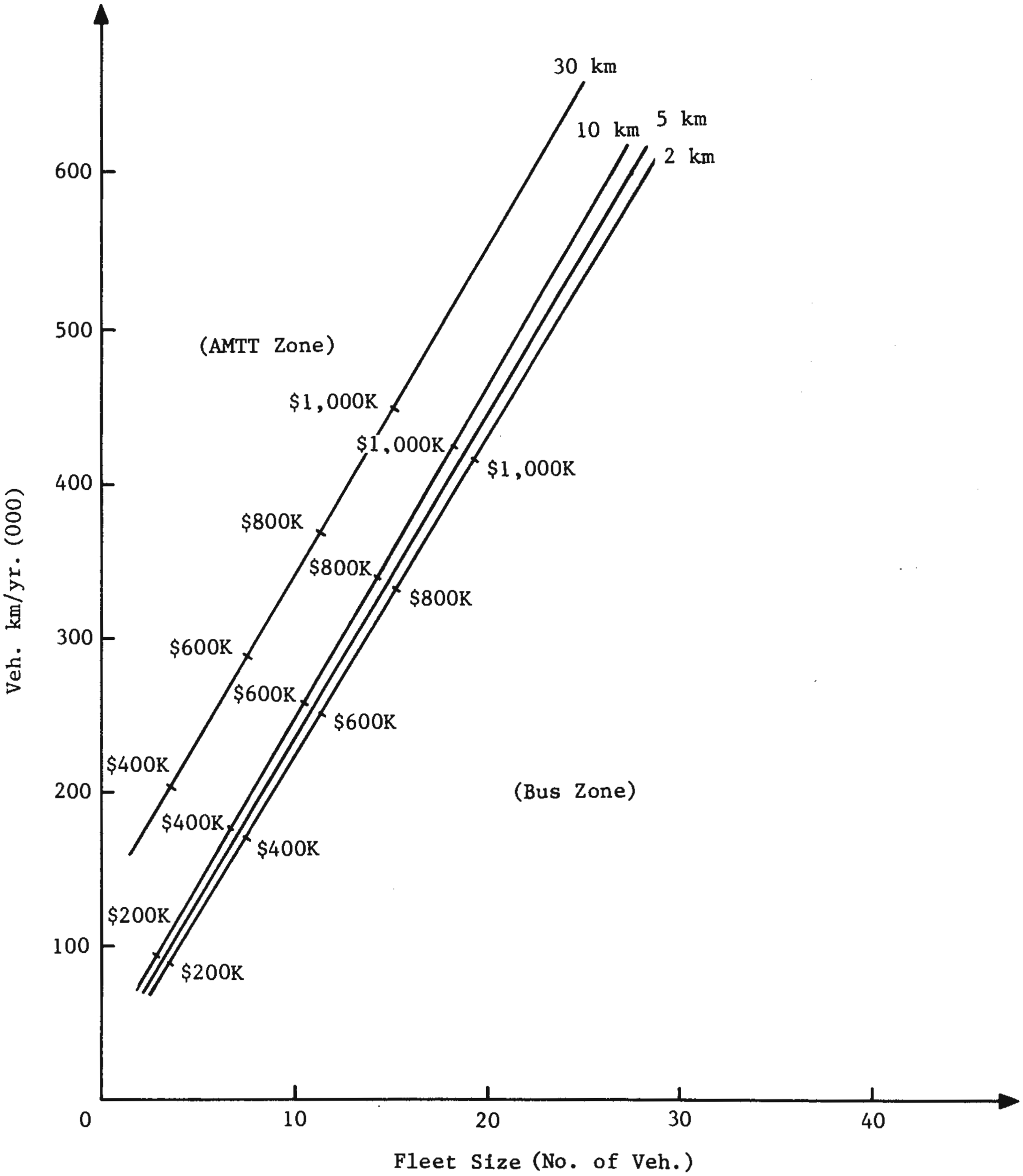

FIGURE 3.4.C ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (LARGE-SIZED VEHICLES).

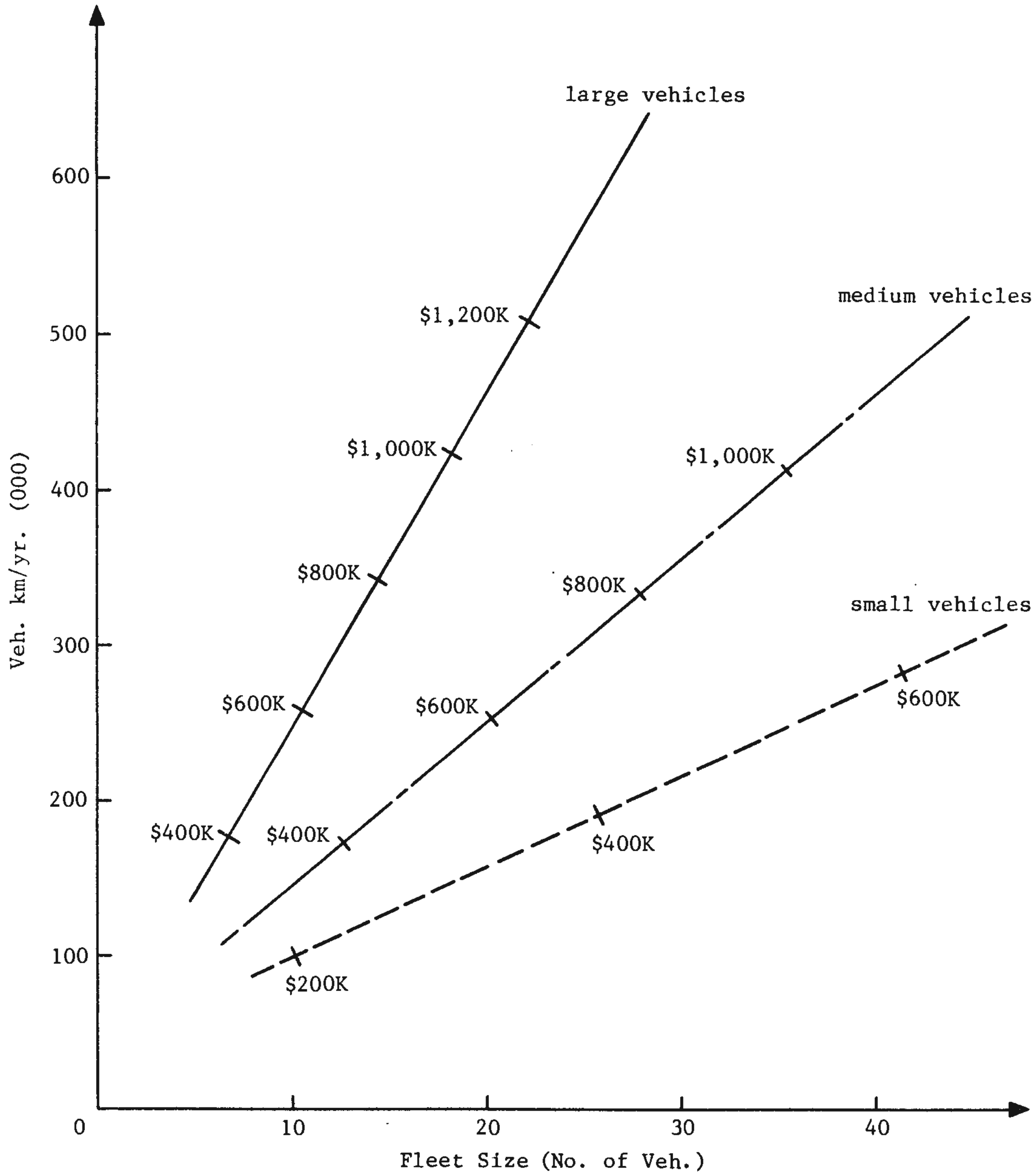

FIGURE 3.5 ISOCOST LINES SHOWING THE EFFECTS OF DIFFERENT VEHICLE SIZES—10 KM ROUTE LENGTH.

competing modes. The degree to which the AMTT is less costly than the alternative mode can also be determined if additional lines are drawn parallel to the isocost lines to indicate the magnitude of the difference in the annualized total cost. Figure 3.6 gives such an example. Transit system A operates on a 2 km. route with 20 medium-sixed vehicles. Total vehicle kilometers operated per year is approximately 375,000. It can be determined that the AMTT mode would have total annual costs approximately $130,000 less than the bus alternative.

The second way to use the isocost lines is for a planner to try different system parameters in selecting the less costly mode before making decisions. Depending on the specific application, different values of the parameters such as route length, vehicle size, frequency of service, hours of operation, and fleet size can be tested to determine whether the AMTT is the less costly mode on a total annual cost basis. Alternatively, ranges of the above mentioned parameters could be developed. These would then be used along with appropriate isocost lines to find out if the AMTT might be a more cost-effective mode than others.

As a result of ongoing sensor development, AMTT is expected to operate in the future in mixed traffic without any physical side barriers for protection. This will reduce the capital cost of AMTT. The amount of this cost reduction and its impact on the parametric analysis are greater for systems with longer route lengths. Appendix E gives a brief discussion of the parametric analysis assuming a long-term AMTT with vehicle capital and O&M costs previously presented but without the capital cost of side barriers.

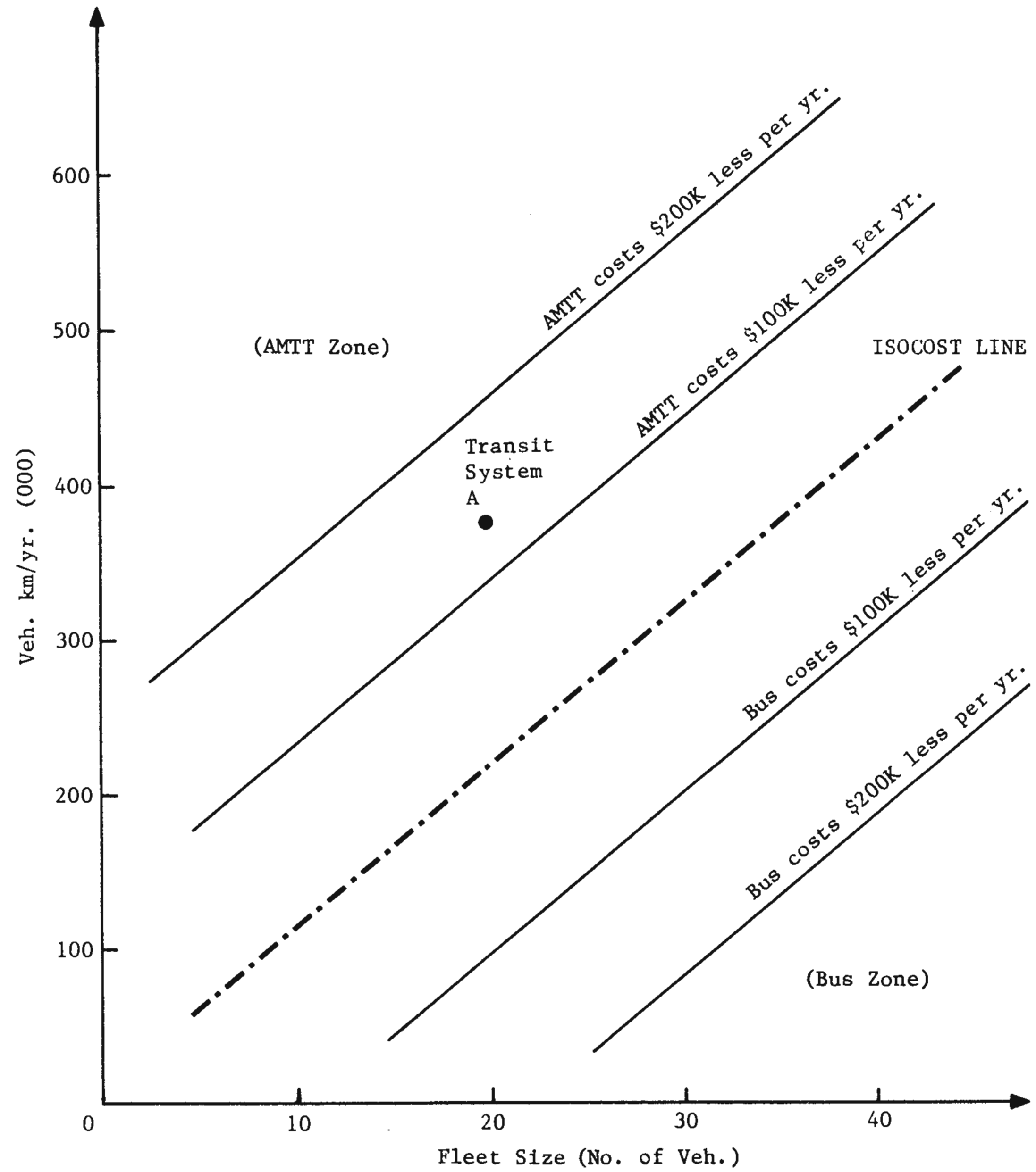

FIGURE 3.6 ISOCOST LINE WITH SCALE ADDED —MEDIUM VEHICLES, 2 KM ROUTE LENGTH.

4. APPLICATION AREAS: CASE STUDIES

As discussed in previous chapters, AMTT has characteristics which could allow it to supplement or even supplant conventional modes of travel for certain applications. In fact, AMTT vehicles may have potential applications in many types of urban and some rural settings. These include university and college campuses, adult and retirement communities, CBDs, shopping centers, air terminals, medical centers, and recreation centers.

In order to analyze the market potential for AMTT, it is useful first to investigate potential application areas in detail to assess AMTT's suitability. Accordingly, the following case studies examine a number of potential AMTT sites to indicate the expected operating conditions of deployed systems.

4.1 Universities and Colleges--the Berkeley Case

Universities and colleges often have large areas where automobiles are restricted or could be restricted if there were an adequate internal circulation system (e.g., AMTT). Campuses that require walking distances of less than about 300 meters (1,000 feet) have little need for modes of transportation other than walking and bicycle, except for handicapped individuals. However, there are a number of large campuses in the country where walking distances among buildings and residences are excessive and pose difficulties. Such a campus is the University of California at Berkeley, which is described below.*

The campus of the University of California at Berkeley is located on a slope at the foot of hills near downtown Berkeley, a city of 111,000. The campus is spread out on almost 6 $km.^2$ of land (over 2 square miles--about 1,500 acres). Most of the main university classroom and library buildings, however, occupy less than 1 $km.^2$ (178 acres). The campus (see Figure 4.1) contains a large stadium, a theater, botanical gardens, Hall of Science, and other facilities that are open to the public. There are at present about 30,000 students enrolled at this campus, plus a large staff and many visitors.

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*The information presented in this case is based for the most part on an interview with Mr. Ken Taylor, Manager of Shuttle Services.

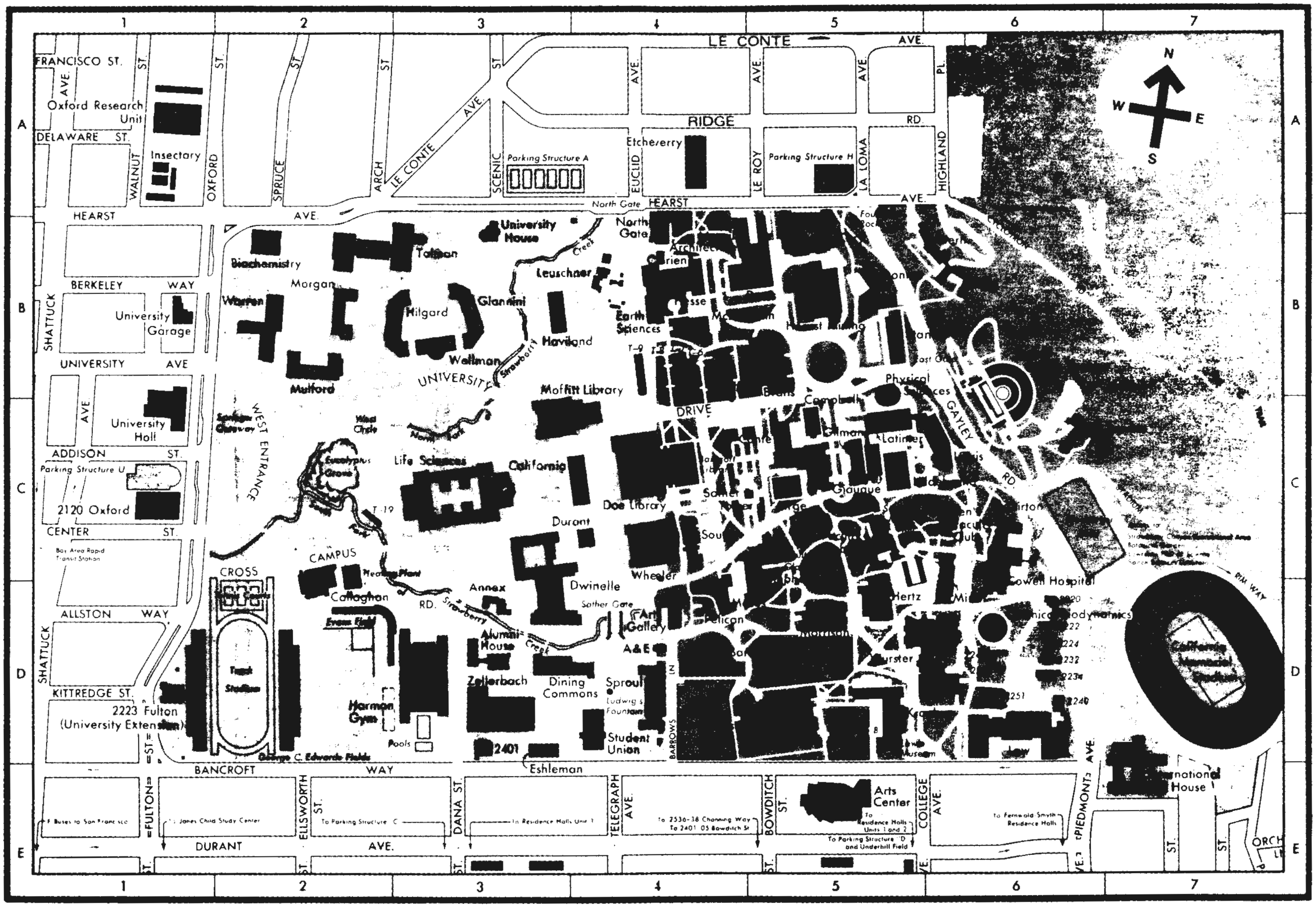

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FIGURE 4.1. CAMPUS MAP—UNIVERSITY OF CALIFORNIA, BERKELEY

4.1.1 Existing Transportation System Characteristics

Automobiles and parking are restricted on the main campus. Only authorized visitors and personnel may enter the main campus by automobile and no through traffic is allowed except for emergency, service, and transit vehicles. Parking is restricted and costly. The west entrance to the campus is two blocks from a BART station. BART is the 114-km. (71-mile) heavy-rail transit system that serves parts of three counties in the San Francisco Bay Area.

At present, a bus service runs between the BART rapid transit station and various locations on campus. There are four routes. Two provide service in the daytime only--the local and "express," and two provide nighttime service--BART/Stern Hall and Southside/Campanile. The system has a total route length of 12.5 single lane kilometers (7.8 miles) and a fleet of six buses. Produced by Mercedes-Benz, each bus carries 19 passengers seated and 6 standees for a total capacity of 26 passengers. Five buses are employed in peak hours, three in nonpeak hours, and one is kept in maintenance or on reserve.

The bus service is free. Service is provided Monday through Friday during the day and evening and on Sunday evening. Service is not provided on Saturdays, on administrative holidays, or during the day on Sunday.

Local service is provided from 7 A.M. to 6:45 P.M. During the peak hours (7:30-9:30 A.M., 11 A.M.-12:30 P.M., and 3:30-5:30 P.M.) buses on this route are scheduled to depart every 5 minutes. Headways are increased to 7 minutes at nonpeak times. Express service is provided from 7 A.M. to 7 P.M. Headways for express buses are 15 minutes during peak hours and 30 minutes at nonpeak times. The two nighttime service routes operate at 10 and 15-minute headways.

The buses carry between 3,500 and 4,500 passengers daily, with an average of about 3,800. During peak hours, buses are filled to capacity, with the result that many potential passengers are forced to walk. The night service from the dormitories carries about 300 passengers in an evening. The six buses traveled approximately 212,400 km. (132,000 miles) during the year.

4.1.2 Economic Analysis

To help evaluate the potential of AMTT vis-a-vis conventional bus service at a university like Berkeley, an economic comparison is made. To acquire results that are more easily generalizable to other colleges, standardized bus costs from previous chapters are used, not the ones peculiar to the Berkeley environment. Equal cost lines showing the annualized total cost for systems using medium-sized vehicles with 12.5 km. route length are developed and shown in Figure 4.2.

Thus, consider a university bus transit system similar to the one at U.C. Berkeley with a fleet of six medium-sized buses and a total route of 12.5 kilometers. If the system is operated a total of 212,400 vehicle kilometers a year, the annualized total cost can be determined to be approximately $400,000 from Figure 4.2.

Alternatively, an AMTT system could be deployed at a university such as U.C. Berkeley to provide similar service as the existing bus transit system with six medium-sized vehicles and a total route length of 12.5 kilometers. For deployment in the immediate future, the AMTT would require barriers along its guidepaths. If the hours of operation were kept the same to provide the same level of service, i.e., if the AMTT were also operated a total of 212,400 vehicle kilometers per year, the annualized total cost of the AMTT system would be approximately $320,000. Thus, using the results of the parametric analysis, an equivalent AMTT system would cost approximately $80,000 less than a conventional bus system in terms of annualized total cost.

4.2 Adult and Retirement Communities--the Rossmoor Case

Adult and retirement communities also hold possibilities for the use of AMTTs. These communities typically have elderly residents, many of whom prefer not to drive automobiles or are unable to do so. Yet most residents are far from inactive and have requirements for getting to shopping centers. Some have extensive golf and recreation facilities and residents use golf carts for internal trips. The case study presented discusses the Rossmoor community in the San Francisco Bay Area.*

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*Most of the information is based on interviews with Mr. John A. Gordon, Administrative Supervisor, Golden Rain Foundation.

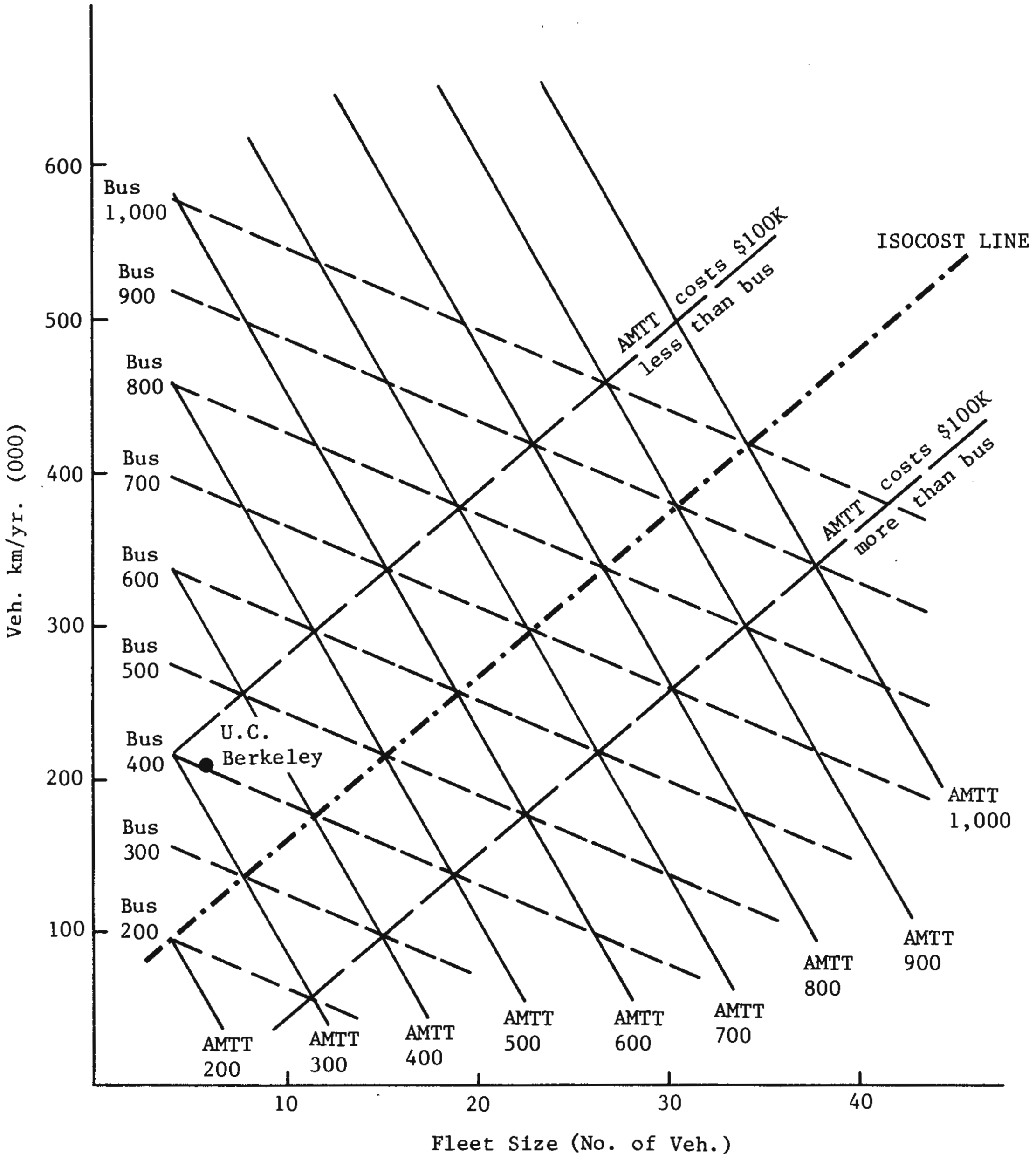


FIGURE 4.2 EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST IN THOUSANDS OF 1979 $ FOR MEDIUM VEHICLES AND 12.5 KM ROUTE LENGTH.

Rossmoor is an adult community 3.2 km. from downtown Walnut Creek, California, and 42 km. northeast of San Francisco. It contains 900 acres (1.4 square miles--3.6 $km.^2$) of valley and surrounding hills, about one-third of which is kept in its natural state. Residences are all in multiple-dwelling units that are located in the rather long, narrow valley and on the lower slopes of the hills.

There are currently about 5,100 homes, which contain about 9,000 residents. About 200 new homes are added each year. The complex of buildings extends for about 1.6 kilometers (1 mile), but because of the curving nature of the road system, several kilometers of street are included (see Figure 4.3). The complex contains, in addition to the residences, four club houses, two swimming pools, a golf course, and other recreational amenities.

4.2.1 Existing Transportation System Characteristics

Automobile ownership by older citizens is generally low, but at Rossmoor 88.7% of the households had at least one automobile in 1970. The median household income of the residents in 1970 was $10,095--15% above the $8,800 median income for the entire San Francisco-Oakland standard metropolitan statistical area (SMSA). The average household contained 1.65 persons. Seventy-four percent of all households had only one automobile.(21)

All residents are members of the Golden Rain Foundation which is responsible for the management and operation of the community facilities and services, including the bus system. It is headed by a Board of Directors, who are residents elected by their neighbors. Transit service was planned as an integral part of Rossmoor. Service was originally provided by a transit company, but the firm went out of business in the latter part of 1968. The Foundation bought the buses early in 1969 and has funded and operated the service to the present.

The bus service reaches every address in the tract. There are five loop routes each served by one bus. Four buses provide service within the complex and to the shopping center and medical clinic just outside the gate. Each of the four buses serves a different area within the complex, but there is some overlap. The routes cover every street in the complex. Routes are modified for Saturday service when only two buses are used within Rossmoor. The fifth bus provides service from the shopping center to the BART rail rapid transit station in Walnut Creek and to various locations in downtown Walnut Creek.

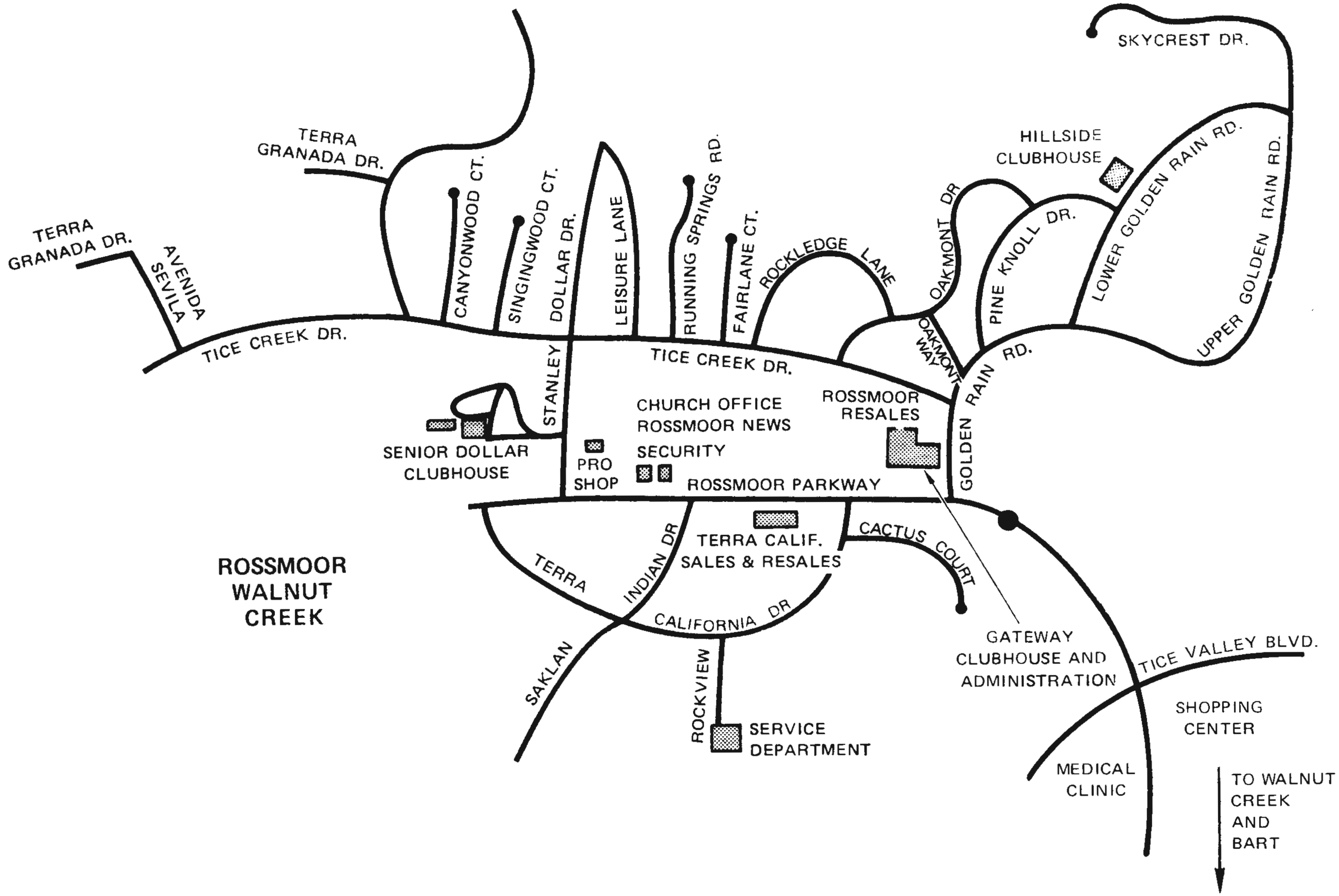


FIGURE 4.3. ROSSMOOR, WALNUT CREEK, CALIFORNIA

Length of the routes within the complex vary. The round-trip loop lengths are 8.1 km. (5.0 miles), 8.9 km. (5.5 miles), 12.9 km. (8.0 miles), and 19.5 km. (12.1 miles). The route from the shopping center to BART and downtown Walnut Creek is 12.9 km. for the round trip. Within the complex, average speeds including stops are 10.6, 11.7, 17.1 and 25.9 km/hr (6.6, 7.3, 10.6 and 16.1 mph), depending on characteristics of the routes. Average speed on the 12.9 km. (8-mile) Walnut Creek route is 17.1 km/hr (10.6 mph), including stops.

The Foundation now owns six buses: four seat 19 passengers, one seats 28, and one seats 24. They have ordered two buses that will seat 30 passengers each. This purchase will provide more than one backup bus and will mark the beginning of a replacement program for the 19-passenger buses. At present, none of the buses are especially equipped for wheelchair accessibility.

Three types of bus services are provided: scheduled service, dial-a-ride, and commuter service. Regularly scheduled service begins between 8 A.M. and 9 A.M. and terminates about 5 P.M. It is provided every 45 minutes on weekdays and once an hour on Saturdays. There are bus stops equipped with benches, but passengers may be picked up or discharged at their homes or anywhere along routes within the complex. Dial-a-ride service is provided on weekdays between 7 A.M. and 8 A.M., as well as between 6:45 P.M. and 9:45 P.M., on Saturdays between 7 P.M. and 9:45 P.M., and on Sundays from 8:45 A.M. to 10 P.M. Most dial-a-ride origins and destinations are within the complex, but they may also go to the BART station or downtown Walnut Creek. Commuter service is provided on weekdays from 6 A.M. to 7 A.M. and from 5:30 P.M. to 6:30 P.M. between the complex and BART. This is similar to subscription bus service in the sense that the workers phone for pick-up at their residences. They need only phone once to receive continuing service. The bus goes from the residences directly to the BART station. In 1976, the system operated about 160,900 kilometers (100,000 miles).

4.2.2 Economic Analysis

An economic comparison of AMTT with a conventional bus system at Rossmoor can give some insights into AMTT's applicability to adult retirement communities in general. As in the analysis for colleges and universities, standardized bus costs are used.

Consider a conventional bus transit system and an equivalent AMTT with a total round trip length of 62.1 km. (38.6 miles) and six medium-sized vehicles to serve the Rossmoor Community. Both systems would have the same route configuration, but only AMTT would have a guidepath and barriers. To provide similar service as the existing buses, the system would be operated a total of 160,900 vehicle kilometers (100,000 vehicle miles) per year. Using the results of the parametric analysis, it can be determined that conventional bus transit service at Rossmoor would cost approximately $140,000 less than AMTT service, in terms of annualized total cost (Figure 4.4).

This is a typical example of providing transit service to a relatively large community with low population density. The combination of low frequency of service and high accessiblity to the system result in low annual vehicle kilometers operated and long route length. Conventional bus is likely to be less costly overall than modes that require construction of fixed guideways even though it may cost more to operate.

4.3 Central Business Districts (CBDs)

With the recent popularity of downtown pedestrian and transit-pedestrian malls and the Environmental Protection Agency's requirements for reduction of air pollutants, CBDs having auto restricted zones are likely to increase considerably in number and size, with a concomitant requirement for better public transit. This presents possibilities for the use of AMTTs. The case study chosen is the CBD of Denver, Colorado where a transit pedestrian mall is being planned.

Planning is in progress for the development of a transit-pedestrian mall and other transportation and pedestrian improvements in the Denver CBD. The district is bounded by Broadway and Colfax Avenue on the east and south respectively. The Civic Center and State Capitol are located just outside the intersection of these two streets. On the west, the area's boundary is Cherry Creek; the north is bounded by the South Platte River and 20th Street (see Figure 4.5).

Like most CBDs, the area contains a number of major traffic generators: retail stores, a federal government complex on its northeast boundary, the University of Colorado Extension Division, the Denver Center for the Performing Arts, the Municipal Auditorium, Currigan Exhibition Hall, the Convention and Visitors Bureau, several hotels located near the Civic Center, and numerous large office buildings.

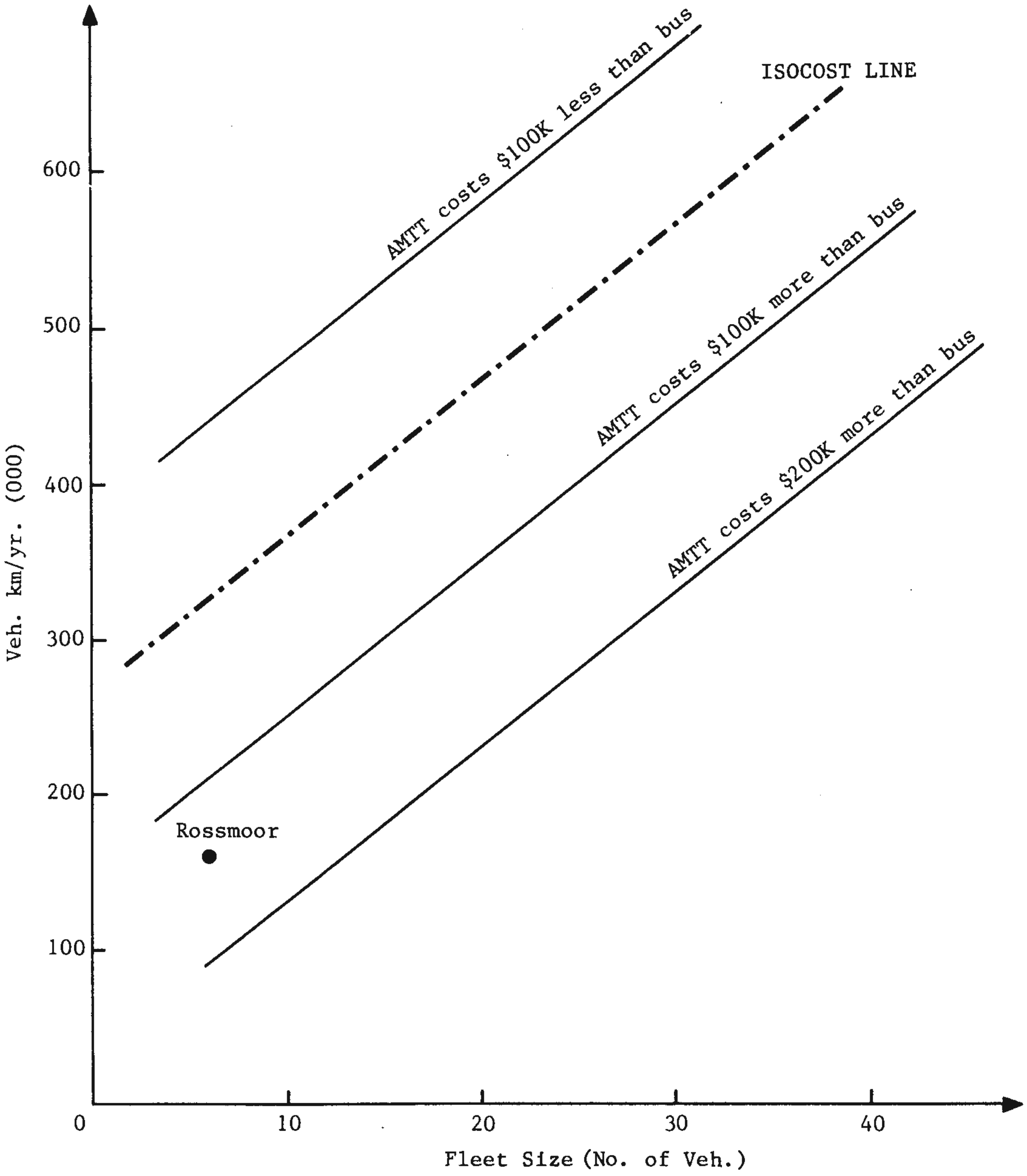
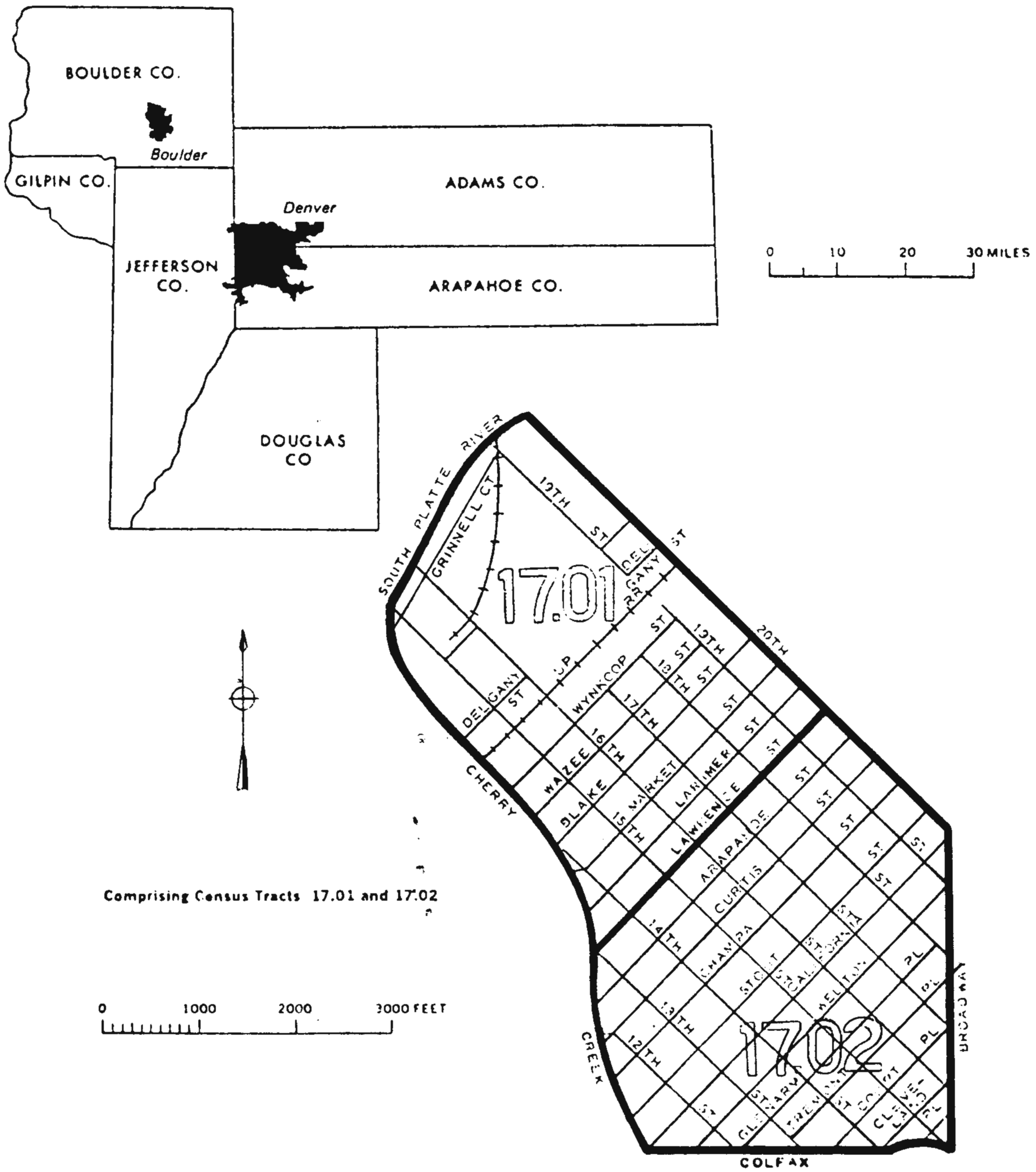


FIGURE 4.4 ISOCOST LINE FOR MEDIUM VEHICLES AND 60 KM ROUTE LENGTH.



DENVER-BOULDER, COLO.
Standard Metropolitan Statistical Area
and Central Business District

FIGURE 4.5. **THE DENVER CENTRAL BUSINESS DISTRICT**

A number of improvements are planned including:

a. conversion of 11-13 blocks of a city street to a pedestrian-transit mall,

b. conversion of about nine blocks of city street to pedestrian malls,

c. adjustment of automobile traffic flow near the mall, and

d. development of transfer facilities between the mall transit system and the urban and regional bus systems.

These developments lie mainly in the southeast half of the CBD--in Census tract 17.02.

4.3.1 Existing Transportation System Characteristics

Since a pedestrian mall for Denver is still in the planning stages, there is no existing mall circulation system. A system has, however, been proposed for the Denver CBD mall.(22,23) In this design, there would be a landscaped area 6.7 meters wide down the middle of the street (already under construction), a 3-meter (10-foot) wide transit way on either side of the landscaped area, and 5.8-meter (19-foot) sidewalks. Automobiles and almost all truck traffic would be prohibited on the mall. With minor exceptions, delivery of goods would be made from alleys and cross streets. Emergency vehicles would be accommodated and cross streets kept open. Regional and local buses would not pass through the mall, but would be routed to the ends of the transit-pedestrian mall and to 15th Street. Passengers would transfer between conventional buses and mall vehicles at new stations to be built for that purpose.

The proposed mall transit system would employ a fleet of 32 manually driven, rubber-tired, electric-powered vehicles. The proposed vehicles would be a new design, with a capacity for 44 persons and two wheelchair passengers. Mall stops and terminals will have platforms at the same level as the vehicle floor. Vehicles will have large glass areas to provide passengers with views of the mall and to minimize the visual impact of the vehicle on the mall.

The vehicles would operate in the designated lanes, with regular passenger stops at every block. Proposed headways are 70 seconds. This corresponds to the interval used by the traffic signaling system in the downtown area. Maximum speed of the vehicles would be 24 km/hr (15 mph), but average speeds would be 11.2 km/hr (7 mph). A round trip would take 15 minutes for the 1.4 km. (0.9 mi.) route. Finally, the route capacity would be 5,000 passengers per hour in each direction.

4.3.2 Economic Analysis

The potential for AMTT to act as a CBD mall circulation system depends partly on economic considerations. While an economic comparison of AMTT with the planned mall transit system would be desirable, the absence of cost data for the planned system makes such a comparison infeasible. Thus, for the purpose of establishing a benchmark, a conventional bus alternative is postulated.

Consider the comparison of a bus and an AMTT system of 32 large vehicles with service characteristics equivalent to those of the planned mall transit system. The AMTT requires the construction of 2.8 km. of guidepath and barriers. Both systems are operated 443,000 vehicle kilometers per year to provide the desired level of service. Using standardized costs for bus and the techniques developed in the previous chapter, the system can be shown in Figure 4.6. It can be determined that AMTT would cost approximately $200,000 more a year than bus in terms of annualized total cost.

4.4 Airports

Large airports require the movement of people between parking lots and terminals, among terminals, and from central terminals to gates. These usually involve long walking distances, compounded by the difficulties of carrying luggage or small children, unless relieved through the provision of some type of transportation system. Airports have chosen a variety of transportation modes to assist passengers. They include pedestrian conveyors used within terminals and parking garages, buses used from parking lots to terminals or among terminals, and AGT systems, usually used to connect terminals. The Detroit Metropolitan Wayne County Airport and the Washington National Airport, presented below as case studies, are considered as two of many possible airports that could be candidates for AMTTs.

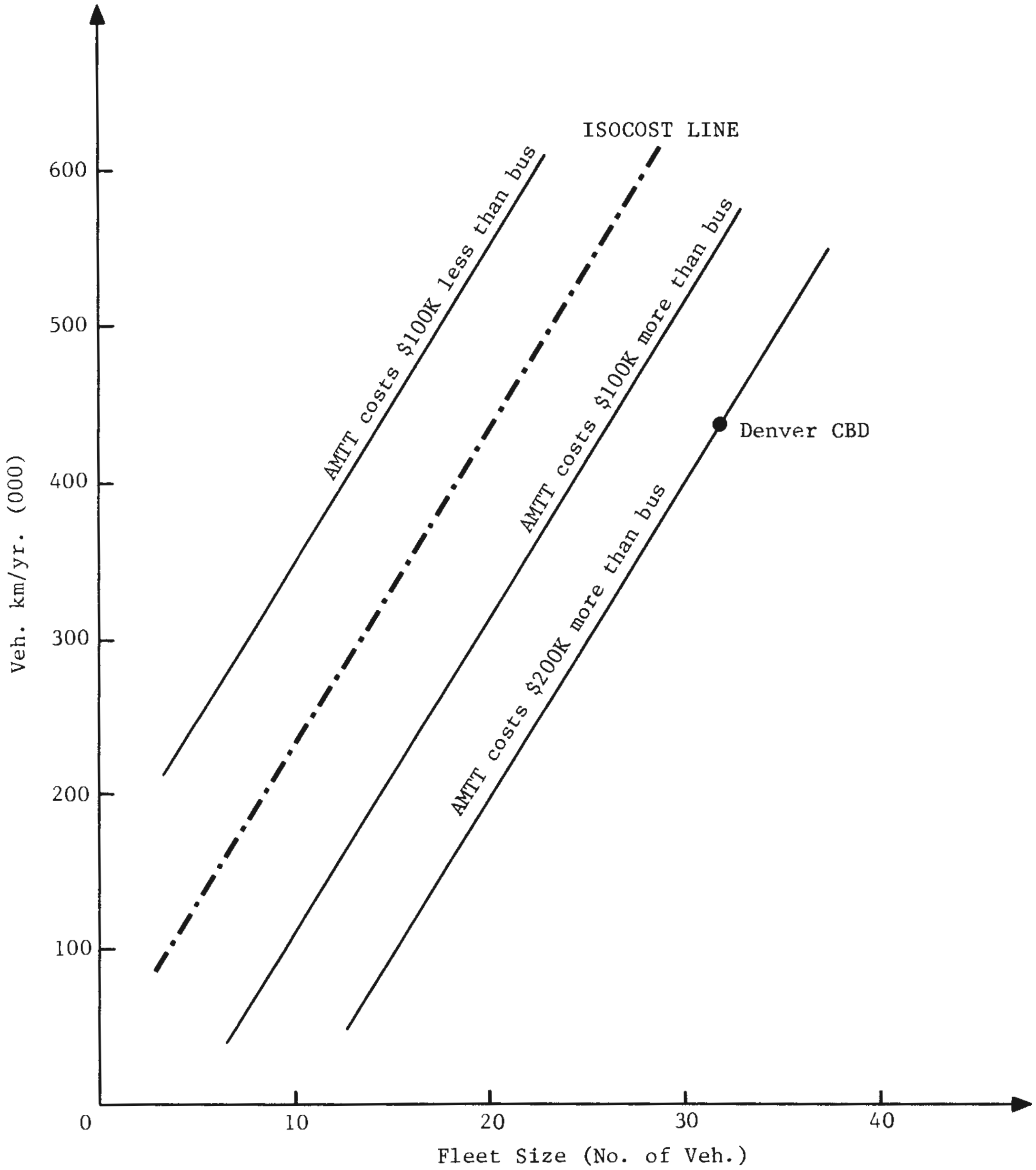


FIGURE 4.6 ISOCOST LINE FOR LARGE VEHICLES AND 2.8 KM ROUTE LENGTH.

4.4.1 Wayne County Airport

The Detroit Metropolitan Wayne County Airport is located on more than 20 $km.^2$ (5,000 acres) of land about 40 km. (25 miles) southwest of Detroit. Like most large airports, it is expanding. The north terminal complex was the first at the site. It now includes a hotel. An international terminal was added recently, and plans are for a south terminal complex to be added later.

Parking at the north terminal complex is provided in a three-deck garage (5,000 cars) and open lot parking (1,100 cars). Parking at the international terminal is in an open lot directly across from the terminal (600 cars).

The Wayne County Airport has contracted with a private firm to provide transportation services within the airport complex. There are two routes, each about 4.4 km. (2.7-2.8 miles) long. One route is served by vans and includes a loop around the north terminal complex. The other route is served by minibuses. It makes a loop around the north terminal complex, the adjacent open lot, and the international terminal. Service is provided free of charge 24 hours per day. Trip time is 12 minutes for each route at average speeds of about 22.4 km/hr (14 mph). Headways are generally every 6 minutes on weekdays between 7 A.M. and 2 P.M., every 4 minutes between 2 P.M. and 10 P.M., and every 12 minutes between 10 P.M. and 7 A.M. Service is increased on Fridays and Sundays between 2 P.M. and 10 P.M. to 3-minute headways. Headways are reduced even further for peak travel periods, which occur for example at Christmas time.

Six vans and five minibuses are employed to provide the service. The vans are Fords, with seating room for seven persons. There is no room for standees. The minibuses are Chevrolet C-20 sport vans. They were modified to raise the height of the roof and to accommodate 12 persons seated around the perimeter of the vehicle and to allow for four to five standees.

The six vans average 62,131 km. (38,832 miles) each year for a total of 372,787 km. (232,992 miles) per year. The five minibuses average 61,490 km. (38,430 miles) per year for a total of 307,440 km. (192,150 miles) per year. The 11 vehicles totaled 680,227 km. (425,142 miles) in a 12-month period.

A comparison of the potential for AMTT vis-a-vis conventional bus service at airports similar to Wayne County Airport can be done using standardized costs for bus. An airport system of eleven small buses operating on a total route length of 8.8 kilometers can be compared with an AMTT system of eleven small vehicles operating on the same routes with guidepath and barriers. If both systems were operated a total of approximately 680,000 vehicle kilometers per year, it can be determined from Figure 4.7 that AMTT would be much less costly than bus in terms of annualized total cost (more than $400,000 less per year).

4.4.2 Washington National Airport*

Washington National Airport is located on the Virgina shore of the Potomac River, approximately 7 kilometers (4.5 miles) from downtown Washington, D.C. The air passenger facilities consist mainly of three air terminals: the Main Terminal, the North Terminal, and the General Aviation/Commuter Terminal. Several short term, long term and employee parking lots are available around the air terminals and other work areas. Two remote satellite parking lots are also available at a greater distance from the terminals.

National Airport is served by the Washington Metro Rapid Rail System. The elevated Metro Station at the airport is located approximately 130 meters from the nearest entrance to the air terminals. Presently, free shuttle bus service is provided by the airport between the air terminals, parking lots, and the Metro Station.

The existing shuttle bus system operates a fleet of 12 medium-sized buses (with seating capacity between 15 and 20 passengers) on three routes totaling approximately 10 kilometers. With an average service headway of 6 minutes, the system is operated a total of approximately 691,000 bus kilometers per year.

Consider an AMTT system and a conventional bus system with 12 medium vehicles each to provide the same service as the existing system. Using the standardized costs for the bus and the results of the parametric analysis, the costs of the AMTT and conventional bus alternatives can be compared. This comparison is shown in Figure 4.8 where it can be determined that AMTT would be a less costly alternative than conventional bus with a difference greater than $400,000 in annualized total cost.

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*Most information comes from: "Automated Mixed Traffic Vehicle Study at Washington National Airport," Cady C. Chung, The MITRE Corporation, November 1979, (NTIS No. PB80-121148).

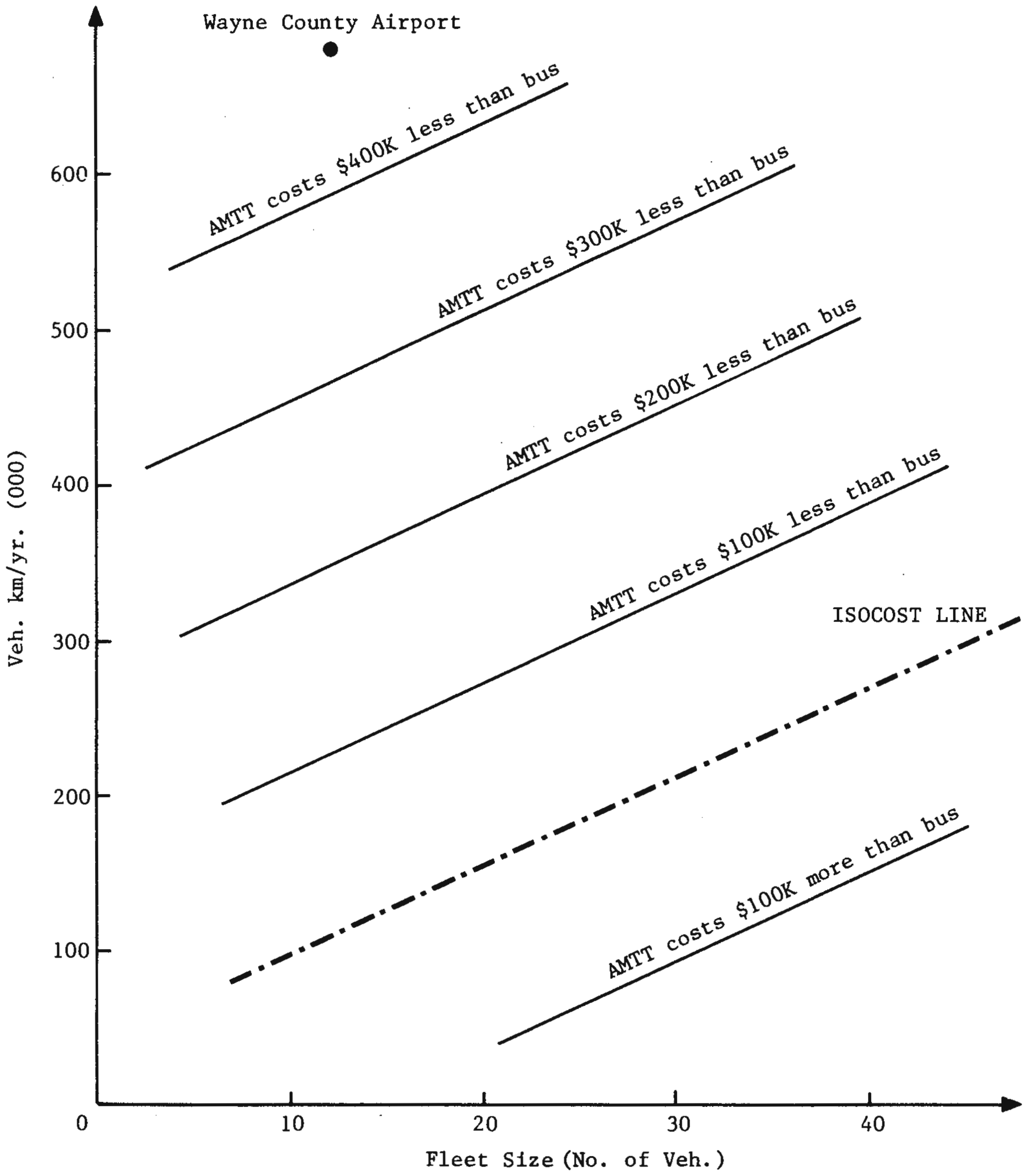


FIGURE 4.7 ISOCOST LINE FOR SMALL VEHICLES AND 9 KM ROUTE LENGTH.

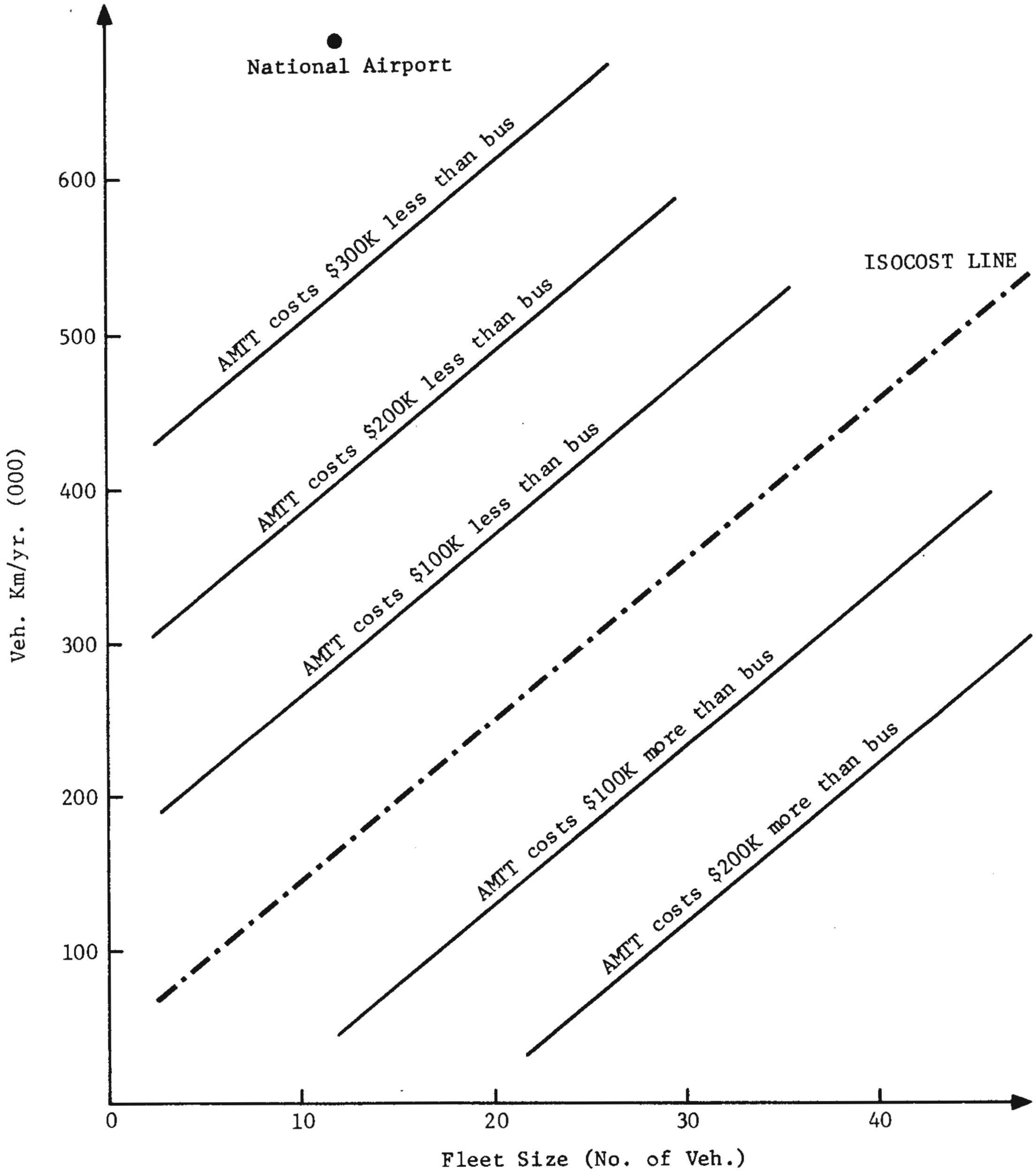


FIGURE 4.8. ISOCOST LINE FOR MEDIUM VEHICLES AND 10 KM ROUTE LENGTH

These two cases illustrate that in applications where a relatively small number of small- to medium-sized vehicles are needed to operate a great number of vehicle kilometers per year, the AMTT can be significantly less costly than the conventional bus.

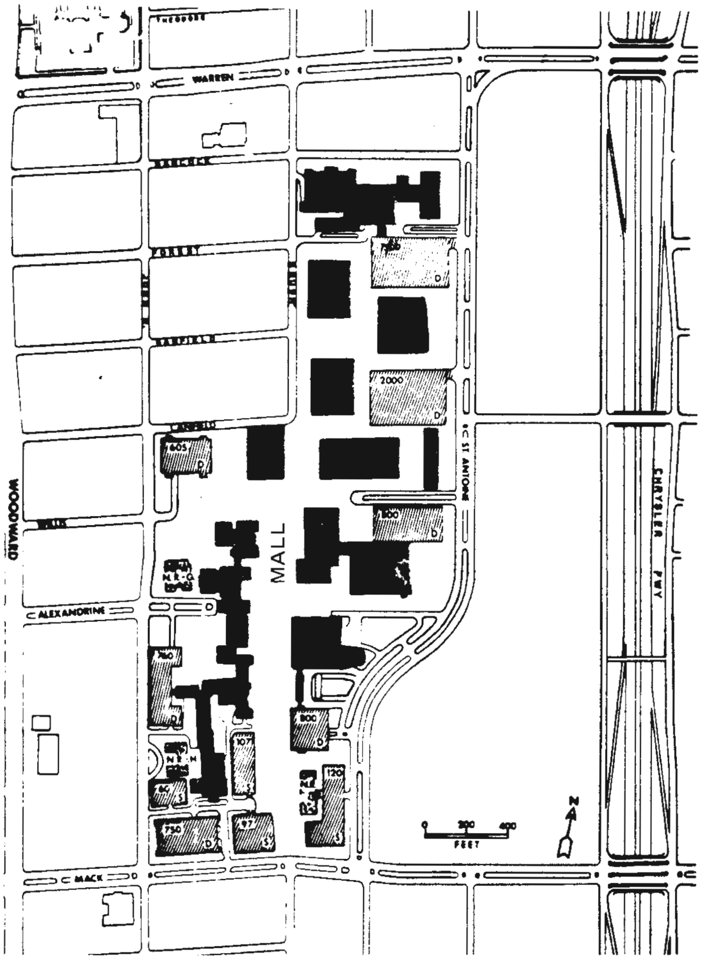
4.5 Medical Centers

Large medical complexes often entail long walking distances among buildings. Because of this, interest has been generated in providing employees, patients, and visitors with some form of transportation assistance. Several of the large medical complexes in the country have considered AGT systems, and one--Duke University Medical Center--has such a system under construction to connect two hospitals. One other large medical complex that considered an AGT system is the Detroit Medical Center presented as a case study below.

The Detroit Medical Center covers 0.4 $km.^2$ (97 acres) in the City of Detroit, about 1.6 kilometers north of the CBD. It is the outgrowth of an urban renewal project. It is the second largest complex in the United States; only the Texas Medical Center in Houston is larger. The Detroit Medical Center has been enlarging since its inception in 1955 and now includes five private hospitals and three major Wayne State University school buildings (library, research, and Scott Hall). Detroit General Hospital is now under construction and will add almost 500 beds to the 2,200-bed complex. The new Wayne State University Clinic, an eight-story building--the tallest in the complex--is also under construction at the present time. As the center has grown, deck parking structures have been constructed to gradually replace surface parking lots. (See Figure 4.9).

The entire complex is about 300 meters (1,000 feet) wide at the southernmost point and extends 600 meters (2,000 feet) to the north. The major north-south street that bisected the medical complex has now been closed to traffic and is to become a mall with landscaping and benches. A two-block long east-west street has also been closed to traffic.

The hospitals employ almost 10,000 employees. Traffic is generated not only by the employees, but also by the many outpatients, visitors, faculty members, and students. A survey conducted in November 1973 indicated that over 12,000 trips were made to the Medical Center on a typical weekday. Of these, most (83%) arrived by automobile, and another 13% (1,600) arrived by bus. The survey also showed that only 1.5-2% of the trips of



LAND USE

■ Institutional and Residential

▨ Parking (Decked, Multilevel and Surface)

FIGURE 4.9. DETROIT MEDICAL CENTER

employees and visitors respectively were made within the complex. However, internal distribution is expected to increase as the hospitals take on more and more specialized functions. For example, when Detroit General Hospital was completed in 1979, it became the emergency center. If the patient requires orthopedic or neurological assistance, he will be transferred to Harper Hospital when he is no longer in critical condition. Tunnels and corridors have been completed or are under construction at the present time to connect all the hospitals in the southern part of the complex.

4.5.1 Current Transportation System Characteristics

There is currently no internal transit circulation system. However, in late 1973, a proposal was submitted to the Michigan Department of State Highways for installation of a 2.9 km. (1.8 mile) AGT system. The proposal was in connection with a design project competition called "New Transit for Michigan Communities." This system was designed to connect the hospitals, medical school buildings, parking structures, public transportation, nursing residences, and the Wayne State University main campus northwest of the medical complex. The automated vehicles were intended to operate in a shuttle or loop configuration. The vehicles were designed to accommodate 14 passengers seated and 16 standing, with a maximum capacity of 2,000 passengers per hour. However, the project was not approved.(24)

Trip estimates for a medical center AGT system were made for 1976-77, when it was expected that Detroit General, the New Clinic building, and a relatively small Wayne Continuing Education Center building would be completed. Although the building program has not kept pace with the estimated schedule, the estimates still appear to be basically sound, if only for 2 years hence.

Estimates were based on the assumption that persons would use the system if the alternative was a walk of more than two blocks or 180 meters (600 feet). Assuming no reduction in the percentage of those arriving by automobile in 1976 (over 1973), the number of one-way trips per week on the proposed system was estimated to be 58,000, or an average of almost 8,300 per day. If the proposed Schools of Dentistry and Vivarium are added to the complex as planned, capacity requirements should increase further.

Recently, some consideration has been given to the possibility of using electric vehicles for internal circulation. Although they apparently would be capable of moving throughout the corridor and tunnel system, the elevators were not built to carry the weight of these vehicles with their heavy batteries. Thus, the vehicles would be confined to serving one level only. The shortage of space for storing is also a consideration.

4.5.2 Economic Analysis

Since there is presently no installed transit circulation system, a cost comparison is made between AMTT and conventional bus systems as alternatives to serve the Detroit Medical Center. Consider a 2.9 km. loop system with five 30-passenger vehicles providing the same service as the proposed AGT system mentioned above. To carry the estimated 8,300 passengers per day, the system would be operated approximately 288,000 vehicle kilometers per year. Using standardized bus costs and the parametric curves developed in Chapter 3, the comparison of AMTT and conventional bus is shown in Figure 4.10. It can be determined that AMTT would cost approximately $190,000 less than conventional bus per year in terms of annualized total cost.

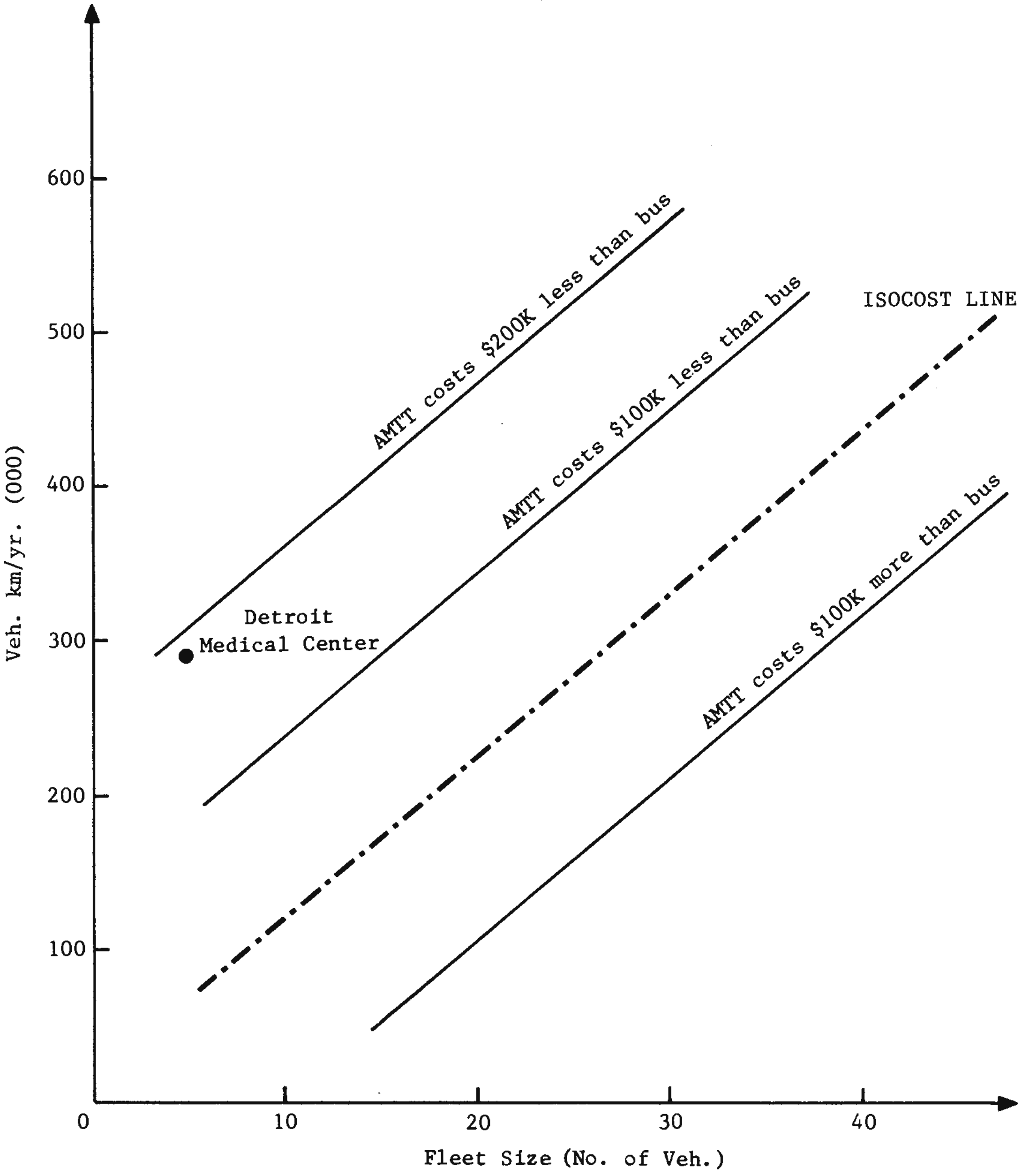


FIGURE 4.10 ISOCOST LINE FOR MEDIUM VEHICLES AND 3 KM ROUTE LENGTH.

5. MARKET ANALYSIS

AMTT technology has some characteristics that make it a more desirable mode of transportation than others in some application areas. AMTT vehicles eliminate the need for drivers. This contributes to AMTT's relatively low O&M costs that makes it desirable in areas where labor costs are high. AMTT vehicles can operate in mixed traffic, particularly with pedestrians at low operating speeds. In activity centers where no transportation system currently exists, but a need is projected for circulating people, an AMTT could be useful.

An AMTT system is not as route flexible as conventional bus systems because it has to follow a guidepath. But since an AMTT guidepath is no more than a buried guide cable or a paint stripe, route changes within an AMTT system can be done with relative ease. The capital cost of AMTT systems is thus relatively low when compared with that of other automated fixed guideway transit systems. Furthermore, in communities where aesthetic considerations are important, AMTT only poses minimum visual impacts because there are no guideway structures or stations.

Another attractive feature of the AMTT technology is that it offers some novelty value to potential application sites such as amusement parks and recreation areas. Operators of these facilities are knowledgeable of the costs and technology involved in new automated systems and possess the liability insurance structure that allows the introduction of new systems.

AMTT will most likely be employed to serve non-work trips. Because of its automated operation, longer loading time may be expected than most manually-operated transit systems, especially when unexperienced passengers are often involved. This consequently limits the overall AMTT system capacity and makes it less desirable in areas where very large passenger demands are anticipated.

This section examines the potential AMTT application areas, develops ranges of transportation requirements for different applications, and, with the results of the parametric analysis, analyzes the AMTT market.

5.1 Potential Application Sites

Potential AMTT application sites include universities and colleges, adult and retirement communities, central business districts, multiuse and mixed use developments, shopping centers, airports, medical complexes, and some other major activity centers such as new towns, parks, sports arenas, etc. The potential market penetration in each application is examined.

5.1.1 Universities and Colleges

In the 1977-78 academic year, there were 3,095 colleges, universities, and branch campuses in the United States.(25) Of these, 160 were universities, 1,938 were other 4-year institutions, and 1,157 were 2-year colleges.

The University of California at Berkeley and Stanford University have unusually large campuses(26)--6.1 and 21.0 km.^{2} (1,500 and 5,200 acres)--for their student population--30,000 and 11,700 respectively. Clearly, campus size is not related to the size of the student body.

To obtain an estimate of university and college sites that might have potential for the use of AMTTs, a circular campus was postulated in which walks to the center of campus from the periphery would be at least 326 meters (1,070 feet)--average observed walking distances (see Section 2). Such a campus would contain 0.33 km.^{2} (82 acres).

A random sample of the size of universities and other accredited 4-year institutions taken from American Universities and Colleges showed that about three-quarters of the campuses were larger than 0.33 km.^{2} (82 acres). This would indicate that over 1,400 of the 1,938 universities and 4-year colleges in the United States have campuses where walking requirements may be excessive, and some form of transportation would be welcome. If the same ratio held for 2-year colleges, over 800 would be potential sites for AMTTs.

5.1.2 Adult and Retirement Communities

Adult and retirement communities range in size from small multi-unit buildings with fewer than 50 residents to over 40-km.^{2} (10,000-acre) low density "cities" containing up to the 38,000 residents who live in Sun City, Arizona. Mobile home parks with restrictions against children are also considered to be adult communities. There are presently many types of retirement communities: sub-divisions, apartments, mobile home parks, clubs and hotels, RV parks and multi-type facilities. Different communities have different transportation needs depending on factors such as age restrictions, income level of residents, car ownership, physical capacity of residents, and size and population of community. Most communities in this category, however, are small and do not require transit as a supplement to walking for internal trips. Long walking trips in the larger communities, such as Rossmoor and Sun City, would be required if supplementary forms of transit were not available. The number of large retirement and adult communities that offer all amenities (e.g., golf course, pools) in the United States is small, estimated to be between 10 and 25 sites.

Adult and retirement communities may present special difficulties as far as AMTT applications are concerned. With many elderly residents, the special need for transportation other than the automobile has been demonstrated. However, a driverless vehicle may cause special apprehensions for the elderly because of their generally slower movements, a greater tendency to fall than younger persons, and a greater number of physical handicaps, such as poor eyesight. Although automobile ownership is apparently high in these communities (as at Rossmoor, Walnut Creek), the popularity of the buses at Rossmoor indicates a need for supplemental transportation in the large communities. Observed walking distances for older persons are shorter than those for younger persons. A number of retirement communities, such as Rossmoor, provide supplemental transportation in the form of buses or vans. In addition, individuals in some communities use golf carts and three-wheeled bicycles for personal transportation.

5.1.3 Central Business Districts

The typical CBD in the United States is about 2.5 km.^{2} (1 square mile). A few of the large cities in the United States have CBDs two to three times that size. Very small cities do not present pedestrians with the formidable walking, parking, or traffic problems that are often present in the larger CBDs.

In 1970, there were 840 cities in the United States that had a population of 25,000 persons or more.(27) Because of traffic and parking pressures as a result of the high densities generally found in CBDs, as well as environmental concerns and the decline of retail sales in CBDs, cities have been strained to find transportation alternatives to the automobile. CBDs thus may offer a good potential for AMTTs. The number of medium size CBDs with populations between 50,000 and 200,000 is roughly 40 to 55.

About 80 cities in the United States have banned automobiles from a portion of the CBD--usually in the retail core. Such areas are generally planned with the pedestrian in mind and tend to be limited to a size that does not entail long walking distances. By supplementing the walking mode with some form of transit, such areas could be extended; and, indeed about a dozen U.S. cities either have or are planning such transit-pedestrian districts (e.g., Denver).(28) It is expected that these districts will grow in number if present EPA requirements for cleaner air remain in effect.

5.1.4 Multiuse Developments

The exact number of multiuse developments in the United States is unknown. Engineering News-Record listed 22 major multi-use projects ($50 million plus) with construction beginning in 1978. Although some are high-rise developments, others cover from 0.05-4.9 km.^{2} (12-1,200 acres).(29) Eight were listed as being larger than 0.34 km.^{2} (85 acres), which would indicate some need for transportation other than walking.

The Urban Land Institute (ULI) identified over 80 mixed-use developments in North America. Most of them were begun after 1960. The ULI report envisions mixed-use developments as having high density land use patterns with "extensive use of escalators, elevators, moving sidewalks, and other mechanical means of facilitating horizontal and vertical movement by pedestrians." Their concept includes the utilization of people movers. Indeed, the 0.93 km.^{2} (230-acre) Post Oak Urban Center in Houston, one of the more famous of the mixed-use developments, proposed a 1.2 km. (4,000-foot) AGT system to connect various facilities within the Center. Because of the high cost of such systems, however, few have been built for these developments. It appears that the AMTT system could fill the transportation gap in such areas by traveling faster than the pedestrian conveyors at less cost than AGT systems.

5.1.5 Shopping Centers

Of the approximately more than 19,000 shopping centers in the United States,(30) only about 1%, or 203, contain more than 92,900 square meters (1 million square feet) of retail space. Regional centers with over 74,300 square meters (800,000 square feet) of retail space totaled 393 in 1978. Although "Shopping Center World" has indicated a slowdown in new shopping center openings in the near future, it says that many of the nation's largest shopping center developers have announced plans for major expansions at existing centers. Such expansions are likely to bring more pressures for some form of internal distribution system. Some of these large shopping centers may have a need for a transit circulation system.

5.1.6 Airports

There are more than 11,000 airports in the United States. Approximately 600 of these airports are regularly served by Civil Aeronautics Board (CAB)-certified carriers. Twenty-six airports in the United States enplane 88% of the passengers in the United States. Each of these airports, listed in Table 5-1, enplaned at least 2.2 million passengers in the 12 months ending June 30, 1976. Another 15 commercial airports enplane between 1.0 and 2.0 million passengers per year, and 24 more enplane between 0.5 and 1.0 million passengers per year.

Airports vary greatly in size, design, and passenger usage, but they all require the movement of people to and from parking lots or mass transportation stations, between and inside terminals, as well as to and between gates. Several of the 26 largest airports in the United States have invested heavily in automated guideway transit systems, but AMTT may serve as a potential transit circulation system for other airports.

5.1.7 Medical Centers

Twenty-six medical schools in the United States have affiliated hospitals. The Detroit Medical Center, discussed in the case study, is one of a few large medical complexes in the United States. Others include the Texas Medical Center in Houston mentioned in Section 4.5, which contains 28 member institutions. A loop AGT system was proposed for this complex, but lack of financing precluded its construction. The Duke University Medical Center in Durham, North Carolina is currently constructing an AGT system to carry passengers and cargo between an existing hospital and a new 600-bed facility. This system is designed to be expanded to connect remote parking, transit stations, a Veterans Administration Hospital, and other facilities. The University Health Center in Pittsburgh is another large medical complex that has considered a shuttle loop transportation system.

Another large complex is the Hennepin County Medical Center in Minneapolis, a new 500-bed teaching facility that is connected to a 736-bed Metropolitan Medical Center. The two centers share certain facilities, such as food preparation, laundry, and a power plant. It is about 2,440 meters (8,000 feet) from one end of Hennepin to the far end of Metropolitan. At present, Hennepin has monorail-type tracks that carry food and supplies in lockers throughout the facility.

TABLE 5-1 - PASSENGERS ENPLANING AT MAJOR U.S. AIRPORTS

Rank	Airport	Enplaning* Passengers (million per year)
1	O'Hare (Chicago)	17.2
2	Atlanta	13.3
3	Los Angeles International	9.6
4	Dallas-Ft. Worth	7.7
5	Kennedy (N.Y. City)	6.9
6	La Guardia (N.Y. City)	6.9
7	San Francisco International	6.4
8	Denver	6.1
9	Washington National	5.5
10	Boston	5.2
11	Miami	4.8
12	Honolulu	4.6
13	Detroit	3.9
14	St. Louis	3.7
15	Pittsburgh	3.7
16	Minneapolis-St. Paul	3.5
17	Philadelphia	3.5
18	Newark	3.2
19	Seattle-Tacoma	3.2
20	Houston	3.1
21	Las Vegas	3.1
22	Cleveland	2.8
23	Tampa	2.5
24	Kansas City	2.3
25	New Orleans	2.3
26	Phoenix	2.2

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*Passengers for domestic and international scheduled flights for the year ending June 30, 1976.

Source: "Airport Activity Statistics of Certificated Route Air Carriers," 12 months ending June 30, 1976, Federal Aviation Administration and Civil Aeronautics Board.

Most other hospital complexes are smaller than the centers mentioned above, but some are being expanded. The trend toward merging hospitals and the building of new medical clinics and other facilities adjacent to hospital centers may increase the need for people-moving systems.

5.1.8 Other Major Activity Centers

There are a number of other types of major activity centers where AMTTs could be deployed. They include new towns, parks (both amusement and recreational), state and county fairs, international expositions and world fairs, railroad stations, sports arenas, large manufacturing or office complexes, and large military installations.

New towns include adult and retirement communities; however, most new towns do not have age restrictions. Typically, automobile ownership is high in new towns, but this still leaves a large portion of the residents with limited mobility. Columbia, Maryland, a new town on approximately 61 $km.^2$ (15,000 acres) of land, planned transit as an integral part of the community. Town planners set aside for transit purposes a 15-meter (50 foot) right-of-way that was to be within a 3-minute walk of 40% of the eventual population of 110,000 persons. Buses provide service on a number of routes in the complex. The town planners later envisioned the construction of an AGT system using six-passenger vehicles. It is likely that Columbia's far-seeing approach in planning for an AGT system is somewhat unique among the 50 to 75 new towns in the United States. However, it is possible that some new towns could use AMTTs effectively and thus these types of settings should be considered in any market analysis.

The availability of an array of transportation modes in theme parks, zoos, recreational parks, and various types of fairs and expositions attests to the requirement to assist pedestrians in these types of settings. Parks and fairs have opted for buses and elephant trains, as well as for monorail and AGT systems. AGT systems, for example, have been installed at Busch Gardens, Hershey Amusement Park, and the California Exposition and State Fair. AMTTs, with low pollution and noise levels, could provide a service in these settings--particularly those where operator-driven vehicles are currently in use. A Barrett AMTT was in service in Freedomland, an amusement park. It appears, in fact, that these settings with their low speed requirements are the most logical for the present AMTTs. For example, the speed of the WEDway AGT system at Walt Disney World is 3.5 km/hr (2 mph) when it passes through exhibit areas and 10.9 km/hr (6.8 mph) elsewhere.

Theme or amusement parks and zoos appear to have better potential for deployment of AMTT systems than, for example, the 32 parks in the U.S. National Park Service, all but two of which contain at least 61 km.^{2} (15,000 acres) and require faster modes of travel. In 1975, Susan Hunter's "A Family Guide to Amusement Centers"(31) listed 101 amusement centers in the United States. Included are wild animal habitats, storylands, oceanariums, theme parks, and historical villages such as Williamsburg, Virginia. There are about 50 major zoos in the United States, a number of which employ trains and trams for sightseeing. As pressure for cleaner air increases, it is likely that large city parks, such as the Golden Gate Park in San Francisco, will increase restrictions on automobiles, resulting in the need for alternative transportation modes.

Also, as urban sub-areas are being redeveloped and revitalized, some type of public transportation is often specified for inclusion. For example, the City of Cincinnati considered the use of pedestrain conveyors to connect their CBD with the riverfront development several blocks away. Detroit is considering a people mover (AGT) to connect part of its riverfront area with the CBD. In San Francisco, a steam train has been proposed to run 4 kilometers (2.5 miles) along the waterfront between a Pier 39 complex of restaurants and shops and the end of Market Street, the major thoroughfare in the city. A people-mover system is proposed to move visitors along the length of the pier. In Santa Barbara, some form of transportation is required to link a proposed restaurant and shopping area on Stearns Wharf with parking lots located some distance away. The proposal is to develop 4,500 square meters (48,470 square feet) of rentable space, but concern has been expressed about the traffic congestion and parking access problems that this would engender. Current plans include two minibus routes: one would provide access to the widely dispersed parking lots and off-street parking available along about 4 kilometers (2.5 miles) of the waterfront; the other would take a somewhat circuitous route (to avoid the traffic signal at Highway 101) to the CBD that begins some five blocks from the wharf. The latter route would be approximately 6.4 kilometers (4 miles) round trip. Both routes were intended to include a route segment some 460 meters (1,500 feet) out on the pier where automobiles and parking are to be prohibited. However, interested Santa Barbara officials have suggested that at least this segment of the service could be provided by AMTTs.

5.2 Transportation Requirements for Different Application Areas

Different application areas have different transportation requirements to meet their local objectives. AMTT technology could respond to selected transportation needs of many types of application areas. In order to identify conditions under which AMTT could be cost-competitive with other transit modes, ranges of transportation service characteristics are developed in this section. These ranges are then used in conjunction with the results of the parametric analysis performed in Section 3 to analyze the AMTT market within the probable application areas discussed earlier in this section.

Each application area has a set of general transportation requirements that can be expressed in terms of the frequency of service, capacity, and hours and days of operation needed. From these requirements and other characteristics of the system such as route length and vehicle speed, the fleet and vehicle size required and total vehicle kilometers to be operated per year can be determined.

Table 5.2 summarizes the ranges of transportation requirements and service characteristics of various potential application areas. Ranges of transportation requirements are based on actual cases and previous studies as identified in the table. Even though there would be exceptions, most application areas are likely to have transportation requirements within these ranges.

Universities and colleges generally require some service every 5 to 15 minutes for an average of 12 hours a day. Most universities and colleges need medium- to large-sized vehicles to meet their demands and their systems generally cover a total length of 2 to 30 kilometers (1.3 to 19 miles). With average speeds between 10 and 25 km/hr (6 and 16 mph), the fleet size required can be determined to be between 4 and 22 vehicles. Operating the system for a total of 250 days a year will produce an annual total of 154,000 to 460,000 vehicle kilometers (96,000 to 288,000 vehicle miles).

Most CBDs with a need for transit service require service every 2 to 5 minutes during peak periods and every 10 to 20 minutes during off-peak periods. Medium or large vehicles are generally required to serve these transit systems with route lengths ranging between 2 and 15 kilometers (1.3 and 9.4 miles). With an average speed of 10 to 25 km/hr (6 to 16 mph), the required fleet size is from 6 to 29 vehicles. With average operation of 8 peak hours and 8 non-peak hours per day for 300 days a year, the system can be determined to operate 307,000 to 734,000 vehicle kilometers (192,000 to 459,000 vehicle miles) a year.

TABLE 5-2 - RANGES OF TRANSPORTATION REQUIREMENTS* AND SERVICE CHARACTERISTICS

	Universities	CBDs	Airports	Medical Centers	Retirement Communities, New Towns
INDEPENDENT REQUIREMENTS					
Frequency of service in minutes (peak/off-peak)	5-15	2-5/10-20	5-10	5-20	10-30/20-60
Vehicle Size (no. of places)	medium-large (20-50)	medium-large (20-50)	small-medium (10-20)	small-medium (10-20)	small-medium (10-20)
Route Length (km.)	2-30	2-15**	2-20***	1-10	10-60
Average Route Length (km.)	16	8.5	11	5.5	35
Hours of operation per day (peak/off-peak)	12	8/8	18	18	12
Days of operation per year	250	300	360	360	300
Average Speed (km/hr)	10-25	10-25	10-25	10-25	10-25
DEPENDENT SYSTEM REQUIREMENTS					
Fleet Size (no. of vehicles)	4-22	6-29	4-16	2-8	4-17
Vehicle km yr. (000)	154-460	307-734	428-855	107-428	168-504
Service Capacity (no. of places/hr.)	80-600	60-1500	60-240	30-240	10-120

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*Ranges of requirements based generally on actual cases and data from the following reports: "Generic Alternatives Analysis, AGT Socio-Economic Research Program," Vol. I by Barton-Aschman Assoc., 1979 and "Characteristics of Urban Transportation Systems," by De Leuw, Cather & Co., 1979.

**CBD areas range from 1.3 to 5.7 km.^{2} (0.5 to 2.2 sq. mi.) among 30 largest SMSA's, except D.C. and N.Y.C.

***Existing airport AGT systems have guideway lengths between 0.8 km. (Miami) and 20 km. (AIRTRANS).

Most airports require service headways from 5 to 10 minutes and use small- to medium-sized vehicles. Route length usually ranges between 2 and 20 kilometers (1.3 and 12.5 miles). Required fleet size ranges from 4 to 16 vehicles with average speeds of 10 to 25 km/hr (6 to 16 mph). Operating the system for 18 hours a day and 360 days a year produces 428,000 to 855,000 vehicle kilometers (268,000 to 534,000 vehicle miles) annually.

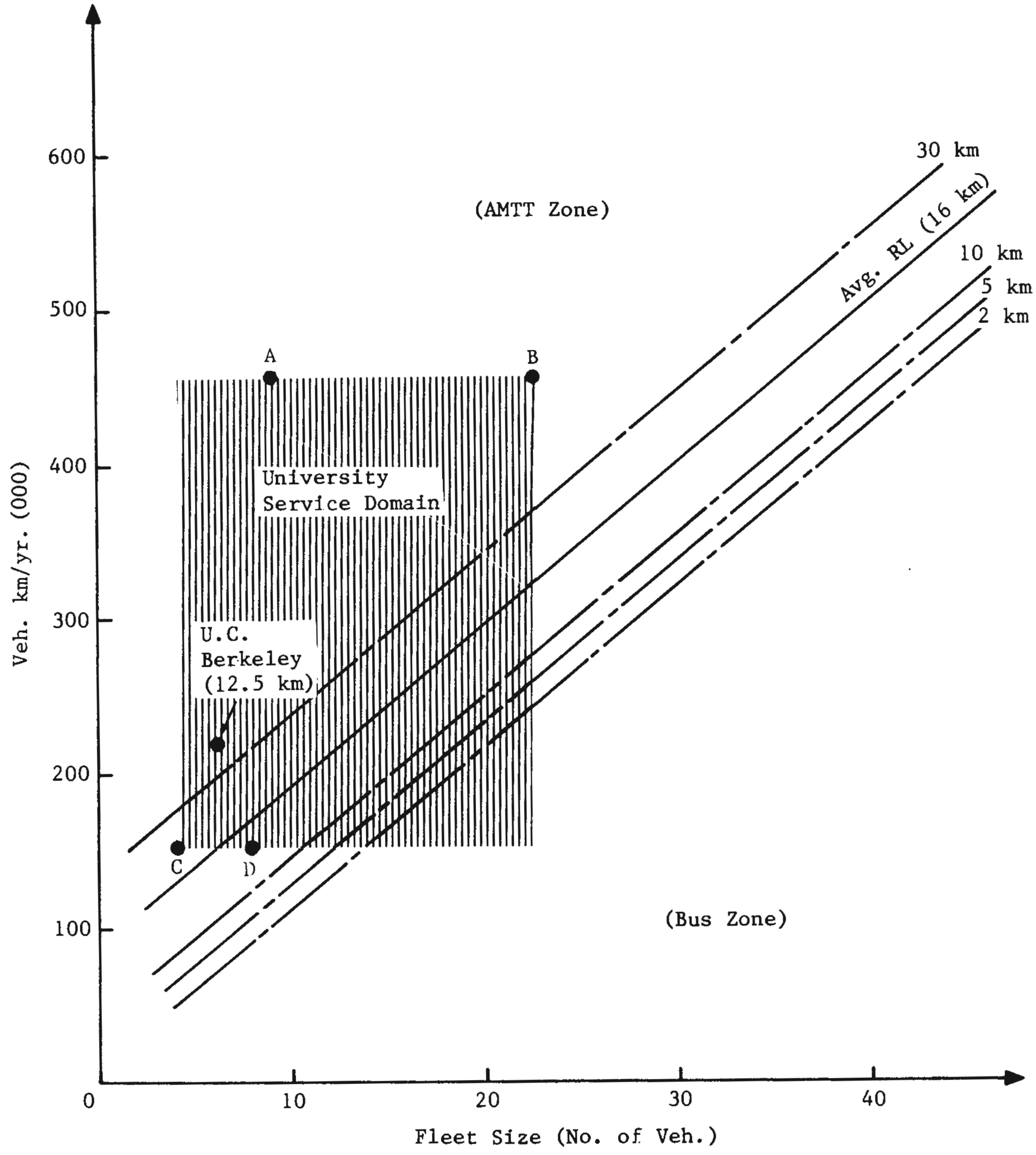
Medical centers with the need for a transit circulation system generally require service every 5 to 20 minutes with small- to medium-sized vehicles. Total route length ranges between 1 and 10 kilometers (0.6 and 6.3 miles). With average speeds of 10 to 25 km/hr (6 to 16 mph), the required fleet size is between 2 and 8 vehicles. If the system is operated an average of 18 hours a day and 360 days a year, the annual vehicle kilometers operated is between 107,000 and 428,000 (67,000 and 268,000 vehicle miles).

Retirement communities, new towns and similar communities that require transit service need a frequency of service ranging from 10 to 30 minutes during peak hours and 20 to 60 minutes during non-peak hours. Small to medium vehicles are normally adequate for these applications. With average speeds between 10 and 25 km/hr (6 and 16 mph), the required fleet size ranges between 4 and 17 vehicles. If the system is operated 12 hours a day and 300 days a year, total vehicle kilometers operated per year is between 168,000 and 504,000 (105,000 and 315,000 vehicle miles).

5.3 Market Analysis

Results of the parametric analysis between AMTT and competing modes can be used with the ranges of transportation requirements to identify conditions under which AMTT is potentially less costly than other modes. In most of the potential AMTT application areas discussed previously, bus transit is the most likely mode to compete with AMTT (some sites already have bus systems in service and a few already have or are planning/building new transit such as AGT). The market analysis undertaken in this study, therefore, is performed by examining the costs of AMTT and conventional bus transit systems providing similar service to various application areas.

Figures 5.1 and 5.2 analyze the market potential for AMTT among university and college campuses requiring medium and large vehicles, respectively. Ranges of fleet size required and total annual vehicle kilometers operated are plotted along with the isocost lines developed previously in the parametric analysis for different vehicle sizes and route lengths. The U.C.



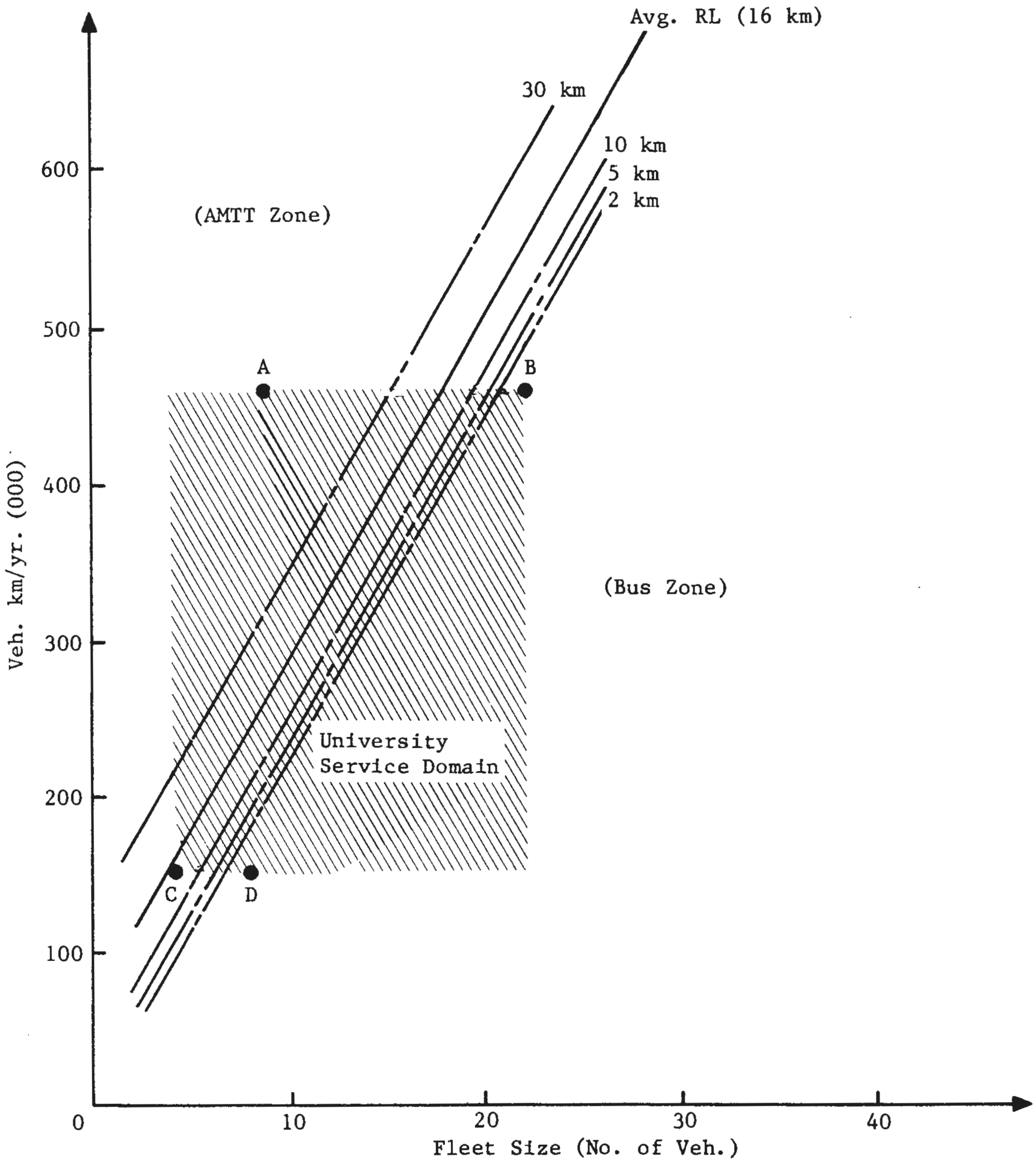
A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

D - low service level, low speed

FIGURE 5.1 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (MEDIUM-SIZED VEHICLES) —UNIVERSITIES MARKET ANALYSIS.



A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

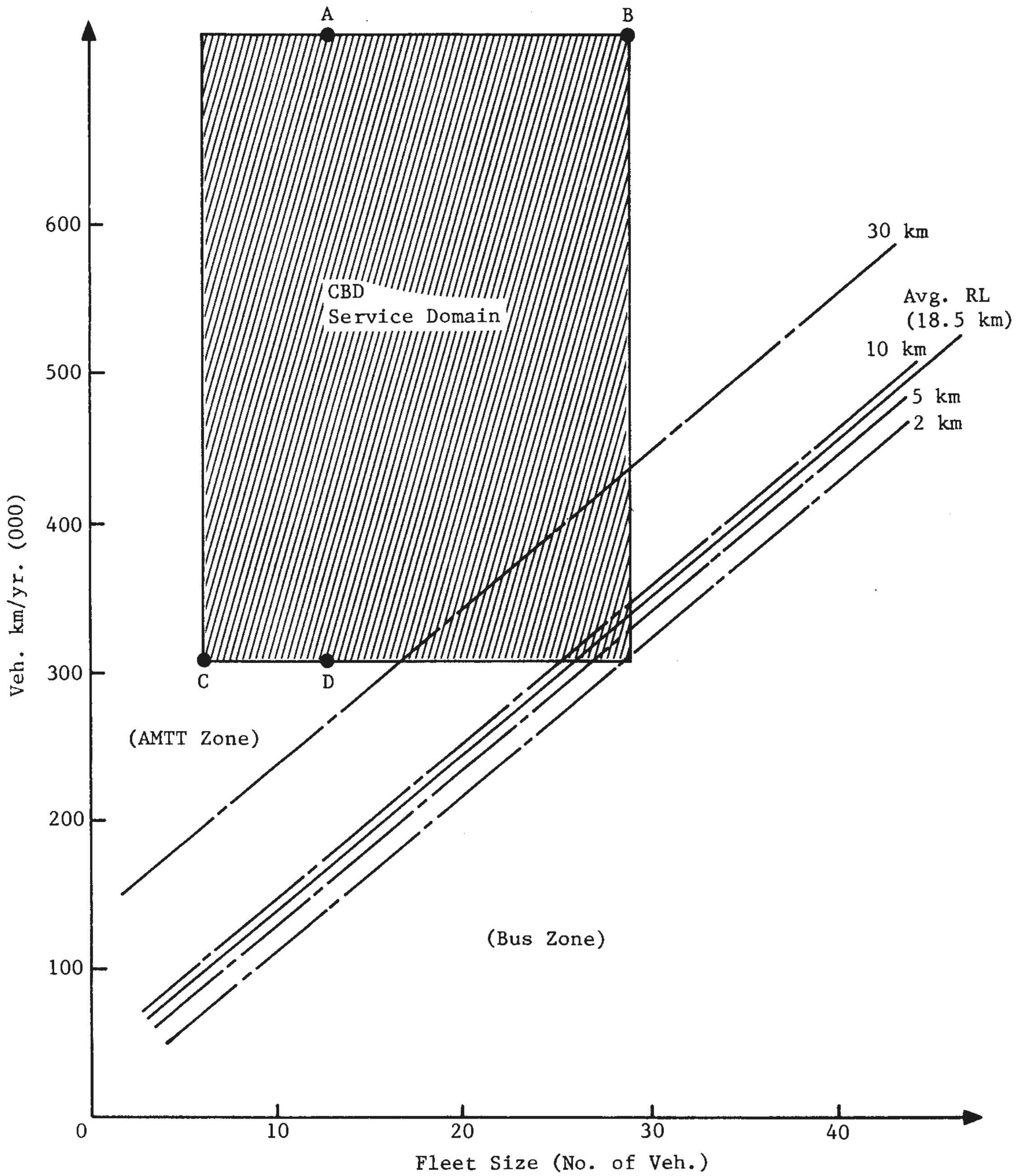
D - low service level, low speed

FIGURE 5.2 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (LARGE-SIZED VEHICLES) —UNIVERSITIES MARKET ANALYSIS.

Berkeley transit system, as described in Section 4, is indicated inside the area enclosed by these ranges. Four other points: A, B, C, and D are also indicated to show the relative cost of AMTT versus bus when different levels of service are desired and different operating speeds are achieved. When a university system requires a high level of service (indicated by 5-minute headway for universities) and can achieve a high operating speed (25 km/hr), i.e., a system indicated by point A, AMTT is much less costly than conventional bus. When a system requires a high level of service (5-minute headway) but only a low operating speed is achievable (10 km/hr), as indicated by point B, AMTT is still less costly than bus, although it is closer to the isocost line than Point A (Figure 5.1). If a system, on the other hand, only requires a low level of service (15-minute headway), AMTT can be either more or less costly than bus depending on whether high speed or low speed is achievable, as indicated by points C and D, respectively. For university and college campuses with an average route length (16 km. or 10 mi.), it can be determined from Figures 5.1 and 5.2 that AMTT has approximately 75% and 40% market penetration potential of being less costly than conventional bus if medium and large vehicles are required, respectively. Considering the range of route length for university applications, AMTT has approximately 60% to 90% market penetration potential for 30 km. and 2 km. systems, respectively, using medium vehicles, and 30% to 50% market penetration potential using large vehicles for 30 km. and 2 km. systems, respectively.

The AMTT potential for CBDs can be analyzed with Figures 5.3 and 5.4. The ranges of transportation requirements and other characteristics are plotted in a similar manner as those of universities and colleges. It can be determined from these charts that for most CBDs where medium-sized vehicles can be used to carry the anticipated loads, AMTT can be less costly than bus. If the average route length of 8.5 km. is used, it can be determined that for the medium vehicle case, there is a 99% market penetration potential that AMTT would be less costly than a conventional bus. For most CBDs with average route lengths that require large vehicles, there is approximately 75% market penetration potential that AMTT is less costly than bus.

Figures 5.5 and 5.6 analyze the AMTT potential in airports using small- and medium-sized vehicles, respectively. The areas enclosed by the ranges of requirements and characteristics are far into the AMTT zone, away from the isocost lines. This indicates that for airports with transportation requirements and service characteristics within the prescribed ranges, AMTT is a less costly transit mode than conventional bus.



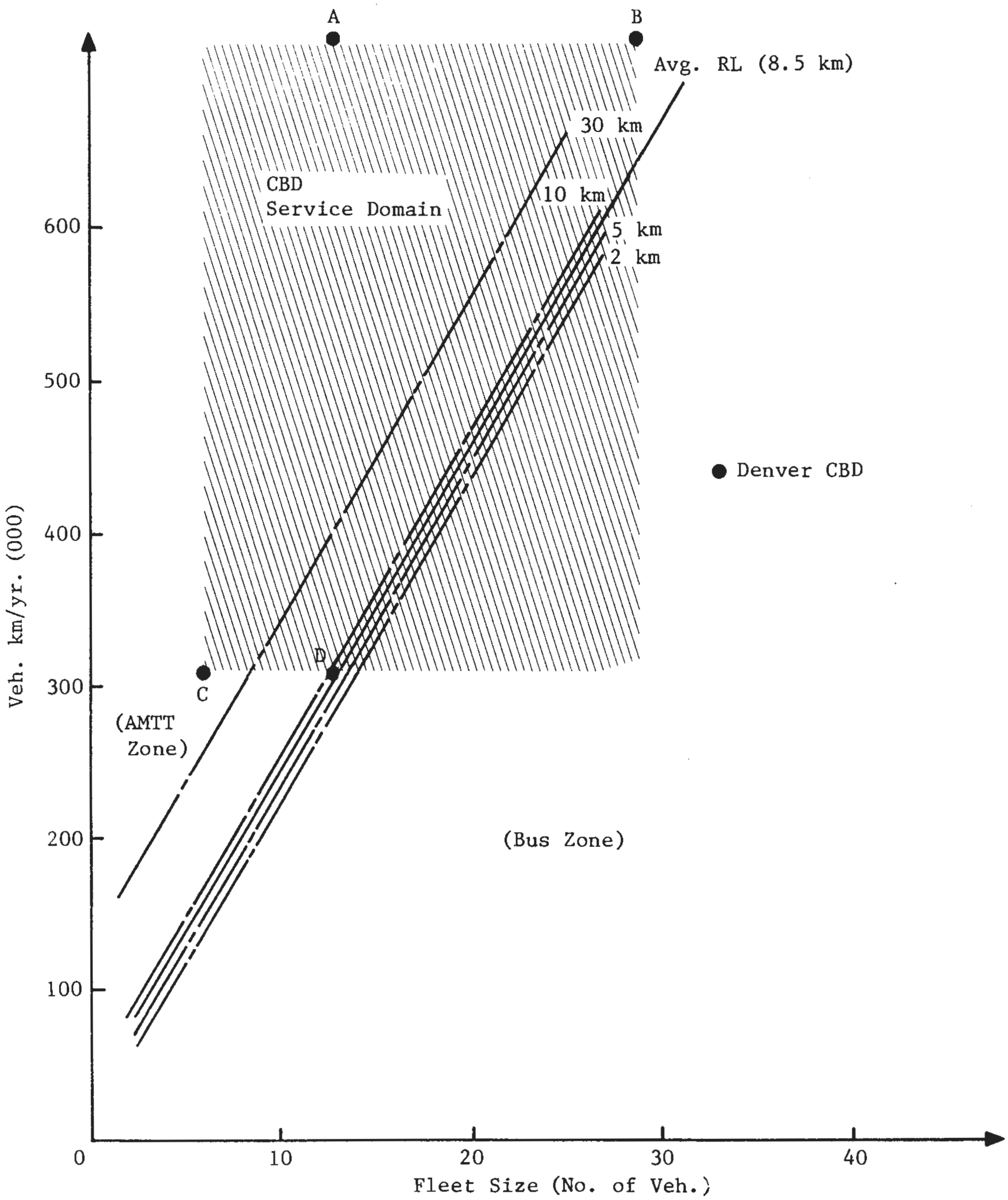
A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

D - low service level, low speed

FIGURE 5.3 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (MEDIUM-SIZED VEHICLES) —CBDs MARKET ANALYSIS .



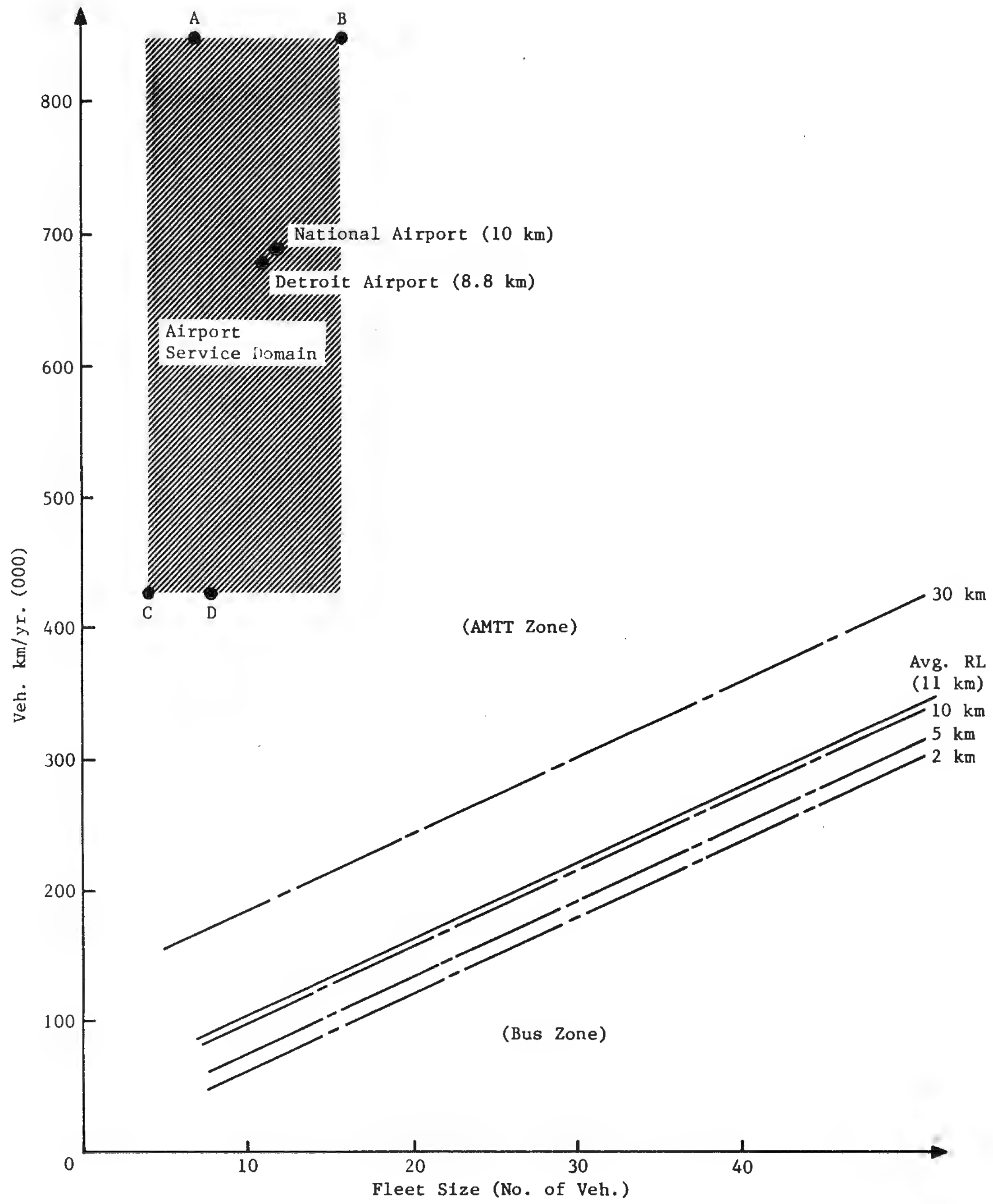
A – high service level, high speed

B – high service level, low speed

C – low service level, high speed

D – low service level, low speed

FIGURE 5.4 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (LARGE-SIZED VEHICLES) —CBDs MARKET ANALYSIS.



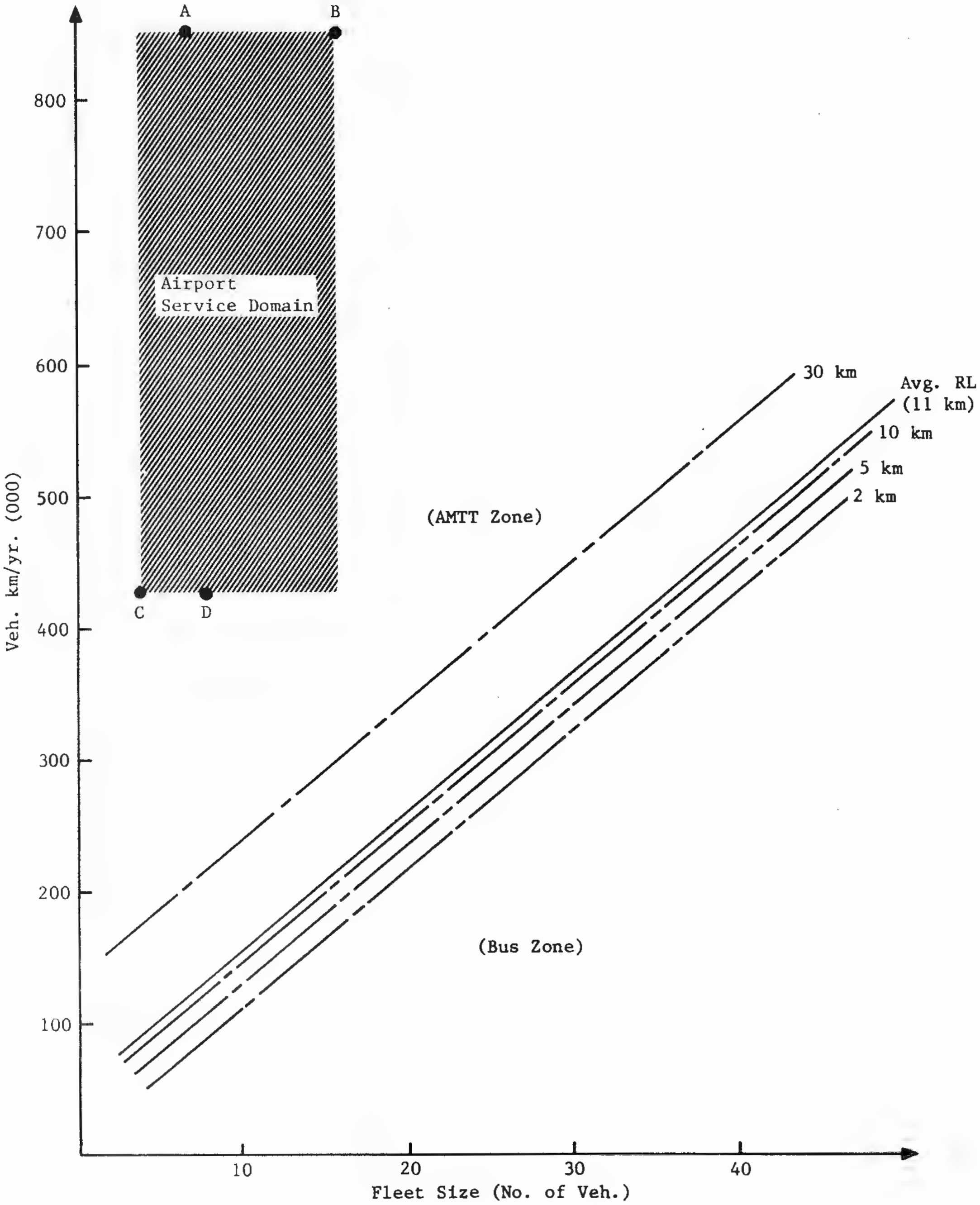
A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

D - low service level, low speed

FIGURE 5.5 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (SMALL-SIZED VEHICLES) —AIRPORTS MARKET ANALYSIS .



A - high service level, high speed

B - high service level, low speed

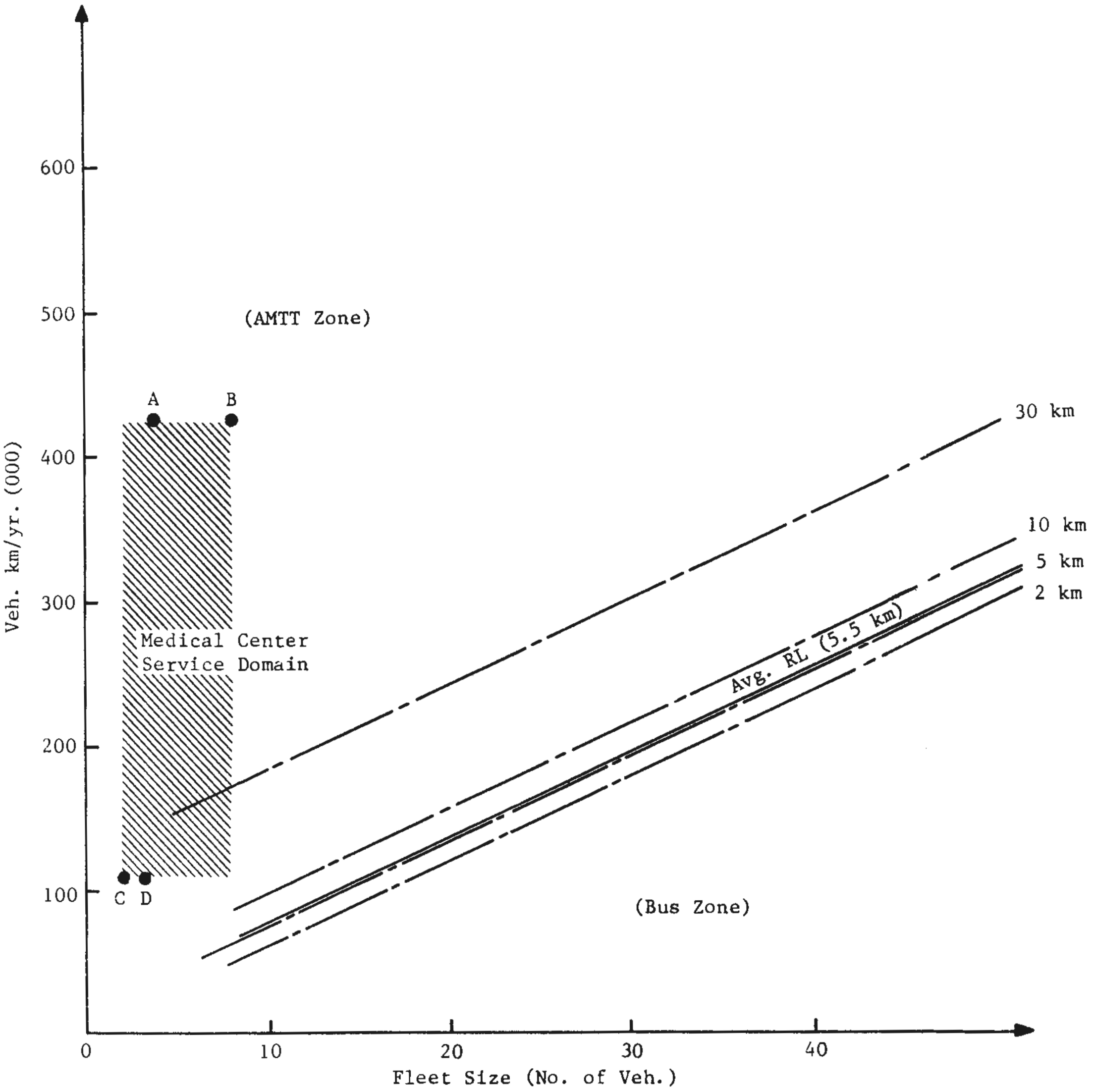
C - low service level, high speed

D - low service level, low speed

FIGURE 5.6 **ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (MEDIUM-SIZED VEHICLES) —AIRPORTS MARKET ANALYSIS.**

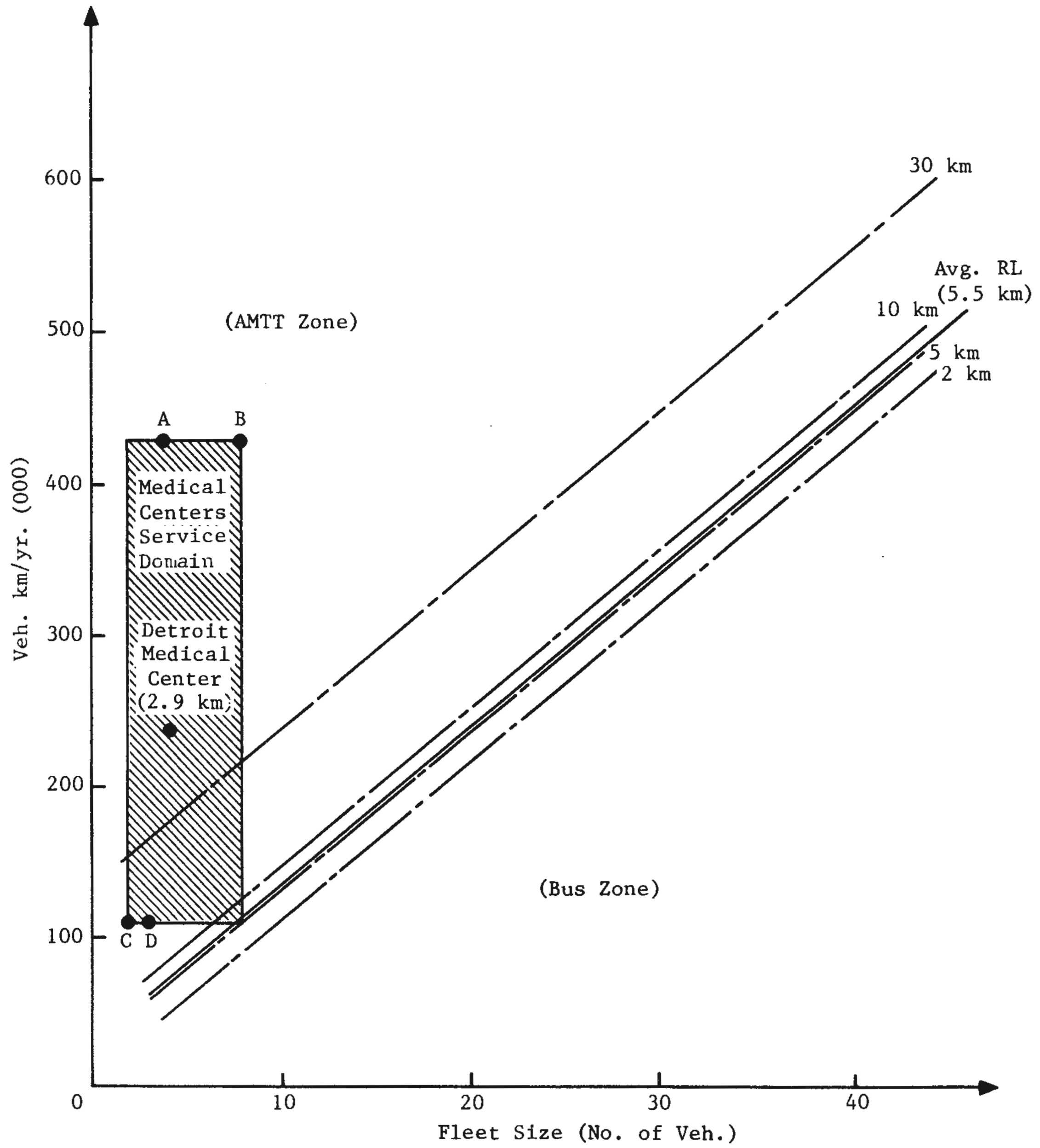
Medical centers with requirements and characteristics within the ranges discussed previously are shown in Figures 5.7 and 5.8. For medical centers with the average route length (5.5 km.), AMTT appears to be less costly than conventional bus. AMTT is relatively less costly when small vehicles are used than when medium vehicles are used.

Retirement communities, new towns, and other application areas with similar requirements and characteristics have long routes and wider ranges of service requirements relative to other application areas discussed previously (Figures 5.9 and 5.10). With an average route length of 35 km. (22 mi.), AMTT has an 80% market penetration potential of being less costly than conventional bus if small vehicles are required. Using medium vehicles, AMTT has a 70% market penetration potential of being less costly than the conventional bus.



A - high service level, high speed
B - high service level, low speed
C - low service level, high speed
D - low service level, low speed

FIGURE 5.7 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (SMALL-SIZED VEHICLES) —MEDICAL CENTERS MARKET ANALYSIS.



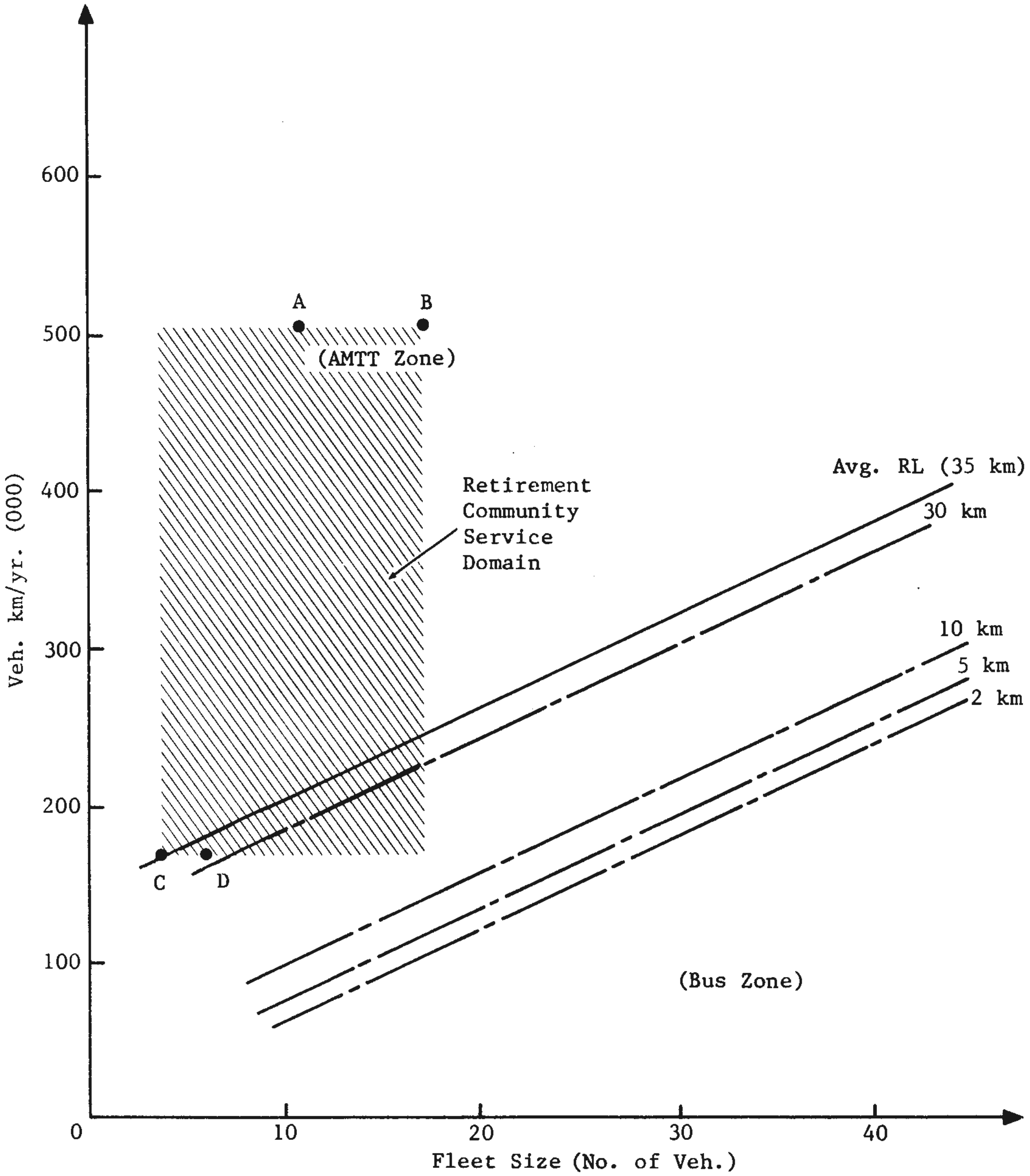
A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

D - low service level, low speed

FIGURE 5.8 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (MEDIUM-SIZED VEHICLES) —MEDICAL CENTERS MARKET ANALYSIS.



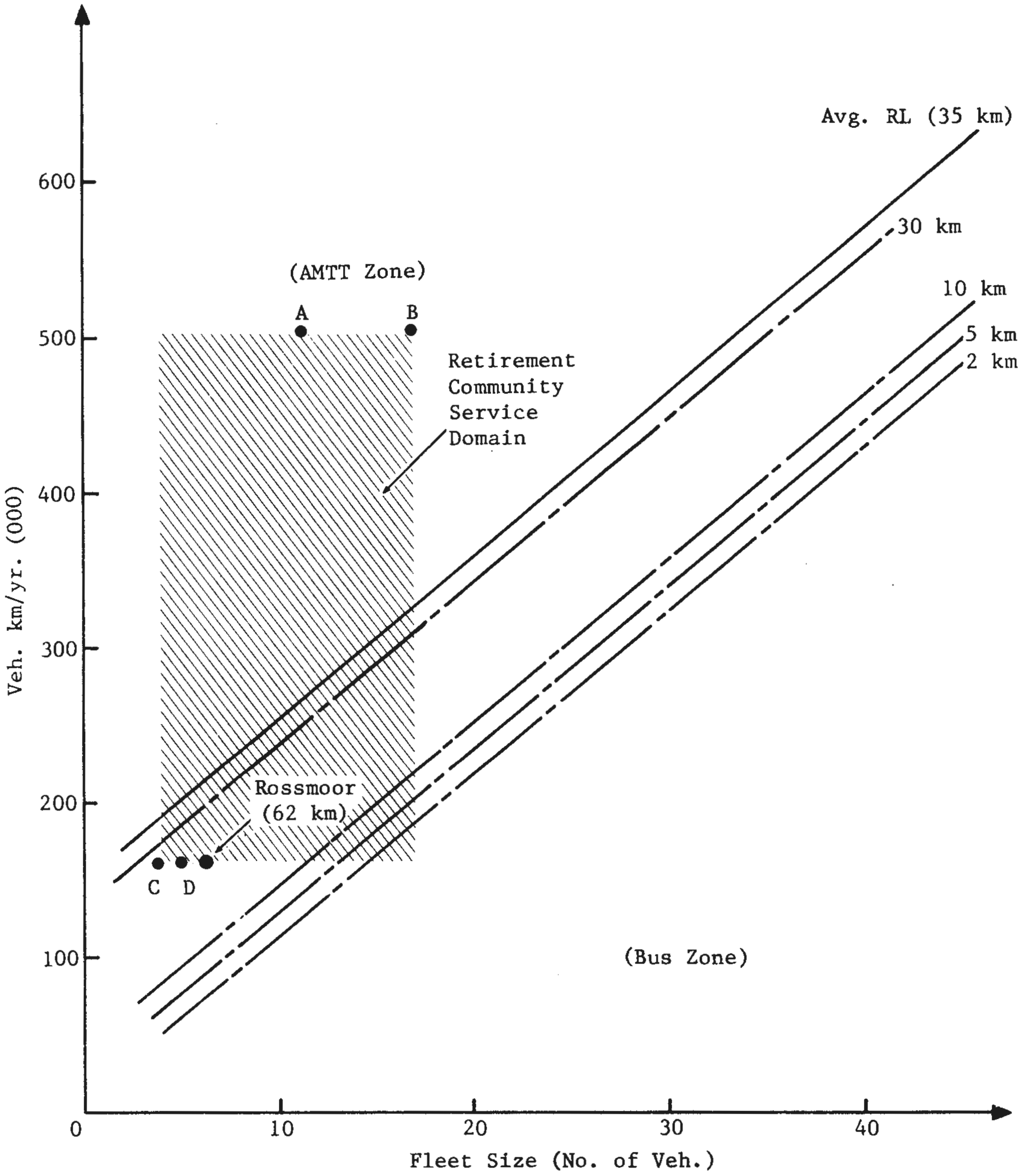
A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

D - low service level, low speed

FIGURE 5.9 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS (SMALL-SIZED VEHICLES) —RETIREMENT COMMUNITIES MARKET ANALYSIS.



A - high service level, high speed

B - high service level, low speed

C - low service level, high speed

D - low service level, low speed

FIGURE 5.10 ISOCOST LINES BETWEEN NEAR-TERM AMTT AND BUS MEDIUM-SIZED VEHICLES) —RETIREMENT COMMUNITIES MARKET ANALYSIS.

6. SUMMARY AND CONCLUSIONS

The information gathered and the analyses performed during this study indicates:

Market Potential

a. AMTTs may find potential application in medical centers, airports, selected CBD malls, some universities and colleges, new towns, large shopping centers, and in a number of recreation areas and amusement parks.

b. AMTT would be less costly compared to conventional bus transit in application areas where the fleet requirement is relatively low and a high level of service is needed (i.e., high annual vehicle kilometers operated). This can best be illustrated by the analyses of airports and medical centers. In both of these application areas, small fleets of small- to medium-sized vehicles are required to provide a relatively high frequency of service. Table 6-1 summarizes the AMTT market penetration potential based on cost comparisons with conventional bus in different application areas with different size vehicles.

c. Parametric curves presented in this study and other similarly developed parametric curves between AMTT and its competing modes can serve as useful tools for transportation planners and transit system operators in evaluating the application potential of AMTT. In the planning stage, specific system information or ranges of transportation requirements and service characteristics can be used jointly with appropriate parametric curves to determine if AMTT is a cost-competitive mode compared with other alternatives. For a transit system operator, several operating parameters can be varied to evaluate the cost of AMTT versus other modes.

d. A suitable AMTT vehicle has not been fully developed although the concepts have been proven on a prototype. Additional technology development is required, particularly in the area of sensors, as well as a public demonstration of the AMTT concept. Actual market penetration will be predicated on the successful results of these efforts.

TABLE 6-1 - POTENTIAL AMTT MARKET PENETRATION BASED ON COST COMPARISONS WITH CONVENTIONAL BUS*

Application Area	Vehicle Size Small	 Medium	 Large
Universities	-	60-90%	30-50%
CBDs	-	80-100%	50-80%
Airports	100%	100%	-
Medical Centers	100%	95-100%	-
Retirement Communities, New Towns, etc.	50-100%	40-90%	-

---

*Based on results of parametric analysis performed in Section 3 and ranges of transportation requirements and service characteristics prescribed in Table 5-1. Vehicle sizes not evaluated are represented by "-".

e. A long-term AMTT may not longer require barriers to delineate and protect the AMTT rights-of-way. Reliability and safety would be further improved. With the removal of barriers, the average market penetration potential of long-term AMTT would improve by approximately five to 25% relative to near-term AMTT in most application areas. The improvement would be more significant in systems with longer route lengths.

Comparison with Alternative Modes of Transportation

a. AMTT systems may be regarded as viable alternatives to other existing modes of travel, when fully developed.

b. Walking speeds average 5 km/hr (3.1 mph); therefore, for AMTTs to demonstrate some travel time advantage, their speeds must be greater than walking speed.

c. Conventional pedestrian conveyors are relatively expensive, usually operate at one-third to one-half walking speed, have a high capacity, but are limited by cost and technical considerations to specialized activity centers such as airports.

d. Minibuses and medium-size buses are most often used to serve small areas such as CBDs, universities, and airports. The cost of the driver is a significant percentage of their operating costs.

e. Electric buses have not yet gained popular acceptance. Route lengths and capacities may be limited by battery recharging and power considerations. The cost of a driver is also included in overall operation costs.

f. Private automobiles serve a major portion of the population. Their usefulness in low density areas is clear, but their advantages over other modes rapidly diminishes in settings such as CBDs, universities, airports, and medical centers.

g. Automated guideway transit systems operating on fixed guideways along exclusive right-of-ways have found application in airport service, amusement parks, on one university campus, and in a mixed-use development.

h. AMTT's main advantages are low O&M cost when compared with conventional driver-operated transit modes and relatively low capital cost when compared with other automated transit modes. AMTT systems are attractive alternatives to other modes, such as AGT, pedestrian walkways, and conventional buses in applications where the annualized total cost of AMTT is less than that of the alternative.

i. Practical operation of AMTT vehicles on sections of at-grade right-of-way protected by barriers is required to achieve speeds competitive with most AGT and bus modes in most applications.

j. Considerable development of sensor systems and vehicle configurations is necessary to make AMTT a more desirable mode of transportation than others in many application areas. Such efforts are currently underway.

Driverless Vehicles: State-of-the-Art

a. The driverless vehicle industry is more than 20 years old, well developed, and continues to improve the state-of-the-art in automatic materials-handling vehicle systems technology.

b. The technologies for the guidance and control of wire-following vehicles are well known.

c. Contact obstacle detectors (bumpers) for wire-guided vehicles have been developed and in use for some time.

d. Driverless vehicles are usually electrically powered, environmentally clean, and able to operate in harsh conditions.

e. Driverless vehicles are currently almost exclusively used to move goods and materials. Three manufacturers of these vehicles--Atco, Inc., Barrett Electronics Corporation, and the Control Engineering Company--however, have attempted entry into the people-moving market.

f. Because all past experience with passenger service driverless vehicles used currently available materials-handling equipment, existing performance and cost data can be used to estimate comparable people-moving costs.

g. At this time, the driverless vehicle manufacturers consider the people-moving market to be too risky because of liability considerations. Liability insurance costs and past settlements unfavorable to the vehicle manufacturer serve as a basis for this judgment. Barrett Electronics Corporation has chosen to evaluate the product liability risk of each potential application prior to its manufacturing the vehicle.

The JPL Automated Mixed Traffic Transit (AMTT)

a. The JPL wire-following driverless vehicle (AMTT) is based on a converted electric tram to which sensing and control components are added.

b. The JPL AMTT is equipped with an array of long- and short-range proximity sensors that can detect obstacles far enough ahead of the vehicle to permit a controlled stop. However, it is not adequate for people moving in mixed traffic, because the current sensor array is not sufficiently efficient to stop the vehicle from hitting a pedestrian who steps in front of it from an angle. Research is currently being conducted to improve the field of scan for the sensors to allow safe mixed traffic operations.

c. The current vehicle operates at 11.3 km/hr (7 mph), automatically slowing to 3.2 km/hr (2 mph) when an obstacle enters the primary sensor field.

d. The relatively low cost of the JPL vehicle, its sensors and the wire guidepath, make it a potentially attractive alternative to other modes of transportation in selected locations.

APPENDIX A.1

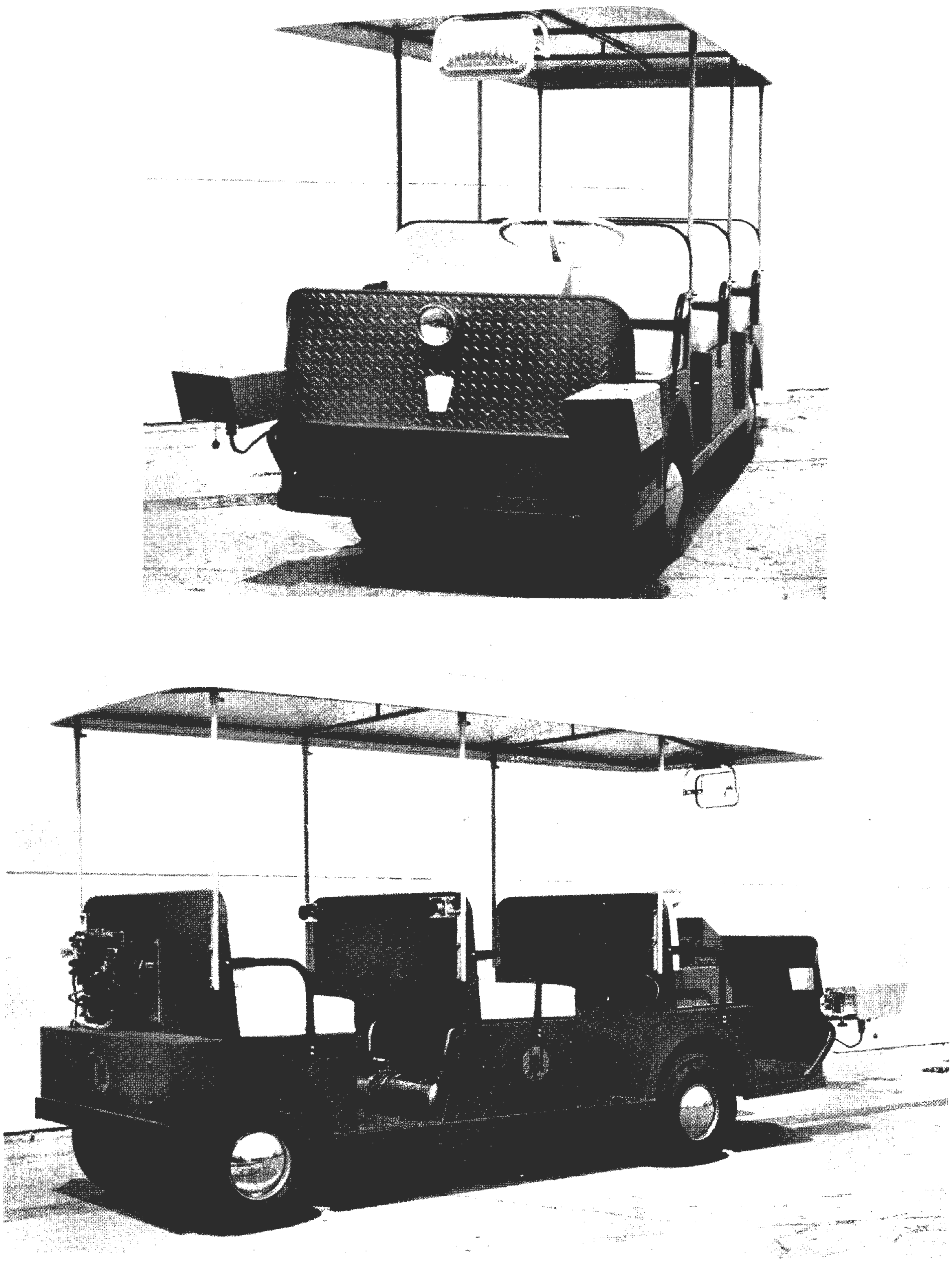
THE JET PROPULSION LABORATORY EXPERIMENTAL AMTT SYSTEM

The technology required for AMTT operation is being developed at the Jet Propulsion Laboratory (JPL), Pasadena, California. The JPL project team has equipped a conventional battery-powered electric tram with optical and contact sensors, motor and braking control, and a lateral steering system to demonstrate the sensor and control technology required by an AMTT in actual use. The experiment was not intended to demonstrate the full transit capability of the AMTT, however. Thus, items such as brake interlocked side-contact bumpers, boarding steps, and interlocked doors were omitted to conserve funds.

A.1.1. The Vehicle and its Operation

The present JPL vehicle is based on a commercial six-passenger electric tram (manufactured by Taylor Dunn, Inc., Anaheim, California) to which sensing and control components have been added to permit automated operation following a buried sense cable. This experimental breadboard vehicle is shown in Figure A.1.1. A speed of 11.2 km/hr (7 mph), about three times normal walking speed, has been selected for the cruise mode on straight sections of the route. Established vehicle guidance techniques for following a buried cable are used. Optical headway sensors are used to detect pedestrians or other vehicles in the path of the JPL vehicle to a distance of 7.8 meters (25 feet). Intrusion into this area, in front of the vehicle, will cause it to slow to 3.2 km/hr (2 mph). A second and independent sensor channel that detects objects at approximately 3 meters (10 feet) in front of the vehicle will cause it to come to an emergency stop.

In the operating mode, the vehicle continuously follows a (buried) guide cable, making brief stops for passengers. Because the desired speed of 11.2 km/hr (7 mph) is too fast for a turn, the vehicle was programmed to stop prior to the entry into a turn, and move through the turn at a walking pace. Riders are instructed to wait at one of several designated points for the vehicle to approach.



SOURCE: JPL

FIGURE A.1.1. THE JPL EXPERIMENTAL VEHICLE

After stopping, the vehicle waits 4 seconds, and then moves on. If one or more passengers board, the vehicle will be inhibited from moving by passenger stop switches located on the canopy supports. When the passenger is seated in the vehicle, he releases his grip, allowing the vehicle to move on. These same pressure switches will command the vehicle to stop at any time so that passengers can get off at will.

As part of the test program, the vehicle described above was operated on JPL property (see Section A.1.5) on a daily basis from February 1 to June 30, 1976, with an onboard safety observer. Although it was pointed out that riders could stop the vehicle anywhere with the canopy support stop switches, passengers chose to leave the vehicle only at the programmed stops. The vehicle was operated for 1 hour each morning and afternoon. During the test period, the loop was traversed a total of 1,432 times, with no accidents or injuries to either passengers or pedestrians. Since the conclusion of the test, the vehicle has been used intermittently, also with no incidents.

Tests of the vehicle's sensor systems were performed regularly as follows:

a. Stopping distance was checked before each run by the use of a blackened test target.

b. Sensor output was noted with the test target in various positions.

c. Background noise level was recorded.

These tests, designed to bring out any change or failure before the tram was run, have confirmed that the sensor performance is stable.

The experiment did point out some areas where further technical development is required. These include improvements in sensors to see higher targets and look in the direction of turns, and improvements in the control system to reduce the control lag in response to sensor stimuli. In addition, the design of the vehicle itself must be modified before it is put into transit use; such modifications include styling, circumferential safety bumpers, wheel skirts, and improved passenger interfaces.

Specific subsystems involved in the operation of the AMTT are described below.

A.1.2 Vehicle Subsystems

A.1.2.1 Headway Sensing Subsystem

The headway sensing subsystem contains an array of long-range and short-range proximity sensors that can detect obstacles far enough ahead of the AMTT to permit a controlled stop. The sensing subsystem also has front and side bumper switches that actuate on contact with smaller objects or large obstacles that for any reason, have escaped detection by the proximity sensors. The contact switches trigger a locked-wheel stop.

A.1.2.2 Steering Subsystem

The steering subsystem contains a set of electromagnetic detectors that receive and resolve lateral error signals from the electrically excited guide cable installed in the pavement, plus control actuators, which operate the steering control linkage to maintain the vehicle on course.

A.1.2.3 Signal Processor Subsystem

The signal processor subsystem consists of the control electronics and associated logic to receive inputs from various sensors (headway, steering, tachometer, etc.) and on-board switches that generate appropriate command signals for speed, braking, and steering subsystems.

A.1.2.4 Drive Motor Control Subsystem

The drive motor control subsystem uses command signals from the signal processor subsystem to control the traction motor torque.

A.1.2.5 Braking Control Subsystem

The braking control subsystem contains the actuators and drive electronics necessary to apply and control the hydraulically actuated service brakes in accordance with signals generated by the signal processor subsystems.

A.1.2.6 Vehicle Chassis Subsystem

The vehicle chassis subsystem consists of the basic chassis, body, suspension, braking system, propulsion (drive motor and battery), and other components that are normally a part of a conventional manually-controlled electric vehicle.

A.1.2.7 "Passenger Interface" Subsystem

The passenger interface subsystem consists of a number of safety and operations-related devices necessary to convert a general-purpose vehicle to AMTT operations. Items such as disembark call button switches, emergency switch buttons, automatic door operations, boarding threshold switches, seat switches, etc., are included.

A.1.3 Stationary Subsystems

A.1.3.1 Route Subsystem

The route subsystem includes the guidewire installation, electric exciters, signalling system for routine stops and turns or curves and traffic separators (fence, curb or painted lines).

A.1.3.2 Passenger Station Subsystem

The passenger stations may include sign posts, marked boarding lanes or stiles, benches, and overhead cover or boarding call buttons to signal the AMTT system that passengers are waiting to board.

A.1.3.3 Maintenance and Storage Garage

The maintenance and storage garage consists of a protected facility with proper equipment for off-line storage, repair, and routine maintenance of vehicles.

A.1.3.4 Dispatching and Fault Detection Subsystem

The monitoring and fault detection subsystem includes equipment for monitoring system operation and for detecting and responding to system breakdowns. Included also are fault recovery and emergency response procedures.

A.1.3.5 Check-out Subsystem

Consists of equipment and procedures to confirm the correct functioning of system hardware before an AMTT is put into service. The dispatching subsystem consists of equipment for automatic control of vehicle schedules, route spacing, and load factors.

Detailed discussions of these systems and their operation have been given in previous reports(32,33) and will not be covered here. The data necessary for the evaluation in this report are given below.

A.1.4 Speed

The current experimental test vehicle has been operated at speeds up to 11.2 km/hr (7 mph). Average speeds may be less than half maximum speed because of the need to stop for passengers and slow for pedestrian and vehicular traffic competing for the right-of-way. Under the best of circumstances, with no competition for right-of-way, the vehicles cannot expect to average more than about 9.6 km/hr (6 mph), however, assuming stops every 409 meters (0.25 mile). A second generation vehicle is envisioned that could operate at speeds up to 32.0 km/hr (20 mph) on an at-grade protected right-of-way separated from pedestrians. The vehicle would leave the separated right-of-way to pick up and discharge passengers. Such operation could substantially increase average travel speeds and vehicle utility.

A.1.5 Route

The present route at JPL is a single loop of 610 meters (0.4 mile) total length, as shown in Figure A.1.2. The U-turns at each end are executed at intersections that are protected by stop signs. The intermediate intersection is also a four-way stop. The guide wire is a No. 12 copper wire buried in a 25 mm. (1 in.) deep groove sawed in the road surface and backfilled with a sealant compound. The wire is in the form of a continuous loop excited at 10 kHz by a low-power oscillator placed near the roadside. The ends of the guidance wire are brought to the side of the road in an intersecting slot cut transverse to the roadway. The dc resistance of the loop is 3.2 ohms, and the drive current was 175 mA rms. A 1.6 km. (1 mile) length of wire could be driven with about 2 watts of power at 10 kHz.

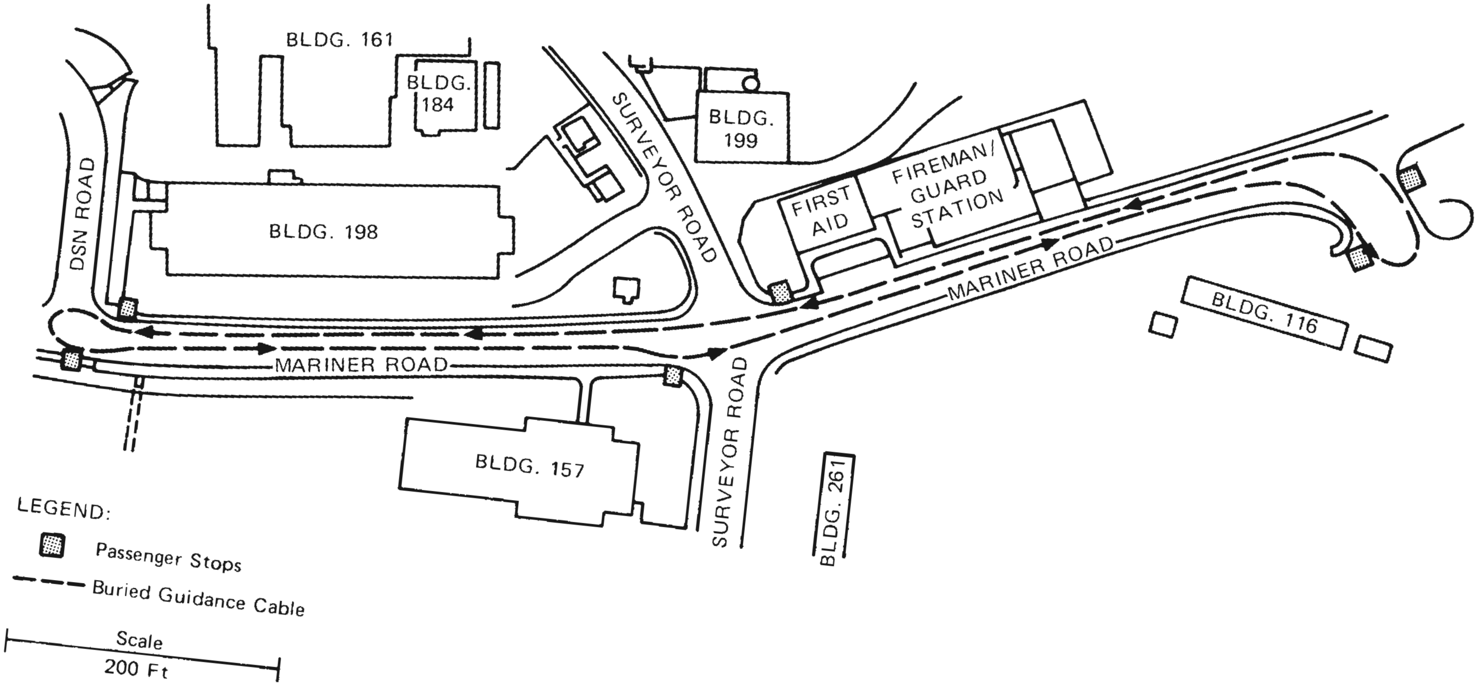


FIGURE A.1.2. ROUTE MAP OF JPL AMTT

A.1.6 Acceleration, Deceleration, Jerk

The specification limits chosen by JPL for the AMTT are:

Normal acceleration/deceleration:	1.5 m./sec.^{2} (5 fps^2)
Emergency deceleration:	3.2 m./sec.^{2} (10.5 fps^2)
Normal Jerk:	1.5 m./sec.^{3} (5 fps^3)
Emergency Jerk:	3.2 m./sec.^{3} (10.5 fps^3)

For purposes of comparison, typical rates for other transit systems are:

	Max. Normal Longitudinal Acc/Decel m./sec.^{2} (fps^2)	Max. Emergency Deceleration m./sec.^{2} (fps^2)	Normal Longitudinal Jerk m./sec.^{3} (fps^3)
AGT SYSTEMS			
Morgantown	0.6 (2.0)	3.2 (10.5)	1.3 (4.2)
AIRTRANS	1.2 (3.8)	2.7 (9.0)	0.8 (2.5)
RAPID RAIL			
BART	1.5 (4.8)	1.5 (4.8)	---

Source: U.S. DOT and JPL.

A.1.7 Capacity

The prototype experimental vehicle has three bench seats that face forward and accommodate a total of six passengers. No standing room is available. Vehicles of this size, given 1-minute headways, could carry 360 persons per hour, one way. The sensing devices are, however, capable of being adapted to larger vehicles. For example, if the GM vehicles envisioned for use in Denver were adapted to AMTT service, a capacity of over 5,500 persons per hour, per direction would be possible.

A.1.8 Costs

JPL has estimated the cost of the prototype vehicle and sensing equipment in 1976 dollars, assuming the vehicle was in production. The cost of the vehicle, with appropriate control electronics and sensors, was $16,462 (see Table A.1-1 for details). The guidepath, as described earlier was estimated at $5,658 per 1.6 km. (1 mile).

If a separated guideway is required, costs would increase. For example, 11-gauge cyclone fencing, 6-feet high with a 41.3 mm. (1-5/8 in.) top rail, costs $3.70/foot or $19,536/1.6 km. (1 mile) installed. Costs for the above system, with fencing and a prepared surface, could reach approximately $45,000. Additional paving and wayside sensors would add to the cost.

TABLE A.1-1 - ESTIMATED AMTT HARDWARE COSTS
(1976 Dollars)

	Subsystem	Total
Vehicle costs		
Basic vehicle including SCR controller		7,150.00
Hydraulic actuation brakes and steering		
Parts	2,200	
Assembly	550	
		2,750.00
Speed control service		
Tachometer	77	
Parts fabrication	220	
Assembly	110	
Electronics	220	
		627.00
Control electronics		
2 circuit cards	440	
Assembly	110	
		550.00
Headway sensor		
21 optical elements	2,310	
4 circuit cards	600	
Assembly	550	
		3,460.00
Steering sensor		
Pickup head	550	
Circuit card	165	
Assembly	110	
		825.00
Bumper and switches	1,100	1,100.00
Total		16,462.00
Route costs for 1 mile of route		
Guideway		
Wire	232	
Layout	290	
Saw cutting	871	
Epoxy filler	580	
Labor to place wire	928	
Signs and placement	1,742	
Magnet placement	290	
Total	4,933	
Exciter		
Box	65	
Electronics	330	
Labor to install	330	
Total	725	

Source: JPL

APPENDIX A.2

GENERAL MOTORS CORPORATION'S ELECTRIC PEDESTRIAN MOVER

A.2.1 Background

Between November 1974 and August 1976, the Transportation Systems Division (TSD) of General Motors Corporation (GM) developed and marketed a 3.5 km/hr (2.2 mph) AMTT based on the free access concept that was called the Electric Pedestrian Mover (EPM). It was demonstrated for 4 days in August 1975 in a shopping mall in Battle Creek, Michigan.

A.2.2 History

In November 1974, GM's TSD began a project to develop a new public transit vehicle called the Electric Pedestrian Mover (EPM). The EPM was intended to provide the same service as a moving sidewalk with the advantage that the passenger could get on or off at any point along the route.

The first test bed vehicle, called EPM-1, was running in May 1975. A major portion of the vehicle was fabricated by Control Engineering Corp., which used their materials-handling driverless vehicle technology and TSD's design. On August 25-28, 1975, EPM-1 was tested in service for 4 days in the outdoor Michigan Mall shopping mall in Battle Creek, Michigan. EPM-1 was then demonstrated in 26 cities in the fall of 1975 and the spring of 1976, as part of GM's Civic Leaders Tour.

On the basis of experience gained with EPM-1, the TSD began the design of an improved EPM, EPM-2, in November 1975. The TSD used Barrett Electronics Corp. as the subsystem contractor.

In the fall of 1975, the City of Memphis, Tennessee expressed interest in using EPM vehicles in their new downtown pedestrian mall. The TSD submitted an unsolicited proposal in February 1976 to install a six-vehicle system. The cost was more than the City of Memphis could afford, however, and the project never began.

In December 1975, with assistance from Peat, Marwick, and Mitchell, consultants, the TSD completed a market analyses of the EPM. The analysis estimated that the total market over a 10-year period for GMs EPM would be less than 50 vehicles per year.

In August 1976, TSD management decided to stop the EPM program, including all technical development and marketing efforts because the estimated sales volume was too small for GM to consider it as a profitable new product venture. Although EPM-2 was then 90% complete, it was never finished.

A.2.3 System Description*

General Motors defined and developed a free access transportation concept to provide a low capacity alternative to walking for those who need or want to use it.

The free access concept(34) has four basic characteristics (Figure A.2.1). First, a passenger-carrying, platform-like vehicle moves continuously at-grade level at about walking speed, without stopping. Second, passengers may board or exit the vehicle at any point by simply stepping on or off while it moves along. Third, pedestrians are free to move without restriction around the vehicles. And fourth, to accommodate users such as those on crutches or with strollers who cannot step onto a moving vehicle, the vehicle stops at certain locations on demand.

A.2.3.1 Test-Bed Vehicles

General Motors used standard industrial drive systems, guidance systems, and programmable control systems (including the blocking feature) supplied by Control Engineering Company for EPM-1 and Barrett Electronics Corp. for EPM-2. The first vehicle, EPM-1, was an open configuration (Figure A.2.2) designed for use in an airport or enclosed mall. Seating for four passsengers and lean pads for at least eight more were provided.

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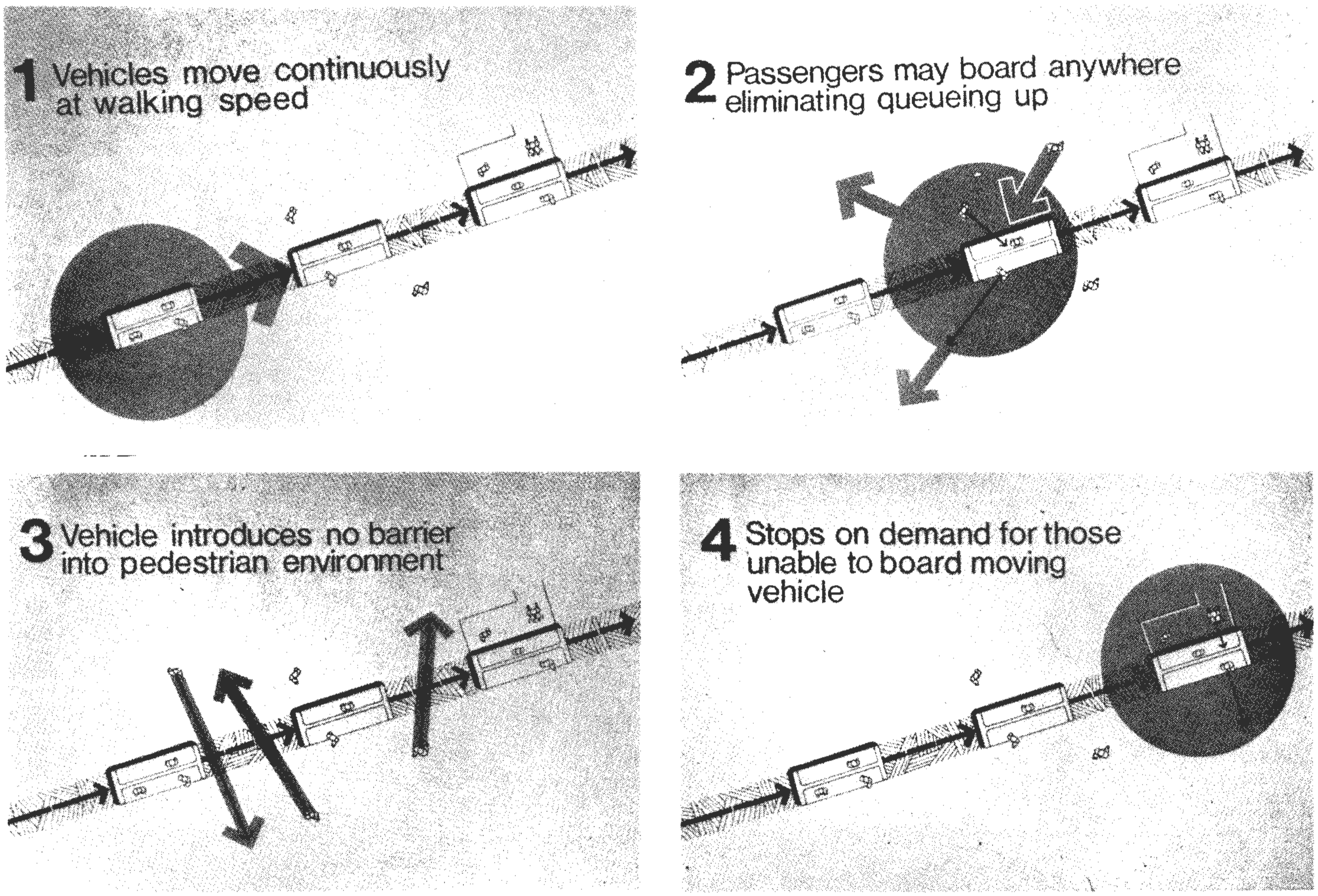
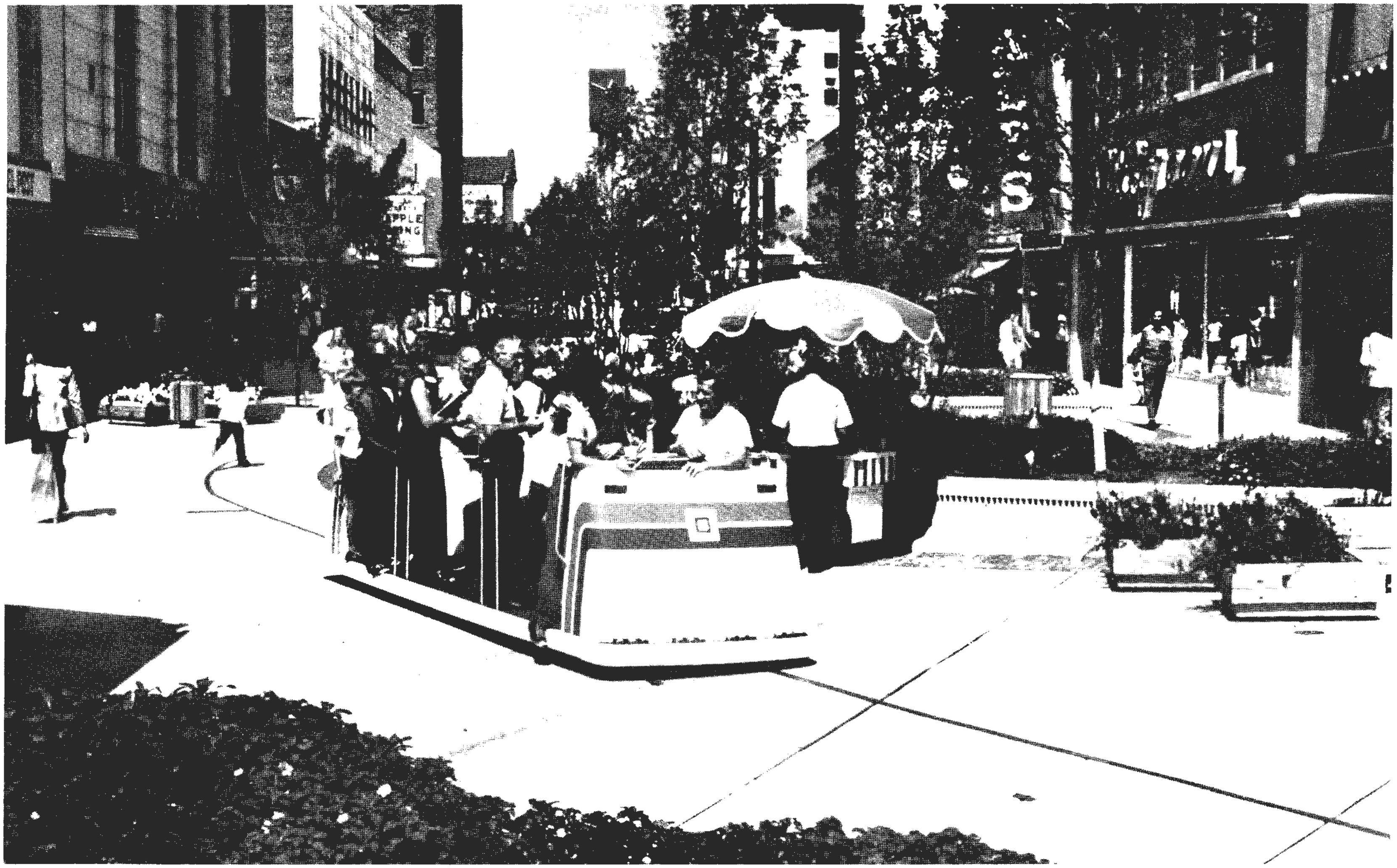
*Much of the following description was obtained from a proposal for "Design, Delivery and Implementation of an Automated Pedestrian Transit System" written by Mr. W. J. Cattin, Manager, Marketing Special Project, GM Transportation Systems.



SOURCE: General Motors Corp.;
Transportation Systems Division

FIGURE A.2.1. THE FREE ACCESS CONCEPT



SOURCE: General Motors Corp.

FIGURE A.2.2. EPM-1, THE OPERATIONAL TEST-BED VEHICLE

Because of the low vehicle step height of 19.1 cm. (7.5 inches), a suspension system was not included. Low vehicle height with a long wheel base limits ramp breakover to 2 (or 2.2%) before the undercarriage hits ground.

The vehicle was powered by a 3-h.p. electric motor with batteries located in the ends. The vehicle had four wheels: the left front wheel steered, the left rear wheel drove, and the two right wheels were castors. Guidance sensors were located on both ends, so the vehicle would run equally well in the forward and reverse directions.

The vehicle was guided by a signal wire and was controlled by an on-board programmable logic system that received inputs from permanent magnets embedded in the surface of the guidepath. This system was used to stop the vehicle or change speed at fixed locations, select the proper guidepath direction at an intersection, prevent vehicles from bunching together, and energize an on-board speaker system.

The specifications for the EPM and other AMTT vehicles are summarized in Tables A.2-1 and A.2-2.

A.2.3.2 Safety

The EPM vehicles had several passenger and pedestrian safety features.

All EPMs had a noncontact obstacle detector. The noncontact object detector used on EPM-1 was an infrared (IR) optical system similar to one that Control Engineering Co. used on its materials-handling driverless tractor system. The IR detector system was made by Scientific Technology, Inc., Mountain View, California. A series of four transmitters and three receivers were located across the front of the vehicle just above the bumper. The detector's range was between 2 and 4 feet. GM identified two problems with this system: (1) sunlight swamped the photodetector making the system inoperable, and (2) it could not detect certain clothes colors (e.g., gray) and textures (e.g., corduroy).

Realizing that the noncontact object detector performance was the key to the EPM's mixed traffic function, GM developed its own infrared detector for use on EPM-2 (Figure A.2.3). Using a transmitter mounted low on each side of the vehicle's front and two receivers above, and special lens developed by GM engineers, GM was able to cover an area equal to the front cross section of

Table A.2-1

DESCRIPTION OF AMTT SYSTEMS

	General Motors Corp. Electric Pedestrian Mover--1	General Motors Corp. Electric Pedestrian Mover--2	General Motors Corp. Electric Pedestrian Mover--Memphis for Mid-America Mall	Barrett Electronics Corp. Tunnel Train in Houston Intercontinental Airport	Otis Elevator Co. People Mover in Cleveland Hopkins Intercont. Airport	Richard Bowen and Assoc. People Mover Specification for Cleveland Hopkins Intercontinental Airport
Vehicle						
Train makeup	1 Vehicle†	1 Vehicle†	1 Vehicle†	1 Tractor* 3 Passenger cars*	1 Tractor 1 Passenger trailer	2 Passenger units with own or separate propulsion unit
Length (ft)	17.1†	16.0†	19.2† max	45†	16*	38.0 max
Width (ft)	4.8†	4.4†	5.4† max	5†	5.7*	4.25 max
Height (ft)	3.7†	4.2†	4.2† max	7.5†	8.0*	5.25 max
Weight (lbs)	3,400†	3,700†	5,000 max	13,500^{*1}	6,000†	7,000 max
Propulsion power (hp)	3†	3†	3†	Two 6-hp motors‡	15‡	
Battery size (volts/amp-hrs)	24/460†	24/680†	36/630	72/600‡	24/980‡	
Service brake type	Coast/dynamic (electronic)†	Coast/dynamic (electronic)†		Electromagnetic* (dynamic)	Dynamic†	Air or electric actuated disc or drum
Emergency brake type	Mechanical disc†	Mechanical disc†		Electromagnetic*	Mechanical shaft‡	Spring load disc or drum
Noncontact obstacle detector type	Infrared optical†	Infrared optical†	Infrared optical	Optical scanner*‡	Ultrasonic detector‡	Sonic
Emergency stop bumper	4.8 ft wide	4.4 ft wide		Feeler for objects ≤ 3 in. above floor	3.4 ft wide on tractor	Impact detector
Suspension type	None‡	None‡		None†		Coil spring and adjustable air shock absorber
Passenger capacity						
Seats	4†	0‡	8-9†	21*	12‡	12
Normal load	14†	12*	14-18†	30*	22‡	36
Crush load	35†	30*	30	40*		42
Elderly and handicapped accommodations	Yes, if stopped at ramp‡	Yes, if stopped at ramp‡	Yes†	Yes*	No*	No
Doorway width (in)	150	130	130	46*	96*	
Step height (in)	7.5†	7.0†	7† max	0*	7.5*	6.0 max
Guidepath						
Location	Level indoor (shopping center or airport) or fair weather outdoor*	Level indoor (shopping center or airport) or fair weather outdoor*	Outdoor mall	Tunnel†	Concourse†	Concourse
Length (ft)				3,340*	2,200*	2,320
Width (ft)	5	4.6		6.0†	6.5	4.75
Height (ft)	8	8		8.0†	9.75	9.75
Maximum grade (%)	2.2† veh. capability	2.2† veh. capability	3.3 min† veh. capability	0*	0‡	0
Minimum turning radius (ft)	9† veh. capability	8† veh. capability	10 min† veh. capability	15.0†	12.5*	12.5
Number of stations				6*	4‡	5 min
Station spacing, average (ft)				700*	580	450
System						
Fleet size						
Tractors	1	1	7	4*	3*	10
Passenger cars				12*	3*	20
Control type	Vehicle programmed	Vehicle programmed		Vehicle programmed and central control*	Vehicle programmed	Vehicle programmed and central control
Blocking type				Zone and continuous‡	Zone‡	
Schedule				Variable*	Variable†	
Passenger information	Brochure			Recorded instructions*‡ and visible destination signs	Signs with boarding instructions and hostess	Public address system

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1 tractor = 3000 lb; battery = 5400 lb; each passenger car = 1700 lb.

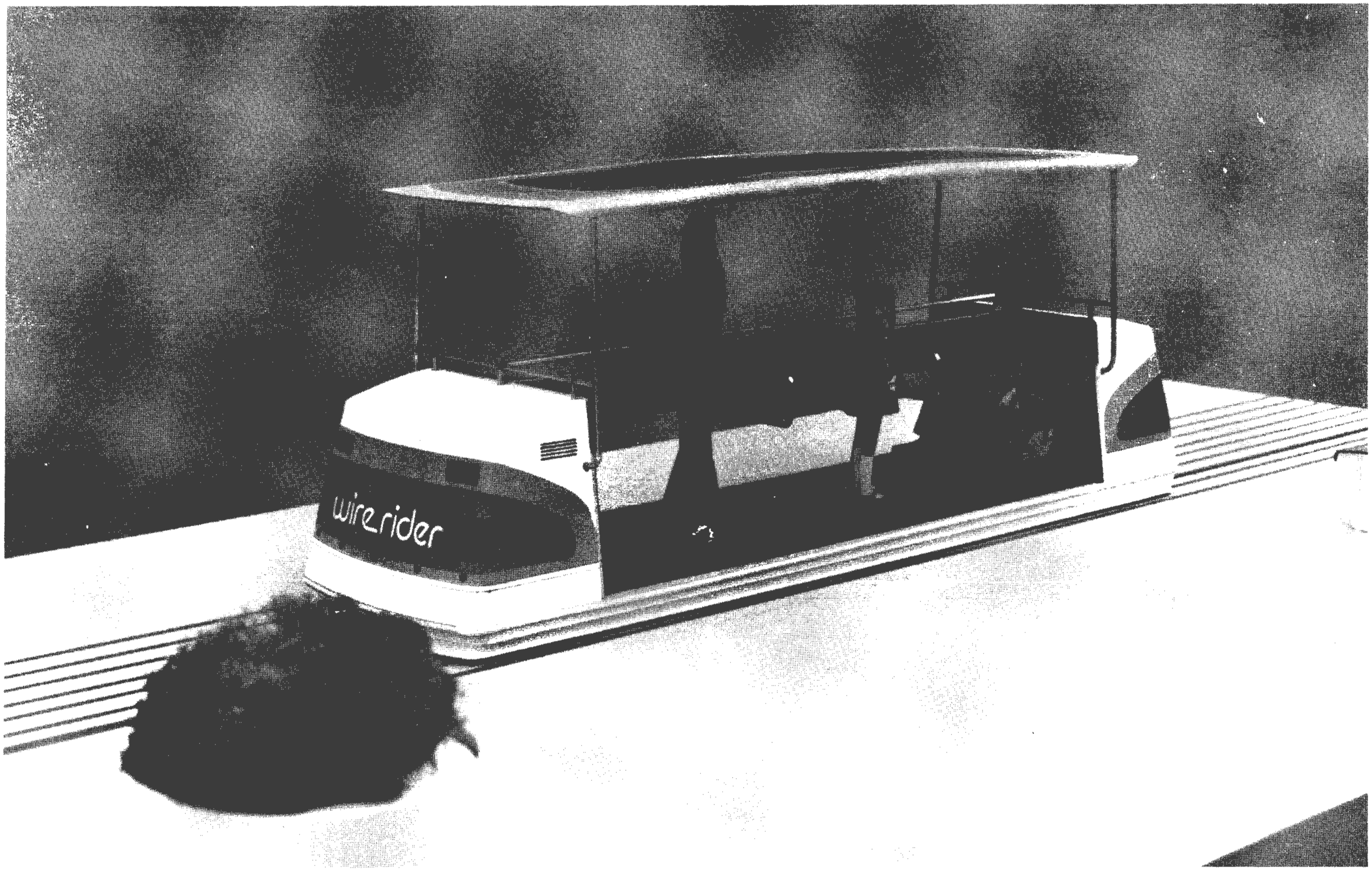
Sources: *Operator
†Literature
‡Manufacturer

Table A.2-2

OPERATION AND PERFORMANCE OF AMTT SYSTEMS

	General Motors Corp. Electric Pedestrian Mover--1	General Motors Corp. Electric Pedestrian Mover--2	General Motors Corp. Electric Pedestrian Mover--Memphis for Mid-America Mall	Barrett Electronics Corp. Tunnel Train in Houston Intercontinental Airport	Otis Elevator Co. People Mover in Cleveland Hopkins Intercont. Airport	Richard Bowen and Assoc. People Mover Specification for Cleveland Hopkins Intercontinental Airport
Vehicle						
Maximum speed (mph)	3‡ (2.2 in service)	6‡	4‡ (2.2 in service)	8.5*	3.5†	5 (3.5 in service)
Acceleration (ft/sec^2)	3.2	3.2	3.2‡	4.4‡	1.4†	1.5 max
Jerk (ft/sec^3)	3.2†	3.2†	3.2†	Low†	Low†	3.0 max
Normal deceleration (ft/sec^2)	3.2	3.2	3.2	2.1‡	3.0*	3.0
Emergency deceleration (ft/sec^2)			12.8	10.4*	8.8	9.0
Emergency stop diatance (ft)				15*	3†	
Obstacle detector range (ft)	2-4	2-4	6-12† and 12-20†	Optimum at 30† Capable to 100†	50†	10
Battery range (hrs)	8†	8†	8*	8*	9†	
Battery change time (min)	Not changed			0.5 to 2*	Not changed	Not changed
Battery recharge time (hr)	8†	8†	8	8*	8†	8
Noise				Between 70 and 80 dBA inside cars	No data	Not exceed NC 45 at 5 ft
Ride quality	Rough on rough† surface			Rough‡	Rough	
Safety				In 3 yr operation, no system caused accidents	No accidents	
Reliability (MTBF)				Minor: 3-4 days* Major: 4-6 months*	No data	1,000 hr
Maintainability (MTTR)				Minor: 1-2 hours* Major: 6-8 hours*	No data	15 min
Availability (%)				91*	No data	
System						
Operating days per week				7*	7†	7
Operating hours per day				24*	14†	20
Operating fleet size						
Peak				4*	3†	10
Off peak				2 or 3*	1 or 2†	3 to 5
Minimum headway (min)				2‡	4*	1.0
Station dwell time (sec)				20-25*	45 at end stops 10 at midway	30-45
Average travel speed (mph)				2.4-2.9	2.2	2.2

Sources: *Operator
†Manufacturer
‡Literature



SOURCE: General Motors Corp.

FIGURE A.2.3. EPM-2, THE PROTOTYPE VEHICLE

EPM-2 out to 1.5 meters (5 feet) ahead. However, there was one conical volume with its base at the vehicle and its apex less than 0.6 meters (2 feet) in front of the vehicle that was a blind area to the GM IR detector. The lens technology used was a key factor in the detectors effectiveness in laboratory tests.

Because EPM-2 was not completed, the GM detector was not tested on the vehicle in service. As a result of laboratory tests, however, GM engineers were confident it would give a much better performance than that of the detector on EPM-1.

GM also considered scanning sensors, sensors that would rotate into the direction of turns, and an array of sensors, some of which would be aimed into turns and others that would be aimed straight ahead. The object detector needs to be designed fail-safe and sabotage proof, according to TSD staff. The system would include:

- A horn that sounded with all stops and starts and when the object detector detected an obstacle.
- Flashing amber lights, two on the front and two on the rear.
- Speeds under 4.8 km/hr (3 mph).
- A foam-filled pressure sensitive contact bumper the width of the vehicle that commanded full braking when hit.
- Hand rails for passengers to hold.

A.2.3.3 Operational Test

In the public test of EPM-1 in downtown Battle Creek, Michigan, the vehicle shuttled back and forth over an approximate 105 meter (350 foot) long guidewire taped to the concrete mall surface. The vehicle operated for a total of 24 hours or an average of 6 hours per day. It operated at 3.5 km/hr (2.2 mph) with one 60-second stop at either end of the path. The average passenger load was estimated by GM staff to be about 25 or 30 people, which was 180% of normal load capacity. There were times, however, when as many as 40 people squeezed on board.

During the 4-day test, GM surveyed riders and nonriders encountered at the mall to get a public assessment of the EPM. The survey results are presented in the Systems Assessment part of this section.

A.2.4 EPM-Memphis

In 1974, the City of Memphis, Tennessee, began a long range program to revamp and revitalize its downtown area. Ten blocks of main street were to be transformed into the longest pedestrian mall in the United States. The mall was to act as a common pathway connecting the new $30 million Convention Center with the main CBD shopping district to the south.(35) The 1,200 meter (4,000 foot) long 47,700 square meter (530,000 square foot) Mid-American Mall was to take the form of a linear park (Figure A.2.4). Except for two blocks on one end, the entire mall was to be closed to automotive traffic.

Actual construction of the $3 million mall began in April of 1975. Aside from a few remaining improvements, it was essentially completed by late 1975. After researching transit system alternatives and seeing a GM film of the EPM, the City of Memphis expressed interest in the fall of 1975 in an EPM installation for the mall. During discussions, GM indicated that it would attempt to price an EPM installation within the city's budget and possibly take a loss in order to use Memphis as a test city.

In February 1976, GM TSD submitted an unsolicited proposal to install a six-vehicle EPM system for about $1.5 million. Even though development costs were included in this figure, city staff report that GM was still expecting to take a loss on the proposed installation. Modifying the EPM prototypes to take grades as high as 10% also contributed to the cost. Because of the high price and the risk of buying an unproven transit system, the proposal was never accepted. The city's project manager reported that had the price been closer to $250,000, the price of five minibuses that were also being considered, the EPM system probably would have been purchased.

A transit system has yet to be installed in the mall. The City Center Commission reports that there is little demand for one. Because the mall is used mostly by downtown office workers who would rather walk, and because few elderly people come downtown, there have been few complaints about the long walks sometimes required. At times, the mall gets so crowded with pedestrians that there would be no room for a vehicle anyway. Even so, the commission said it would still consider an AMTT system for a price of about $330,000. A description of the EPM-Memphis vehicles and the GM installation plan follows.

A.2.5 System Description

The following has been summarized from GM's proposal to the City of Memphis.

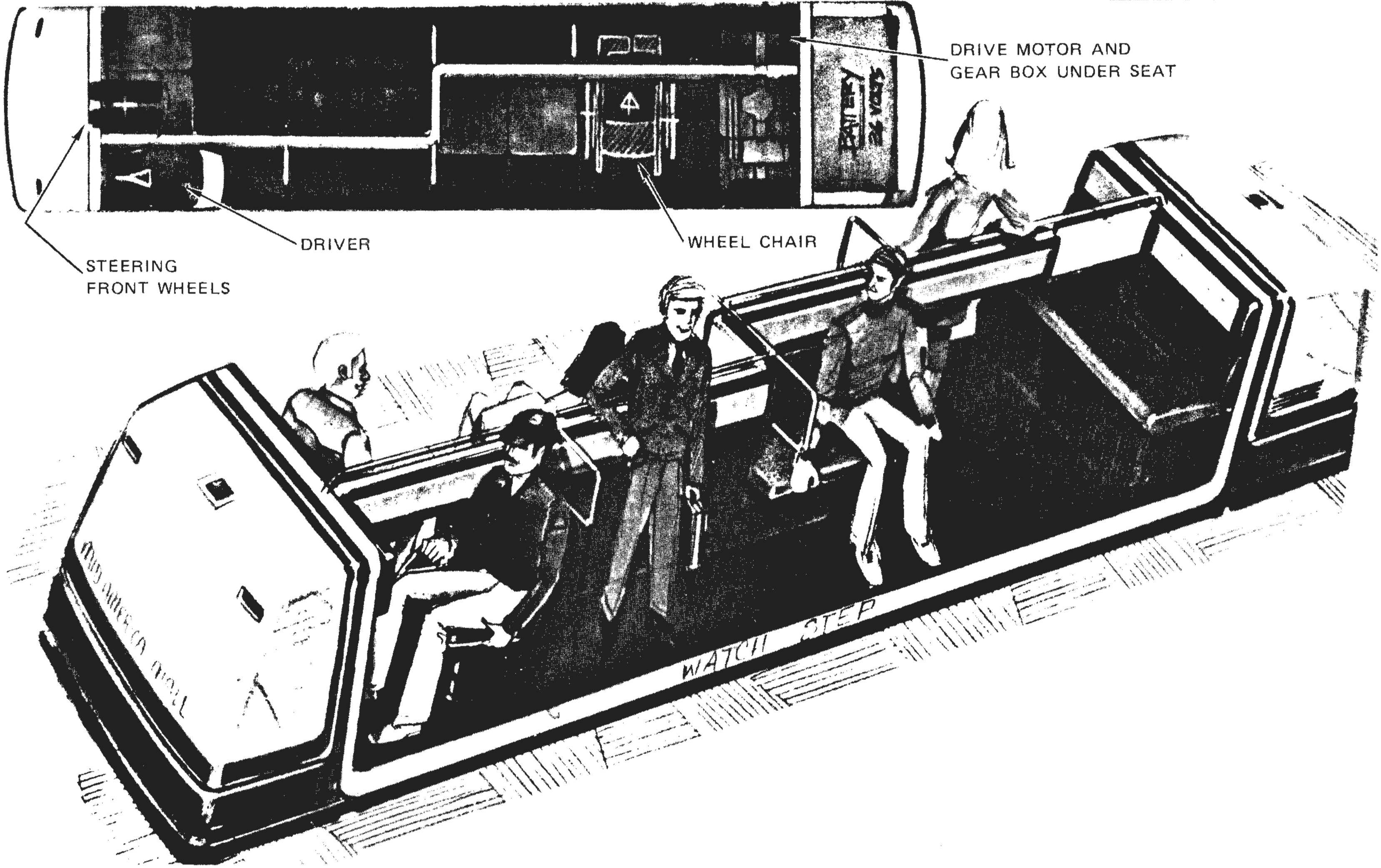
The pedestrian transit system proposed for the Mid-American Mall consisted of six vehicles (and one spare) that would operate in a continuous loop. Although the actual route of the system through the plaza areas was to be dictated by the pedestrian traffic and use patterns in these areas, the preliminary route was to be a loop, with McCall Street at one end and the fountain in front of City Hall at the other. The total loop would have been over 2,400 meters (8,000 feet) long. With six vehicles operating, the headway between vehicles was to be 3 minutes.

Two different vehicle configurations were considered for the Mid-American Mall. They are shown in Figures A.2.5 and A.2.6. The primary difference between these configurations is the arrangement of the drive axle and steer wheel: Configuration 1 is a tricycle arrangement with these components located in the ends of the vehicle, whereas Configuration 2 has the drive axle in the center of the vehicle. A preliminary description applicable to both vehicles is summarized in Table A.2.1.

The vehicles had the following features: boarding from either side, seats available from either side, removable top for weather protection, and space provided for wheelchairs. General Motors was also planning to build a suspension system because the vehicle would have to go over brick in the mall. The suspension system was to consist of spring-loaded castors and pneumatic tires because of the low height of the vehicle. General Motors also considered putting a vertical hinge in the Configuration 2 vehicle to increase the ramp breakover angle capability.

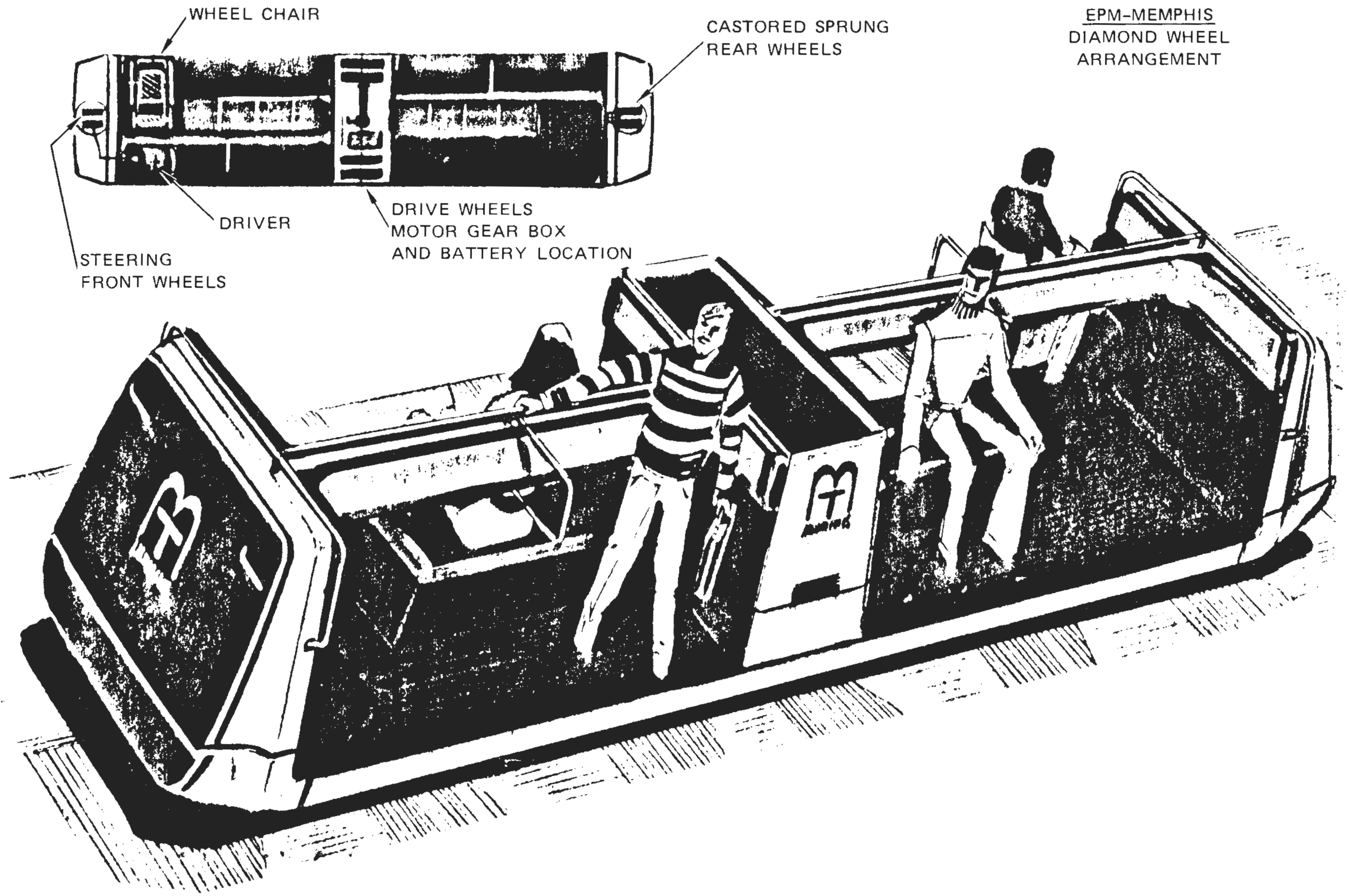
A.2.6 Implementation Plan

The implementation plan had three phases. The first phase was to initiate pedestrian transit in the mall with a manually operated system of vehicles. In the second phase, the steering and speed control functions were to be automated. This was to include a blocking system to maintain vehicle spacing, requiring the operator to simply start and stop the vehicle. The objective of the third phase was to completely automate the system so the operators could be removed from the vehicles. This required the addition of an object detector system to stop the vehicle if there were any obstacle in its path, as well as control elements to start and stop the vehicle at programmed locations.



SOURCE: General Motors Corp.

FIGURE A.2.5. CONFIGURATION 1



SOURCE: General Motors' Corp.

FIGURE A.2.6. CONFIGURATION 2

A.2.7 System Economics

SRI estimates the capital cost of an EPM vehicle would have been about $20,000. General Motors staff said that Barrett Electronics Corp. charged GM about $5,000 for the basic drive, control, and guidance systems of EPM-2; GM itself built the body and object detector. Included in the cost are extensive engineering costs. This $20,000 figure also reflects the production of a small quantity and some style and performance changes required for different EPM application sites.

General Motors expected its vehicles to have a 10-year lifetime. At a 10% cost of capital, the equivalent annual capital cost for the seven-vehicle system would have been $244,000, and the equivalent annual cost per EPM vehicle would have been $35,000.

General Motors staff estimated one full-time man could handle maintenance, battery changes, and battery charging for a system.

A.2.8 Product Liability and Insurance

Product liability was not a major concern to GM. The corporation is self-insured, very large, and experienced with making products for moving people in both public and private transportation. Even though GM assumed full liability responsibility, both subcontractors, Control Engineering Company and Barrett Electronics Corporation, were concerned.

A.2.9 System Assessment

General Motors conducted two surveys of EPM riders to obtain preliminary information on user response to the concept and to record reactions to its utility as a transit mode.

The first rider responses were taken on the GM Technical Center site. EPM-1 shuttled back and forth along the 170-foot section of indoor hallway moving at 3.5 km/hr (2.2 mph). Forty-eight printed questionnaires were completed by 36 males and 12 females of which 60% were skilled or professional workers. The results indicated a favorable response to the concept.

The second survey was of the general public when EPM-1 was tested in the Michigan Mall.

In the 4-day test, 335 riders and nonriders encountered at the mall responded to seven questions presented in a questionnaire. A modified, stratified random sampling procedure was used to obtain approximately equal numbers of men and women, older and younger persons. Riders reacted favorably to the system and did not seem to be concerned about safety. The tabulated response of the adults surveyed were:

a. 75% thought the vehicle speed was about right,

b. 88% indicated that boarding and exiting was about the same as or easier than using an escalator,

c. 90% said they felt EPM would be a convenience in a shopping mall,

d. 91% said they would feel comfortable taking children aboard the EPM,

e. 70% were sure the vehicle would stop if pedestrians were to walk in front of it,

f. convenience was the most frequently mentioned when respondents were asked to comment on what they liked most, and

g. crowding and children playing on the EPM were most frequently mentioned when respondents were asked to comment on what they liked least.

General Motors staff reported that every time EPM-1 went over expansion joints in the Michigan Mall concrete, a small jolt was felt that reduced the ride quality some. Larger diameter tires (i.e., greater than 7 inches) and semipneumatic tires were improvements that could improve the ride quality. General Motors staff assessed AMTT to be a viable distinct transportation system for a mixed traffic environment, as long as the AMTT has the following characteristics:

a. Speed limited to 3.2-4.8 km/hr (2-3 mph). Higher speeds throughout the free access concept would require station stops and increase the risk of a collision.

b. Free access concept allowing passengers to board or depart any place along the route.

c. An effective noncontact obstacle detector that will "see" all people and all potentially hazardous objects in its path and will be resistant to sabotage. According to GM staff, the object detector is the key subsystem for safe AMTT operation in mixed pedestrian traffic.

d. A guidepath not shared with other vehicles.

The TSD saw no need for improvement of the vehicle guidance or control systems used for materials-handling driverless vehicles.

A.2.10 Potential as an AMTT Supplier

Although GM TSD spent over 2 years developing an AMTT system and was close to commercializing the product, several factors caused TSD management to stop the EPM program.

Because GM believed that the only viable AMTT concept was its EPM (i.e., slow speed, mixed pedestrian, but not mixed vehicular traffic, and free access), the market potential was limited to certain environments. Consequently, the market survey estimated EPM sales over 10 years at a low of 155 vehicles, a high of 465, and a medium estimate of 230. The system installations were estimated to range from 30 to 115. Although many application sites were considered, the survey concluded that CBDs, shopping centers, and airports were the primary application sites for EPM.

Although GM indicated that it questioned some of the procedures used in the survey, the high estimate of less than 50 vehicles in 12 installations per year was a small market by GM standards.

General TSD staff believe AMTT manufacture is a good business opportunity for a smaller company whose size may be more appropriate to the market size. They indicated that GM would reexamine the potential GM business opportunity profitability of AMTT vehicles if a substantial increase in the market size were to be forecast.

APPENDIX A.3

THE SOUTH CONCOURSE SHUTTLE AT THE CLEVELAND HOPKINS INTERNATIONAL AIRPORT

In the south concourse of Cleveland Hopkins International Airport, three AMTTs manufactured by Otis Elevator Company operated on a guidepath shared with pedestrians as part of a 2-week feasibility test. Because the concourse is 0.4 km. (0.25 miles) long, a transportation system was needed to shuttle people to and from the aircraft gates and the main lobby of the airport.

A.3.1 History and Institutional Framework

Ever since it opened in 1969, the 0.4 km. (0.25 miles) long south concourse of Cleveland Hopkins International Airport was criticized because of the long walk required between most gates and the terminal main lobby. Because of constant pressure by Cleveland citizens and the Aviation Committee of the City Council, the mayor initiated a project to install and test a people-mover system in the south concourse in 1974. The system had to be one that could be quickly and inexpensively installed. In addition, because the aircraft gates were spread along the length of the concourse, the system had to allow people to get on and off at any time. The airport architect and engineering consultant, Richard L. Bowen and Associates was given the task of carrying out the project. Although other transportation systems were considered (i.e., moving walkways, AGT, etc.) Bowen and Associates suggested that an adaptation of a wire-guided materials-handling driverless vehicle system would meet all the requirements.

Thirteen companies were contacted by Bowen and Associates. Otis Elevator Company had already installed elevators and escalators in the airport, and their Automated Vehicle Systems Division, which made driverless tractor systems for handling materials, was interested in testing a people-moving AMTT as a potential new product line. Consequently, Otis agreed to install a wire-guidance system and three AMTT people-mover vehicles in the south concourse and conduct a 2-week in-service test.

Otis was given less than 5 weeks to build and install a people-mover system by the city. Otis's standard industrial tractor was adapted, and three trailers were quickly designed and built to carry people.

The in-service test of the system began on October 3, 1974. On October 4, the test was stopped because airport officials noticed that the aluminum and rubber expansion joints in the floor were sagging under the weight of the vehicles. Steel plate bridges were laid across the joints and the vehicles resumed operation on October 13. Two weeks later, on October 28, the contract was completed and the test was halted.

At the time, the city's Ports Director said that technical and legal details needed to be worked out before the city could approve a permanent installation. In addition, the Ports Director wanted to know how the expansion joint problem would be solved permanently, what the operating costs would be, what type of maintenance contract or guarantee Otis would offer, and how well the final system would run.

However, the test was considered a success by the city. The city council approved plans to procure a permanent people-mover system in 1976. In the meantime, however, Otis got out of the driverless mixed traffic vehicle business. Consequently, Bowen and Associates issued a specification in August 1976 to a number of prospective bidders.

A.3.2 System Description

The Otis system was called the South Concourse Shuttle. A guidepath loop was installed in the center of the concourse walkway, so the vehicles shared the guidepath with pedestrians and manually driven airports service carts. This lack of dedicated guideway was needed for the free access concept used. Moving at walking speed, the vehicles could be easily boarded and left at any point along the route.

A.3.2.1 Route

The route consisted of a 660 meter (2,200 foot) loop in the center of the concourse with only several inches of clearance between vehicles traveling in opposite directions.

Figure A.3.1 depicts the layout of the south concourse and the route of the people mover. The vehicles had to run in the center of the concourse because the aircraft gates line both walls through most of the concourse. Although there were no fixed stations, there were reduced speed zones and stops at both ends and the center area of the loop to make passenger boarding and disembarking easier.

Most of the concourse walkway is 7.5 meters (25 feet) wide, and the 1.8 meter (6 foot) wide vehicles occupied, at most, 4.2 meters (14 feet) when passing in opposite directions. There was less than 1.8 meters (6 feet) of walking space between a passing vehicle and the wall.

A.3.2.2 Equipment

The guidepath was a wire recessed in the floor with a modulated alternating current supplied by an energizer. The stopping points were marked aberrations in the guidepath.

The vehicles consisted of a standard Otis Automated Vehicle System electric tow tractor, weighing about 2,250 kg. (5,000 lb.) with batteries, towing a 1.8 meter (6 foot) wide, 3 meter (10 foot) long trailer. It had seating for 12, standing room for 10, and about a 2.4 meter (8 foot) wide opening for boarding. The boarding step height was about 19 cm. (7.5 inches) from the floor. Figures A.3.2 and A.3.3 show two views of the Otis AMTT.

The tractor was controlled by on-board electronic guidance, programming, and vehicle-sensing circuits. The programming could be changed every vehicle loop cycle. This allowed the vehicles to meet incoming airplanes. A contact safety bumper extended about 0.15 meter (0.5 foot) in front of the tractor. An ultrasonic object detector was set to have a range of about 15 meters (50 feet) and to sense an area that was close to the floor and the width of the trailer.

According to Otis Elevator Company:

> Ultrasonic object detection is an optional safety device. The heart of this device is a pair of ultrasonic transducers mounted above and slightly behind the front safety bumper. These sensors emit a burst of energy and scan the area directly in front of the vehicle for any objects that may be in the travel path. When an object in the travel path is sensed, the vehicle will automatically slow down

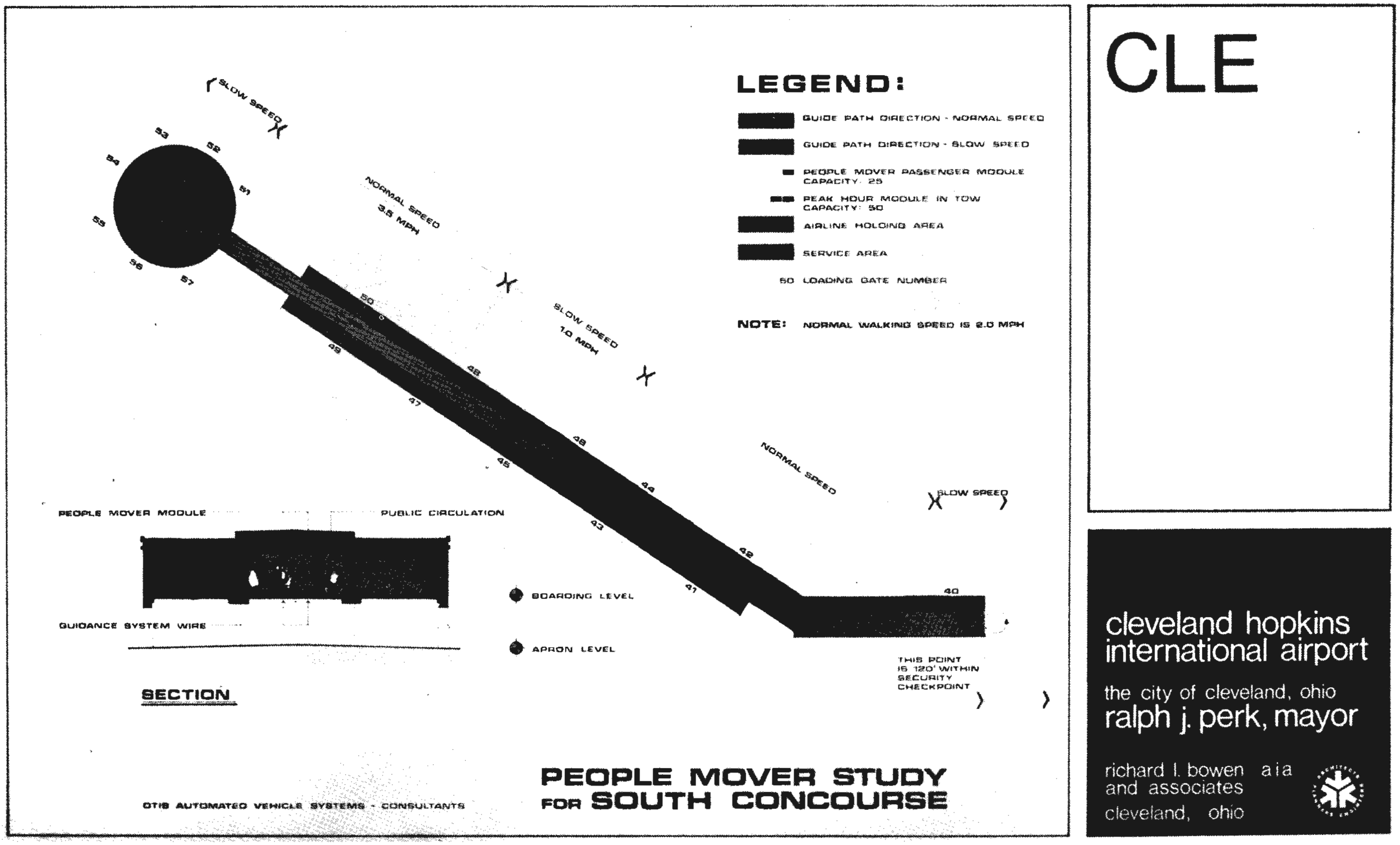


FIGURE A.3.1. ROUTE OF THE SOUTH CONCOURSE PEOPLE MOVER

SOURCE: R. L. Bowen & Associates

FIGURE A.3.2. FRONT VIEW OF OTIS AMTT VEHICLE

SOURCE: R. L. Bowen & Associates

FIGURE A.3.3. SIDE VIEW OF OTIS AMTT VEHICLE and stop without making physical contact with the object. If the object moves or is removed before the stop range is reached by the vehicle, then it shall proceed at its preprogrammed speed. Should an object within the stop range be encountered by the sonic unit, the vehicle will stop and sound the electric horn at approximately one second intervals until the obstacle is removed. The range of the slow zone is programmable and is controlled by the vehicle logic. An electronic digital failsafe signal is provided to inhibit automatic operation of the vehicle should the ultrasonic unit fail to activate prior to or during vehicle movement.

The tractor was also equipped with manual controls.

A.3.2.3 Operations and Service

The vehicles were tested in service 7 days a week from 8 A.M. to 10 P.M. With a top speed of 5.6 km/hr (3.5 mph) to allow free access boarding, zones of 1.6-2.8 km/hr (1.0-1.75 mph) reduced speed, and four stops totaling about 2 minutes, the average travel speed is estimated to have been 3.5 km/hr (2.2 mph). The jerk was reported to be very low.

When the sonic object detector sensed obstacles within 10 feet, the vehicle slowed to 1.6-2.8 km/hr (1-1.75 mph) and at 1.5 meters (5 feet), the vehicle began to brake so as to stop no closer than 0.3 meters (1 foot) from the obstacle.

Two vehicles were in service most of the time. All three vehicles were in service only at peak hours.

A.3.2.4 Performance

Noise and Ride Quality--Vehicle noise level data were not available, but the ride was said to be quiet and smooth except when the vehicles went over the floor expansion joints.

Safety--There were no accidents or injuries during the 16-day test. Even though Otis had a uniformed man on each vehicle to stop it in case of a pending accident, they did not have to override the automatic control.

The Otis vehicles were designed with the following safety features:

- safety bumper with failsafe design
- guidance system that caused emergency stop if guidewire signal was lost
- ultrasonic obstacle detector with a failsafe circuit
- same failsafe circuits in the power and control subsystem
- visible flashing red light and a horn
- manual override of automatic control

Reliability and Maintainability--The short test period did not allow collection of reliability or maintainability data. The vehicles had solid state electronics with reliable integrated circuits.

The only problem that occurred with the equipment was some motor overheating, which was easily corrected by making more ventilation openings and redirecting the fan.

Degree of Automation--The Otis project manager estimated a 10-vehicle system could be operated by one person from a computer-assisted central control station. A central control system was not installed for the test. Otis supplied technical personnel, and a hostess who provided passenger information.

A.3.3 System Economics

Otis Elevator Company agreed to do the test for $23,600. It is reported that Otis built, installed, and tested the system at a loss, the amount of which was not revealed.

Some sources indicate that a permanent Otis installation of 5 power units with two 18-passenger modules each, relocating the guidewire for narrower vehicles, and a central computer control system was discussed for a price of about $500,000.(36)

A.3.4 Product Liability and Insurance

For the test, Otis Elevator Company was prepared to take the liability risk. Because Otis already made automated passenger transportation systems (i.e., elevators and escalators) at that time, the company's insurance policy was probably appropriate. Since that time however, the insurance situation has changed and an AMTT would not be included under such coverage.

A.3.5 System Assessment

The initial rider assessment of the vehicle system reported in the Cleveland newspaper was very favorable, primarily because the system saved people a long walk.(37)

After the test, Bowen and Associates suggested two needed improvements: (1) make the vehicles accessible to wheelchairs and (2) use smaller passenger trailers in the concourse. Several additional improvements of the system were planned for a permanent installation:

- a spring suspension system
- stronger floor expansion joints
- safety bumpers on the side of tractor and trailer
- smaller and lighter passenger trailers
- programmable central control
- a constant audible warning (e.g., music tape)

APPENDIX B

MATERIALS-HANDLING AMTT TECHNOLOGY: SYSTEMS AND COSTS

B.1 Introduction

Much of the people-moving AMTT technology is based on electric-guided industrial vehicle systems. These driverless vehicles are typically programmed to automatically follow a course, make stops for loading and unloading of freight, or carry out other tasks in the process safely and effectively. Considerable experience in AMTT operational performance, economics, and market acceptance has been gained by its users and manufacturers of the past 20 years. Current suppliers of electric-guided industrial tractor systems are primarily candidates as suppliers of people-moving AMTTs or as vendors to companies already in the people-moving equipment market who might become a people-moving AMTT supplier. Consequently, descriptions of the state-of-the-art of industrial AMTT technology, operational performance, and associated costs are highly relevant to people-moving AMTT market considerations. Such descriptions are the subject of this section.

B.2 Technical System Description

Whether materials are transported on a single unit cart or on trailers towed by a tractor, the industrial AMTT system can best be described as a standard vehicle designed for driverless operations by the addition of the following subsystems: guidance, control, obstacle detection, and safety devices. Table B.1 has descriptive data for each driverless vehicle model currently offered commercially, as supplied by its manufacturer, unless otherwise noted. This information is discussed below.

B.2.1 Vehicles

The smallest industrial driverless vehicle stands only 0.5 meters (1.5 feet) high and carries one pallet (see Figure B.1). The vehicles can, however, vary in size from a small 317 kg. (700 lb.) (empty) cart, 1.5 meters (5 feet) long, 0.6 meters (2 feet) wide, and 1.2 meters (4 feet) high to a large 1,800 kg. (4,000 lb) tow tractor that is 2.4 meters (8 feet) long, 1.1 meters (3.5 feet) wide, and 1.5 meters (5 feet) tall. Figure B.2 illustrates various sizes of industrial tow tractors available.

Table B.1

DRIVERLESS VEHICLES: DESCRIPTION

	Propulsion Power (hp)	Size, Length x Width Height			Weight Without Battery	Battery Weight	Battery Size		Wheels (number)	Drive Wheel(s)	Service Brake Type	Emergency Brake Type	Guidance Type	Unique Path	Random Access	Central Programming	Noncontact Obstacle Detector Type
		Ft	Ft	Ft			Volts	Amp-Hr									
Barrett Electronics Co.																	
GS-4	2	4.3	2.5	4.7	1,000	800	24	570	3	1 Front	Dynamic	Drum	Magnetic/ visible optical	X	X	X	Sonic
Radox	2	4.1	2.5	4.8	1,000	800	24	570	3	1 Front	Dynamic	Drum	↓	X	X	X	Sonic
GMG-24	6	4.3	2.5	4.8	1,225	800	24	570	3*	1 Front	Dynamic	Drum		X	X	X	Sonic
G30-B	10-14	7.8	3.5	5.1	3,000	1,200	36	700	4*	2 Rear	Dynamic	Disc		X	X	X	Sonic
GDG-24/36	12	7.8	3.5	5.1	3,000	1,200	24 or 36	700	4	2 Rear	Dynamic	Disc		X	X	X	Sonic
Clark Equipment Co.																	
20,000	4.0	6.0	3.0	4.5	1,750	900-3,200	24	425-1,190	3 front=dual	2 Rear	Dynamic	Disc	Magnetic	X	X		Sonic
40,000	6.9	6.0	3.0	4.5	1,800	900-3,200	36	429-935	3 front=dual	2 Rear	Dynamic	Disc		X	X		Sonic
55,000	10.3	6.0	3.0	4.5	1,800	900-3,200	36	425-935	3 front=dual	2 Rear	Dynamic	Disc		X	X		Sonic
Control Engineering Co.																	
302	6*	7.7	2.6	4.6	1,100	1,000	24	935	3 front=dual	2 Rear	Dynamic	Disc and drive shaft	Magnetic/ visible optical	X	X		Sonic/ optical
601	10*	7.7	2.6	4.6	1,100	2,000	24	935	3 front=dual	2 Rear	Dynamic	Disc and drive shaft	↓	X	X		Sonic/ optical
1000	12*	7.7	2.6	4.6	1,600	3,000	36	990	3 front=dual	2 Rear	Dynamic	Disc and drive shaft		X	X		Sonic/ optical
Mini-Cart	1*	5.3	2.4	3.3	435*	65	12	270	3	2 Rear	Dynamic	Disc		X			Sonic
Lear Siegler, Inc.																	
Mailmobile	0.5	4.8	2.0	4.3	630*	70*	24	135	3	1 Front	Dynamic	Dynamic or mechanical	Invisible optical				Radar
Mobility Systems, Inc.																	
Electote	2.0	4.0	4.0	1.5	675	550	36	210	4	2 Rear	Mechanical	Mechanical	Magnetic	X	X		Sonic

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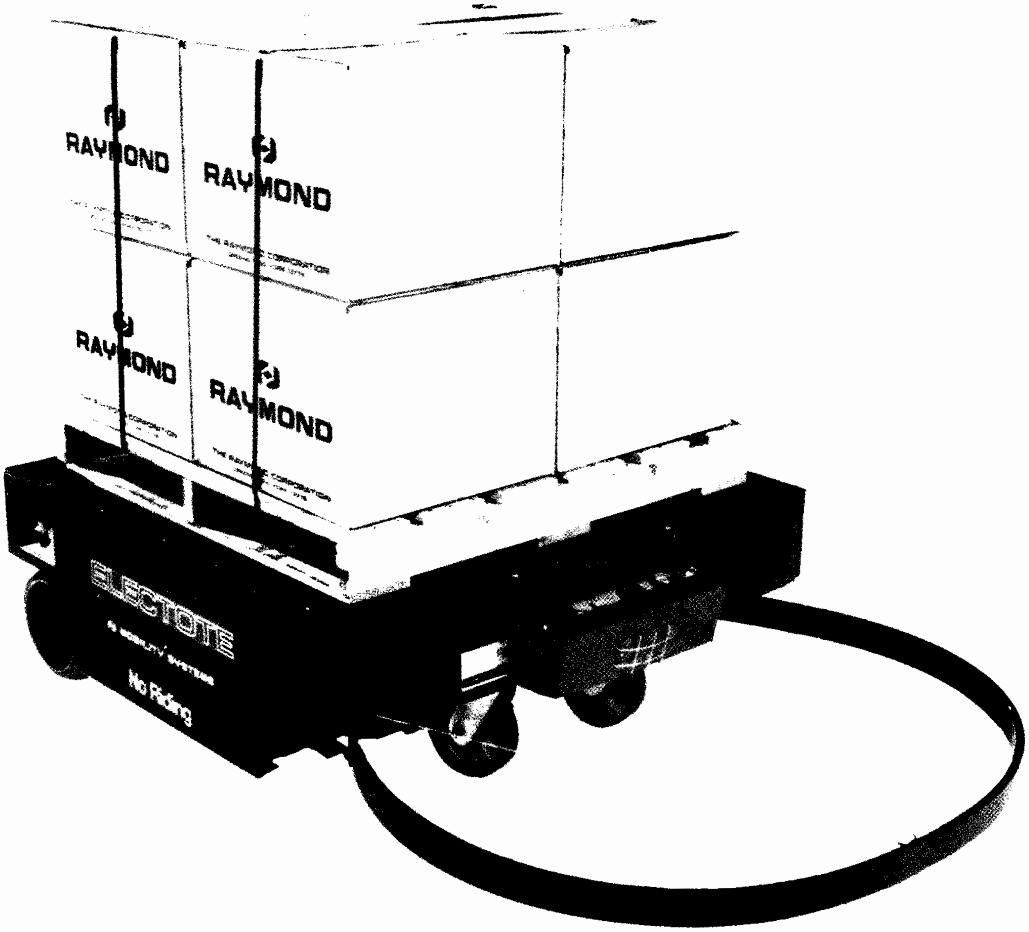
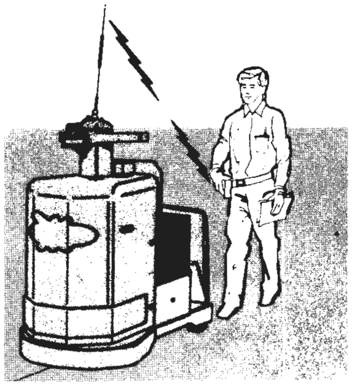
*SRI estimate.

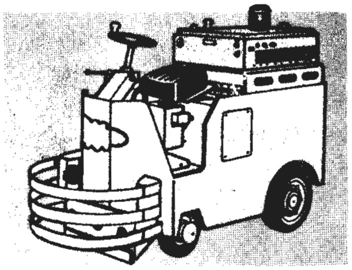


SOURCE: Raymond Mobility Systems

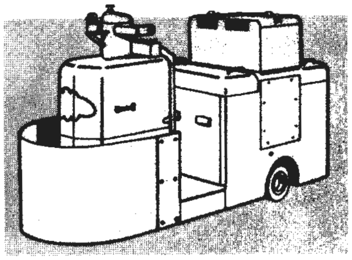
FIGURE B.1. SMALL INDUSTRIAL DRIVERLESS VEHICLE



(a) 10,000 lb ROLLING LOAD CAPACITY



(b) 30,000 lb ROLLING LOAD CAPACITY



(c) 50,000 lb ROLLING LOAD CAPACITY

SOURCE: Barrett Electronics Corp.

FIGURE B.2. THREE AUTOMATIC INDUSTRIAL TOW TRACTORS

Most driverless vehicles are designed specifically for materials handling and are similar to fork trucks in that a single or double wheel is centered in front of the vehicle for steering. The lighter vehicles have one steering wheel, and the heavier vehicles have two steering wheels. Other than the action of the hard rubber tires, the vehicles commonly have no suspension system. Propulsion is provided by electric d.c. motors that vary from 0.5 h.p. for a cart to 14 h.p. for a large tow tractor. Battery sizes vary from 24-volt, 135-ampere-hour batteries for a small cart to 36-volt, 990-ampere-hour batteries for the large tow tractors. Depending on their size, batteries weigh from 29-1,440 kg. (65-3,200 pounds).

B.2.2 Guidance Systems

Two basic guidance systems are used; wire-following and optical line-following. Optical systems are the simpler and more economical, but are recommended only for indoor, clean floor use. The wire systems, although more costly to install, provide high reliability and are more easily adapted to course switching, stopping, and programming, both indoors and outdoors. Most industrial tow tractor systems have a magnetic (wire-following) guidance system, and most carts use optical guidance.

The magnetic system consists of a vehicle-mounted sensing device that follows an energized guide wire embedded in a shallow slot in the floor. Figure B.3 shows two parallel wire-guided driverless tractor pathways. There are five basic components of the magnetic system:

1. The electrically closed loop wire guidepath, which typically consists of 14-16 gauge insulated wire embedded in a 0.32-cm. (0.125-inch) wide slot, 0.64 cm.-1.3 cm. (0.25-0.5 inch) deep in the floor. The slot can be left uncovered and backfilled with epoxy resin or grout.

2. The guidepath converter, which uses regular 110-120 volt, 60 cycle, a.c. power to produce a signal frequency somewhere in the 7-11 kHz range in the guidepath wire. The current in the wire is a fraction of an ampere and voltage is low (under 56 volts).

3. The energizer: one energizer is commonly needed for every 1.5 km. (5,000 feet) of guidance wire.

SOURCE: Perin Co., Inc.

FIGURE B.3. WIRE-GUIDED INDUSTRIAL DRIVERLESS TRACTOR TRAINS

4. The vehicle-mounted sensing device, usually consisting of two signal coils, detects the location of the magnetic field around the wire and directs the vehicle's steering function. Sensed deviation from the guidepath activates the steering motor.

5. The steering system (consisting of the steering servo control system, the steering motor, and the steering wheel), which repositions the front wheel(s) in proportion to any deviation from the guidepath.

The optical system works on the same principle as the magnetic system with the exceptions that the guidepath wire and energizer are replaced with a contrasting-color, 2-inch-wide painted or taped line on the floor, and the coil sensor is replaced with a photoelectric optical sensor and a light. Figure B.4 shows a line-guided tractor system. Most mail cart guidance systems use an ultraviolet light source and photoelectric sensors to stimulate and track a substantially invisible fluorescent guidepath. (Figure B.5).

All driverless vehicles have as part of the vehicle guidance sensor system a signal level detector that permits vehicle operation only when the signal strength is sufficient for guidance. An automatic gain control circuit can compensate for variations in signal strength along the guidewire.

B.2.3 Control

Because guidepath routing can range from a simple closed loop of almost any shape to multiple, interconnected loops, with spurs and stops (see Figure B.6), a control system is often needed. The control system directs the vehicle's decisions regarding speed, stopping points, intersections, vehicle separation, route selection, switching, and interface stationary equipment (i.e., automatic door, elevator, warning device, and machine).

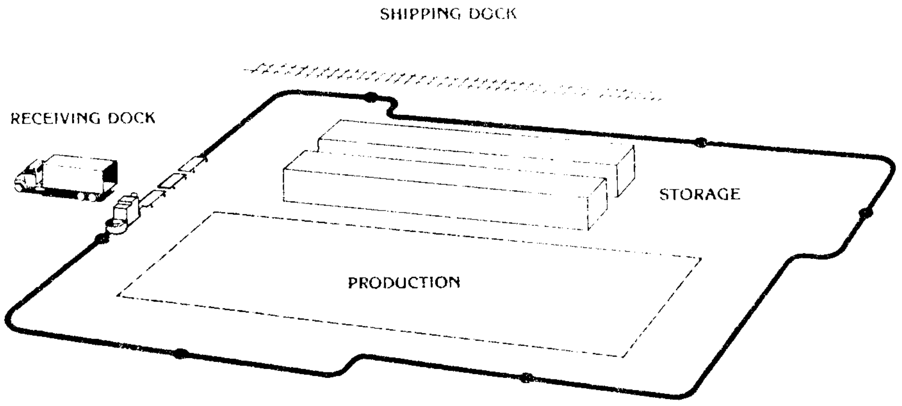
Most industrial tractors have on-board programming that requires each point along the guidepath at which the tractor is to perform some prescribed function to be marked in a manner that the tractor can recognize. For simple optically guided vehicle systems, painted or taped spots adjacent to the guideline are counted by the vehicle. When the vehicle reaches the desired programmed decision point, it performs its programmed function.

SOURCE: Perin Co., Inc.

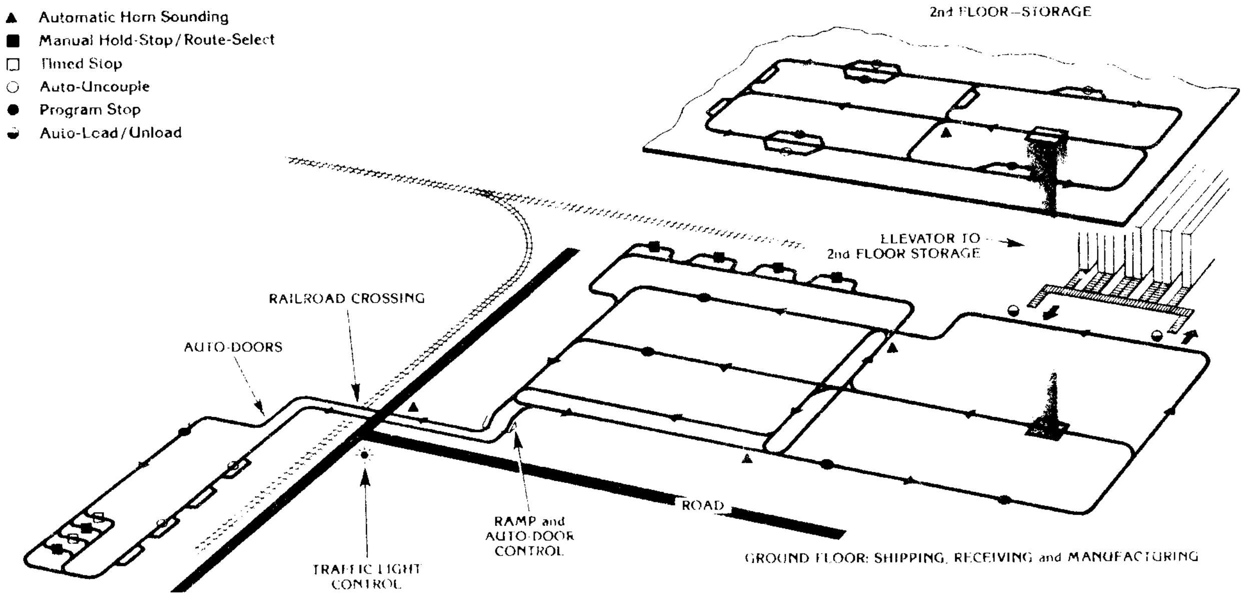
FIGURE B.4. DRIVERLESS TRACTOR FOLLOWING A VISIBLE LINE ON THE FLOOR

SOURCE: Lear Siegler, Inc.

FIGURE B.5. AUTOMATIC OFFICE MAIL DELIVERY CART



(a) SINGLE LOOP SYSTEM



(b) MULTIPLE ROUTE SYSTEM

SOURCE: Control Engineering Corp

FIGURE B.6. EXAMPLES OF DRIVERLESS VEHICLE GUIDEPATH ROUTING ALTERNATIVES

Simple wire-guided systems operate in a similar way; a single permanent magnet marks the decisions point and a tractor-mounted reed switch detects the magnet.

For more complex vehicle systems, each decision point has a unique code that corresponds to a tractor stored memory and programmable automatic control function. Tractor mounted magnetic array sensors (consisting of reed switches) recognize each array of floor-mounted permanent magnets, by a binary code established by their position and/or their polarity.

Automatic course switching is sometimes done by installing a course control unit at the switching point, which operates a relay upon receiving a command signal from the oncoming tractor. Usually, however, course switching is done by leaving all courses continually energized and utilizing a different guide wire signal frequency for each course. At converging and diverging points both the branch course wire and the main course wire overlap for a few feet. In this case, the tractors have multiple frequency sensing devices that can operate on each of the frequencies used. A coded decision point pattern prior to the diverging point tells the tractor control which frequency in the wire overlap region to follow.

Functions that require interfacing with stationary, automatic equipment (e.g., elevators, warning devices, and machines) are done in several ways. A tractor-mounted permanent magnet can be detected by a floor-mounted reed switch of an a.c. relay module that activates pre-programmed equipment. The tractor can also communicate with wayside equipment via frequency coded radio signals.

Vehicle spacing or separation along the same guidepath and collision control at guidepath intersections is done by several blocking systems. These systems are not fail-safe and thus, not useful for passenger applications. They include the following:

a. A tractor magnet trips a floor reed switch which activates a wire loop located at the entrance(s) to the zone being blocked. The inductance in the loop is read by a standard coil on any other vehicle that tries to enter the zone as a command to stop. When the lead vehicle leaves the zone, another reed switch is tripped to deenergize the loop.

b. A passive wire loop that runs along opposite sides of the guide-wire at each end can also be used as an antenna. A continuously working transmitter on the right side of the tractor establishes a signal in the wire loop that is detected by a receiver on the left side of next vehicle to enter the zone and the tractor stops. When the first tractor leaves the zone, the signal in the loop stops and the second tractor starts.

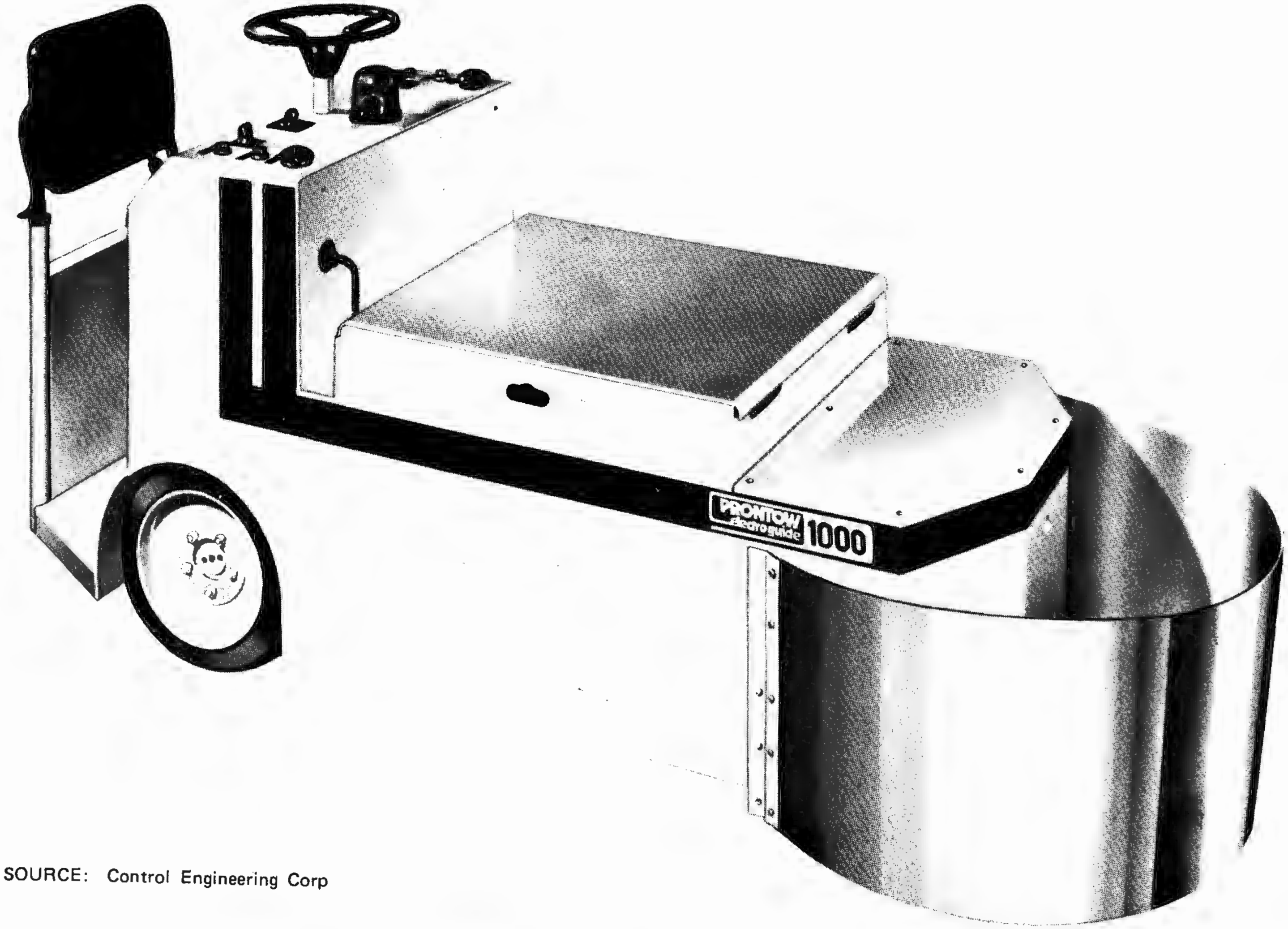
c. A powered wall mounted receiver/transmitter unit can also be used for radio communication between vehicles for blocking.

d. Noncontact obstacle detectors can also be used for vehicle spacing on the same route. The effectiveness of the obstacle detector can be enhanced by putting reflective paint or tape on the rear of vehicles. This system is effective, however, only on straight pathways.

There are several other programmable control systems available depending on the degree of programming flexibility needed. A sequential system only allows the vehicle to stop at the programmed stations in the order that they are encountered along the guidepath. A unique path system allows the vehicle to select the shortest route between programmed station stops, but still requires sequential station stops. A random access system allows the vehicle to stop at stations in any order and to take the shortest path between each programmed station stop. Central programming can be used to monitor all vehicle locations and to transmit programmed instructions to tractors from a control center.

B.2.4 Obstacle Detection

All industrial driverless tractors have a mechanical safety bumper (see Figure B.7) that extends 36-46 cm. (14-18 inches) in front of the vehicle, at its center, and covers an area 7.6-15 cm. (3-6 inches) wider than the vehicle and between 5 cm. (2 inches) to 66 cm. (26 inches) above the floor. All the bumpers require a maximum pressure of 3.6 kg. (8 lb.) to cause detection and for the vehicle control system to initiate emergency braking. At least three different types of bumpers are in use:



SOURCE: Control Engineering Corp

FIGURE B.7. SAFETY BUMPER ON AUTOMATIC TRACTOR

1. A fiberglass bumper with a small section of light reflective foil attached to the inside of the bumper. A tractor-mounted directed light beam is aimed at the foil for reflection back to a tractor-mounted light detector. When the bumper deflects from external pressure, the foil alignment changes causing the light detector signal to stop.

2. A bumper consisting of two bands of spring steel separated by an air space. An obstacle causes the bands to touch one another, disabling an electrical circuit.

3. A bumper consisting of two bands of plastic with four 8 ounce pressure switches between.

For trailers wider than the tractor, side bumpers or hinged extensions can be added at right angles to the tractor sides.

In addition to the mechanical bumper, all driverless vehicles can be equipped with a sonic or optical obstacle detector to "see" as far as 4.5 meters (15 feet) ahead. The sonic systems consist of one or two directionalized transmitters of a conical pattern of sound waves in the 32 kHz frequency range and two or three receivers. Two zones are commonly monitored, a primary zone out to 3.6-4.5 meters (12-15 feet) and a secondary zone out to 1.5-2.1 meters (5-7 feet). The receivers are commonly located on each side and/or in the center of the vehicle front. In some available systems, timing differences correlated with the transmitter(s) permit the same receivers to cover both zones.

One commercially available detector is similar to radar. The system consists of a tuned circuit that detects the presence of objects by sensing the resulting change in capacitance between an antenna array and the chassis of the vehicle.

The only optical obstacle detector in common use on driverless vehicles is used for close headway vehicle-to-vehicle spacing. The transmitter is a pulse-coded infrared light-emitting diode and the detectors are spectrally matched phototransistors. Two beams point in the forward direction of travel of the vehicle, one beam with a slight vertical angle and the other with a slight lateral angle in order to hit a 7.6 cm. (3 inch) by 30.5 cm. (12 inch) strip target of retroreflective tape or paint located in the rear of each tractor and trailer ahead. The range of the system in use is 11.3 meters (25 feet).

B.2.5 Safety Devices

Warning devices and vehicle design features used to enhance safety are:

a. manual operation controls that allow one driver to have complete operating control on and off the guidepath;

b. emergency stop devices (e.g., buttons, strip switch) mounted on the tractor so they can be actuated by personnel on either side of the vehicle--the devices are red and palm operable;

c. sound producing warning devices (e.g., horn, whistle, bell) that can be automatically activated at corners, intersections, or other hazardous locations and activated when an emergency stop is made or an obstacle is detected;

d. turn signals to alert personnel in the area whenever the vehicle is about to make a turn;

e. constantly flashing warning light(s) mounted on the vehicle; and

f. remote warning flashers or traffic signals or gates at intersections or pedestrian crosswalks that can be turned on and off by the vehicle.

B.3 Operational Performance

The operational performance of the automatic driverless vehicle systems can be described in terms of each of the primary subsystems--vehicle, guidance, control, and obstacle detectors--as well as the total systems performance relative to safety, reliability and maintainability, and the environment. Table B.2 has performance figures for each driverless vehicle model as supplied by their manufacturers (unless otherwise noted). These data are detailed below.

B.3.1 Vehicle

The load capacity of the vehicles is proportional to their motor power. The carts have motors of 0.5 to 2.0 h.p. and are designed to carry a maximum load of 225-1,800 kg. (500-4,000 lb.) on level ground. The industrial tractors having motors of 2-12 h.p. can tow a maximum of 3,600-24,750 kg. (8,000-55,000 lb.) of materials on the level ground. The load capacity is reduced when the vehicle goes up or down grades. For example, the vehicles' load capacity is reduced to one-third for an 8% grade and one-quarter for a 10% grade. Most manufacturers do not recommend their vehicles for grades greater than 8-10%.

The maximum load capacity is limited more by the vehicle's capabilities in going down grades rather than going up grades. The vehicle's dynamic brake must be able to control the speed, and the trailers must not jackknife. Too much of an initial step in the grade can also cause a break-over or high centering problem with the low chassis on some of the vehicles.

Although vehicle speed is adjustable, the maximum available for tow tractors is 16 km/hr (10 mph). The maximum operating speed for use for tow tractors is 4.5-6.1 km/hr (2.8-3.8 mph) when empty and 3.2-5.3 km/hr (2.0-3.3 mph) with a full load. The carts operate at 1.61-2.1 km/hr (1.0-1.3 mph). The standard operating speed for driverless tractors is 4.8 km/hr (3 mph).

The tow tractors generally accelerate at 0.3-0.6 meters/sec^2 (1-2 feet/sec^2) have a service deceleration rate of 0.3-0.9 meters/sec^2 (1-3 feet/sec^2) with dynamic braking, and an emergency deceleration rate between 1.8-6.9 meters/sec^2 (6-23 feet/sec^2), depending on load, with mechanical braking. Depending on the load, the stopping distance from full speed (e.g., 4.8 km/hr) with service braking is between 1.8 and 6 meters (6 and 20 feet) and with emergency braking between 0.15 and 0.6 meters (0.5 and 2 feet). The lighter carts need only a few inches for an emergency stop from 1.6 km/hr (1 mph).

Most of the manufacturers offer no data on jerk, but all claim acceleration can be adjusted to be very smooth with SCR control.

The maximum range between battery recharges is between 8 and 16 hours of operation. The type of service, loads moved, and the battery size are the main affecting factors.

B.3.2 Guidance

Wire-guided vehicles follow the path with no more than a 1.3-5.1 cm. (0.5-2 inch) deviation on either side. An automatic gain control circuit assures steering accuracy despite guidewire signal strength variations.

The signal in the guidewire does not interfere with radio communications or process controllers, because of its low power and frequency. Also, the vehicle has a narrow tracking bandwidth assuring no interference from outside signal sources.

The maximum path deviation of vehicles following a visible line is about 5.1 cm. (2 inches) and the maximum deviation of a cart following a black-light activated fluorescent line is 0.6 cm. (0.25 inch). Loss of guidepath energization causes all vehicles to come to an emergency stop.

B.3.3 Control

There are at least 10 functions that can be controlled by computer to help ensure that driverless tractors operate safely and efficiently. A computer can:

a. respond to "priority" requests transmitted from data terminals at or near the pickup stations,

b. keep track of the identity of the materials carried on each trailer,

c. control automated devices that load and off-load trailers at pickup stations,

d. monitor the travel of one or more tractor trains,

e. maintain a safe distance between two or more tractor trains,

f. safeguard against collisions of tractor trains at intersections,

g. direct tractor trains over the shortest route,

h. shunt one tractor train to a spur so that another tractor can pass safely,

i. open and close fire doors in the warehouse or plant, and

j. operate automatic elevators that carry the tractor trains between floors.

B.3.4 Safety

Although the driverless vehicles are not 100% safe, they are as safe as many other types of mechanized devices (e.g., tow lines, elevators).

The safety of the total driverless vehicle system is dictated primarily by the failsafe design of the automated guidance, control, and obstacle detection subsystems and the effective performance of the warning devices.

B.3.5 Reliability and Maintainability

All suppliers claim that the reliability of driverless vehicles is very high, largely because most control components are solid state electronics. Two claim a mean time between failure (MTBF) of 3-4 months and another claim a MTBF of 6 months with proper preventative maintenance.

Maintainability is also claimed to be excellent as the vehicles are designed for easy replacement of modular components. A mean time to repair (MTTR) of 0.5 hour was quoted by one supplier and 2 hours by another.

B.3.6 Environments

Driverless tractors can operate indoors or outdoors in most temperature extremes. One installed system operates in a freezer set at -23 C (-10 F). Humidity does not affect operation. The vehicles do have limited traction and steering control on snow and ice just as other rubber-tired vehicles do. Snow covered ground does not affect the detection of the guidewire signal.

B.4 System Costs

Driverless tractor trains can provide about the same throughput as a manually operated tractor train at approximately 3-4 times the equipment cost. A battery-powered manually driven tractor costs about $5,000, whereas an automatic tractor typically costs between $15,000 and $23,000. A one-tractor driverless vehicle system (including guidepath and wayside equipment) of average complexity typically costs $20,000 to $30,000. As with all automated systems, the primary economic savings of an automated tractor system is perceived as reduced operating labor costs. All the costs in this Appendix are shown in 1976 dollars.

The savings resulting from the fork truck driver labor cost (i.e., $13,000 to $26,000 per year including payroll taxes and benefits) pays for the capital cost of the driverless vehicle system in 1 to 2 years. Fully automated systems also last 2 to 3 times longer than manual ones as a result of the more controlled operation of the vehicles within their performance capabilities.

B.4.1 Capital Costs

Of the total capital cost of a driverless tractor system, approximately 65-70% results from the automated vehicle, batteries, trailers, and battery charger, 15% results from the guidepath and floor-mounted control equipment, and about 15-20% results from the engineering design of the system layout and control logic.

Prices as quoted by the driverless vehicle manufacturers are shown in Table B.3. In general, the price increases with the greater horsepower or load-pulling capacity of the vehicle. In addition, the price of a single model can vary depending on the capabilities of the vehicle's control subsystem, optional equipment, and the quantity of purchase. A unique path control system will cost \$1,000 to \$2,000 more than the simple sequential control system, and the random access control system will cost an additional \$1,000 to \$2,000. The automated vehicles with on-board control subsystems typically vary from \$10,000 to \$35,000. Batteries for the vehicles can cost from \$300 to \$3,500, depending on size. Battery chargers cost from \$200 to \$1,200, depending on their size and special features.

Typical prices for four sizes of driverless vehicles are included in Table B.4. Each value in Table B.4 is an average of Table B.3 prices supplied by different manufacturers for approximately comparable equipment.

The guidepath, line driver (wire energizer), and simple control points (e.g., permanent magnets) cost from \$5 to \$10 per 0.3 meters (1 foot) installed for the wire-guided systems, largely dependent on the local installation labor rates. The optical guidepath (i.e., painted or taped line) is much less costly at \$0.50 to \$1.00 per 0.3 meters (1 foot) installed.

A central control option costs from \$6,000 to \$150,000 depending on the capabilities of the control system. The higher prices include computer control of vehicle operations.

Some price information was obtained on some of the important components. A guidewire energizer costs \$500 to \$600, permanent magnetic decision points cost about \$15 per location installed, and floor-mounted relay or reed switches cost \$20 to \$30 installed. When the control logic is at each decision point, as opposed to being on each vehicle, the equipment can cost \$600 to

$1,500 at each location. For vehicle-mounted components, contact bumpers cost $350 to $500, sonic obstacle detectors cost about $2,000, short range radar obstacle detectors cost $1,300 and a simple two-head optical headway (obstacle) detector system is priced at about $300.

B.4.2 Operating Costs

The annual operating costs per vehicle are based on the electric power needed to recharge the batteries, to energize the guidewire, and to power any control equipment along the guidepath. The estimated annual power cost (at 2 cents/kWh.) for battery charging is $22 for the small carts and $125 to $190 for the industrial tractors. This assumes each vehicle operates 40 hours per week, 50 weeks per year. The power needed for the guidepath and guidepath control equipment, assuming a 100 watt average total power requirement costs only $5 per year.

If it is assumed that 20 minutes of labor is required to check out, start, stop, and battery charge each vehicle each day, it costs $800 per year for what would otherwise be a $20,000 per year labor cost (including payroll taxes and benefits). With the assumed labor requirements, annual operating costs vary from $800 to $1,000 depending on vehicle size. Without the labor factor, the annual operating cost is less than $200 per vehicle.

B.4.3 Maintenance Costs

Maintenance costs are lower for electric vehicles than for comparable internal combustion engine vehicles. The average maintenance cost (parts and labor) for a manually driven electric fork truck is $0.40 per operating hour according to one survey.(32,33) The average total maintenance cost for a driverless tractor is $0.20 to $0.35 per operating hour according to one manufacturer. This is equivalent to $400 to $700 per 2,000 operating hour year. Figures of $400 to $600 per year for the vehicle and an added $100 per year for maintenance of the guidepath and equipment along the guidepath were used in the analysis in Table B-4.

According to a major supplier, the average annual maintenance cost for an optically guided automatic cart is $960. Most of this is needed for maintenance (including partial replacement) of the guidelines, which is done two or more times per year.

B.4.4 Life-cycle Costs

The average functional lifetime of a driverless vehicle is 10 years as is the lifetime of its trailers and battery charger. Batteries last only about 5 years, but a wire guidepath usually lasts for 20 years.

Using a 10% cost of capital rate and the equipment's average lifetime, the equivalent annual cost of the capital equipment is given in Table B.4. The wire-guided vehicles have an equivalent annual cost of $2,400 to $3,700 with an added $800 to $1,300 for the battery, battery charger, and trailers; 304 meters (1,000 feet) of guidepath for these vehicles is equivalent to a $940 annual cost.

The equivalent annual capital cost of the optically guided cart is $2,200 of which only $100 is for 304 meters (1,000 feet) of the low cost guideline.

When the equivalent annual cost of the capital equipment is added to the annual operating costs and annual maintenance cost, the total annual cost of owning and operating a driverless vehicle on 304 meters (1,000 feet) of guidepath is $4,000 for the cart, $5,600 for the 4,500-6,750 kg. (10,000-15,000 lb.) load capacity tractor, $6,600 for the 13,500 kg. (30,000 lb.) capacity tractor, and $7,700 for the 22,500 kg. (50,000 lb.) capacity tractor.

Assuming each vehicle operates at cruise speed for 4 hours per day, the total cost per vehicle mile is also calculated. The cart costs $4.00 per 1.6 km. (1 mile), and the industrial tractor costs from $1.90 to $2.50 per 1.6 km. (1 mile). The cost per ton-mile of load-carrying capacity makes the larger vehicles more economical. The cart costs $5.00 per ton-kilometer ($8.00 per ton mile), whereas the tractors cost from 6-19 cents per ton-kilometer (10-30 cents per ton-mile) capacity.

APPENDIX C

DRIVERLESS VEHICLES: AN INDUSTRY PROFILE

C.1 Market Structure

The U.S. driverless vehicle industry got its start in 1954, when the first wire-guided driverless tractor was introduced. The market has grown such that there are now six U.S. manufacturers of driverless vehicles.

The best applications for driverless vehicles are those that reduce the labor-intensive transportation of operator-driven vehicles. They are generally used for travel distances over 305 meters (1,000 feet) with several load and unload points, not necessarily in a simple loop, for system through-put of 10 to 50 loads per hour.* Alternative materials-handling transportation systems are conveyors, tow lines, tractor trains, low lift transporters, and fork trucks. Of these, those requiring manual operation result in high operating costs per load for distant (horizontal) material transport, especially when driver/operator wait time at load and unload points is considered.

The six U.S. manufacturers of driverless vehicles are: Atco, Inc.; Barrett Electronics Corp.; Clark Equipment Company; Control Engineering Company; Lear Siegler, Inc.; and Mobility Systems, Inc. Atco, Lear Siegler, and Mobility Systems entered the market in the past few years. All of the manufacturers make industrial driverless tractors, except Lear Siegler, which makes only optically guided carts. Control Engineering makes both tractors and carts. SRI estimates that about 700 industrial driverless tractor installations consisting of about 2,000 tractors have been sold by the above suppliers in the United States. It is estimated that about 1,200 carts have also been sold.

In 1977, sales are estimated to have been about 50 tractor installations representing sales of about 150 tractors, and about 30 cart installations accounting for about 120 carts. Although Lear Siegler has 100% of the optically guided cart market, the wire-guided driverless tractor market is estimated to be divided between the other five manufacturers as follows:

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*A complete description of currently available vehicles and their costs is given in Appendix B.

	Percent
Atco	1
Barrett Electronics	55
Clark Equipment	20
Control Engineering	20
Mobility Systems	4

It is expected that Barrett Electronics will continue to hold over half the market share and that Clark Equipment and Control Engineering will maintain about one-fifth of the market share each. Mobility Systems will probably increase its market share by aiming at the small industrial driverless tractor segment of the market that is not completely served by the other manufacturers. Atco is continuing in the driverless tractor product line that Otis Elevator Company, Automated Vehicle Systems Division used to make.

A brief profile of the manufacturers is included later in this section, along with an assessment of their potential to be a people mover AMTT supplier.

C.2 Profile of Driverless Vehicle Manufacturers

C.2.1 Atco, Inc.

C.2.1.1 The Company

Atco, Inc. was formed in mid-1976 by a former employee of Otis Elevator, Automated Vehicle Systems Division, when Otis discontinued its driverless tractor product line. Atco is a small (estimated two to four person) company located in Vinton, Virginia. The company is installing a driverless tractor system for the U.S. Navy in Charleston, South Carolina.

C.2.2 Barrett Electronics Corporation

C.2.2.1 The Company

Barrett Electronics Corporation, Electronic Systems Division, developed the world's first industrial driverless tractor system in 1954. The company's automated horizontal materials-handling system, named Guide-O-Matic, has been installed in over 500 locations in the world. The company offers five models of industrial driverless tractors and claims to hold 65% of the

U.S. driverless tractor market and 40% of the market in the rest of the world. Sales revenues have been increasing with between 12 and 30 new system installations being made each year over the past 5 years. Installations vary from 1 to 22 vehicles, although the typical installation has about 3 vehicles.

Sales revenue of the industrial driverless tractor systems are almost all of the division's total yearly sales and 15-20% of the company's approximate $16 million in annual sales. Other products made by the Electronic Systems Division are radio remote control tuggers and radio guide receivers and transmitters for remote vehicle operations. Products made by Barrett Electronics Industrial Truck Division are fork lifts and material transporters.

The Electronic Systems Division of Barrett is headquartered in Northbrook, Illinois. The Guide-O-Matic Tractor System manufacturing plant is also located in Northbrook, although the R&D section and the printed circuit board manufacturing plant is in Palo Alto, California. Barrett has 85 worldwide service outlets, with 70 of them in the United States.

C.2.2.2 Potential As AMTT Supplier

Of all the industrial driverless vehicle manufacturers, Barrett Electronics has been the most active and has had the greatest success with AMTT applications. The company first started by installing automatic trains for amusement park rides (the first installation was completed in 1959). The company has since then built and installed the people mover that operated at the Houston Airport from 1969 to 1972, and has installed its automatic guidance and control systems for demonstration and promotional purposes on buses, automobiles, farm tractors, and earth-moving equipment.

Barrett is interested in the AMTT as a market concept, but evaluates each market opportunity as it presents itself.

C.2.3 Clark Equipment Company

C.2.3.1 The Company

The Handling Systems Division of Clark Equipment Company has been manufacturing driverless tractor systems since 1 April 1971. In that year it acquired the physical assets of the driverless tractor system line from Mechanical Handling Systems Division of American Chain and Cable Company, which began selling driverless tractors in 1966. Clark's three models of driverless tractor systems are used only for materials-handling in production and warehousing activities. Clark Equipment has a total of 36 installations with 100 tractors in the United States and Canada. The company has not sold any in other countries. The company claims to hold 20-30% of the U.S. and Canadian market for driverless tractors.

Driverless tractor system sales represent less than 1% of the Handling Systems Division sales and less than 0.1% of the company's approximate $1.3 billion annual sales. The main product of the Handling System Division is high rise storage-handling systems. Other products made by Clark Equipment Company are fork lifts, narrow aisle trucks, straddle carriers, towing tractors, handling devices, automated storage systems, transmissions and related automotive components, and construction machinery.

The Handling Systems Division and the driverless tractors manufacturing plant is located in Battle Creek, Michigan. Industrial materials-handling products are sold through 125 independent dealers, and installation and service on the driverless tractor systems are handled by engineers based in Battle Creek.

Although Clark is the largest company in the U.S. driverless vehicle market, its driverless tractor is one of the company's smallest product lines and is not marketed heavily. The driverless tractors also must compete with the company's more important fork truck product line.

C.2.3.2 Potential As AMTT Supplier

Of the three major industrial driverless tractor system suppliers, Clark Equipment Company has exhibited the least interest in the people-moving market. The company considered adapting its driverless tractors to such people-moving applications as airports (e.g., Cleveland Hopkins International Airport) in the early 1970s; however, the increased risk of product liability problems kept the company from this type of application. If product liability claims could be limited to some acceptable value, Clark Equipment Company might reconsider this decision.

C.2.4 Control Engineering Company

C.2.4.1 The Company

In 1962, Control Engineering Company, a Jervis B. Webb Company affiliate, was the second U.S. company to enter the driverless vehicle market. Control Engineering Company's Pellston Division has sold over 300 PronTow Electroguide driverless tractors and automated hospital mini-cart systems. Control Engineering Company makes three models (sizes) of driverless industrial tractors. Control Engineering Company is the only company to make the hospital carts that are used to transport meals, linen, and other goods through a hospital. The company buys the chassis, body, and wheels for its vehicles from the Taylor Dunn Company and adds the drive system and all the electronics. The company claims to have had about 50% of the total driverless vehicle market (including hospital carts) or 30% of the driverless tractor market over the past 3 years. In 1977, however, both these figures dropped to about 20%, with sales revenue of the driverless vehicle systems at about 30% of the division's sales in 1977. Driverless vehicle sales have decreased from a high of 40-45% of CEC sales in 1970-71 to about 10% of the company's 1977 sales of approximately $10 million. This decrease is the result of the decline in the hospital cart market caused by a great reduction in new hospital construction.

The Pellston Division headquarters and manufacturing plant are in Pellston, Michigan.

C.2.4.2 Potential As AMTT Supplier

CEC has made three attempts to build AMTT systems based on its industrial driverless tractor systems. The first attempt consisted of a proposal submitted to the City of Houston for the airport that was then in the planning stages. Although the Houston airport proposal was not accepted, several years later, CEC worked with the city of Orlando, Florida, to integrate an AMTT system with the city's plans to close a section of the downtown to automotive traffic. The closed downtown plan was never implemented, and neither was the CEC design. Finally, in 1974, CEC made all but the body of two electric pedestrian movers for General Motors Corportation.

Since the early 1970s, CEC stopped pursuing the people-moving market for their driverless vehicles because of the increased risk of product liability. As the dollar amount of product liability court settlements increased, the owners of the Jervis B. Webb Company decided not to risk manufacturing AMTT products. In the GM case, GM assumed complete liability responsibility for the two prototype vehicles CEC made.

C.2.5 Lear Siegler, Inc.

C.2.5.1 The Company

The Automated Systems Division of Lear Siegler, Incorporated (LSI) began selling its automatic office delivery cart (trademark Mailmobile) in early 1976. Mailmobile technology is unique with respect to the other driverless vehicles. The LSI patented guidance system follows an invisible fluorescent line painted on the floor which is illuminated for the vehicles guidance sensors by an ultraviolent light installed on the undercarriage of the cart. The LSI system utilizes a noncontact obstacle detector that registers the change of capacitance caused by an object intruding into an electromagnetic field. The detector system generates such a field and any significant change in its capacitance causes it to stop.

The carts are currently designed for a single guidepath operation.

An estimated 250 units have been sold for use in 60 systems in the United States. Any given installation may use from 1 to 40 carts. Except for a few mail carts sold by Control Engineering Company a few years ago, LSI has been the only company in the office delivery cart market and currently has 100% of that market segment. Sales for the Mailmobile are estimated to be less than 1% of LSI's annual sales; however, LSI expects continued growth in the automated materials-moving market.

Lear Siegler, Inc. had fiscal year 1976 sales of almost $700 million. Lear Siegler reports that its four primary markets are electronics and communications, vehicle components, construction and housing products, and industrial equipment. The company claims to be a leader in the design and manufacture of precision instruments and flight navigation systems for aircraft, missiles, and spacecraft.

The headquarters for the Automated Systems Division of LSI and the Mailmobile manufacturing plant are located in Zeeland, Michigan. Sales are made directly from the factory with the help of several field sales representatives.

C.2.5.2 Potential As AMTT Supplier

Lear Siegler, Inc. appears to have the technical and production capabilities to become a supplier of people-moving AMTTs. The company does not appear to have extensive experience with marketing AMTTs to end users, however, because most of its products are sold to other manufacturers for assembly into end products.

LSI reports that as of early 1978, the company has not even considered the AMTT market because the company thinks it has greater growth potential in the automated materials-moving (vehicle) market.

C.2.6 Mobility Systems, Inc.

Mobility Systems, Inc., a subsidiary of the Raymond Corporation, began selling the smallest commercially available industrial driverless vehicle in April, 1977. The company has made wire guidance systems for manned order selector vehicles for over 8 years. The company has four installations totaling 15 "Electote" driverless vehicles to date, and believes its small vehicle can serve the segment of the market that does not need the larger tow tractor vehicles.

Sales revenue of the "Electote" was less than 5% of Mobility Systems' 1977 sales of $10 million and less than 1% of Raymond Corporation's 1977 sales of $75 million. Mobility Systems also makes manned wire-guided order picking vehicles. Raymond Corporation makes a full line of electric industrial trucks (e.g., fork trucks, order picking trucks, high and low lift trucks, and tow tractors).

Mobility Systems and Raymond Corporation are headquartered in Greene, New York. The Raymond Corporation has 47 dealers in the United States.

C.2.6.2 Potential As AMTT Supplier

Mobility Systems, Inc. has no experience or interest in automated people-moving vehicles because the company believes its growth will be in the industrial automated vehicle market.

APPENDIX D

DERIVATION OF COSTS

For the economic analyses in this report, costs of providing the existing or planned fixed route service were developed for:

- conventional buses using "transit" labor rates, and
- AMTT (based on buses and AGT).

The following standardized operating and maintenance (O&M) costs (in 1979 $) were derived and used:

- Bus O&M cost using "transit" labor rates ($1.66/veh. km. or $2.68/veh. mi.)
- O&M cost for AMTT ($0.82/veh. km. or $1.32/veh. mi.)

The American Public Transit Association (APTA) reports on bus operations provide a slightly different breakdown than that required by the Urban Mass Transportation Administration (UMTA), but with little or no more detail. Although some more detailed information is available on some transit properties from other sources, it is not possible to correlate between line items on different properties. Also, any attempt to disaggregate the numbers further would be ineffective because of differences in definitions between properties (for example, some properties include maintenance management under "maintenance," others under "administrative").

The O&M cost of AMTT is derived using two different approaches; employing data from conventional bus systems and from AGT systems. Data on AGT system's Operations and Maintenance costs are from four systems: Airtrans, Tampa, Sea-Tac, and Disney World. The O&M costs for electric buses are also presented here as a reference.

A figure of $0.30/veh. km. (48 cents per vehicle-mile) has been used for "spares" for the AMTT. Although an electric bus is less complex than the conventional diesel-bus from which this figure was derived, an AMTT will require additional spares for the control system. Also, a cost of 5 to 8 cents/veh. km. (8 to 13 cents per vehicle-mile) must be allowed for battery replacement. At the current state-of-the-art, batteries for electric vehicles have to be replaced many times during the life of the vehicle; the battery is therefore treated as an "expendable" rather than a capital item. This is included in the 30 cents.

Cost components of operating and maintenance costs for conventional buses using transit labor rates are shown in Table D-1 with some explanations and assumptions. The O&M and energy costs of AGT are shown in Table D-2. The O&M cost components of electric vehicles are shown in Table D-3. The O&M cost of AMTT is derived using two different approaches in Table D-4. The higher cost values were used in the analyses.

Standardized capital costs for conventional buses used in the economic analyses are shown in Table D-5. These are average costs derived from 263 bus purchases in the United States. It should be noted that actual bus costs would vary depending on number of buses ordered, interior finish, air conditioning, and engine specifications.

TABLE D-1 - OPERATING & MAINTENANCE COSTS
OF TRANSIT SERVICE BUSES*

	1976 $		1979 $**		Percent****
	$/veh.mi.	$/veh.km.	$/veh.mi.	$/veh.km.	
Operation & Maintenance***	2.10	1.30	2.68	1.66	100
Operation	1.47	0.91	1.88	1.16	70
Drivers	1.00	0.62	1.28	0.79	48
Fuel	0.15	0.09	0.19	0.12	7
Servicing & Inspection	0.32	0.20	0.41	0.25	15
Maintenance	0.63	0.39	0.80	0.50	30
Parts	0.38	0.24	0.48	0.31	18
Labor	0.25	0.15	0.32	0.19	12

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*Transit service buses are operated by a transportation authority using union labor.

**Consumer Price Index (CPI) used for cost escalations.

***Basic assumptions and explanations (with 1976 $):
a. Nationally, total O&M cost varies from $0.65 to $2.20/veh. km. ($1.04 to $3.54/veh. mi.).
b. Labor rate-$8.00 per hour plus 25% fringe (nationally varies from $4.50 to $9.78).
c. Fuel cost 60 cents per gallon and fuel use 6.4 km. (4 miles) per gallon.
d. Average operating speed 16 km/hr (10 mph); nationally varies between 8.5 and 28.8 km/hr (5.5 to 17.9 mph).
e. Distribution between operations and maintenance labor based on national average.
f. Distribution between drivers and maintenance labor based on national average.

****Note that 70-75% of O&M cost is labor.

Data Sources:
a. American Public Transit Association, "Transit Operating Report", Washington, D.C. November 1978.
b. DeLeuw, Cather and Co., "Characteristics of Urban Transportation Systems-A Handbook for Transportation Planners", June 1979.

TABLE D-2 - OPERATING AND MAINTENANCE LABOR AND ENERGY COSTS OF AGT SYSTEMS*

(1979 $)

	Airtrans	Tampa	Sea-Tac	Disney World	Average
Vehicle Kilometers Traveled	5,403,000	662,900	850,400	999,300	1,978,900
(veh. mi. traveled)	(3,358,000)	(412,000)	(528,500)	(621,100)	(1,229,900)
Total No. of Employees	107	7	19	12	36
Average Productivity, Vehicle km/employee-year	50,500	94,700	44,800	83,300	55,000
(veh. mi./employee-year)	(31,380)	(58,860)	(27,820)	(51,760)	(34,160)
Labor Cost,** $/veh. km.	0.35	0.19	0.39	0.21	0.32
$/veh. mi.	0.55	0.30	0.63	0.34	0.51
O&M Cost per veh. km. ($)	0.61	0.87	0.85	0.31	0.62
O&M Cost per veh. mi. ($)	0.98	1.39	1.36	0.49	0.99
Energy Cost as % of total O&M	8.4	2.3	13.4	17.4	10.4
Energy Cost $/veh. km.	0.05	0.02	0.12	0.06	0.07
$/veh. mi.	0.09	0.03	0.19	0.09	0.11

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*Data Source: "Summary of Capital and Operations & Maintenance Cost Experience of Automated Guideway Transit Systems", Costs and Trends for the Period 1976-1979, Supplement II, by Transportation Systems Center, March 1980. Figures for Disney World reflect train miles since the system operates with 5-car trains.

**Using average annual salary of $17,300 based on $7.65 per hour plus 25 percent fringe.

TABLE D-3 - OPERATING & MAINTENANCE COST OF ELECTRIC VEHICLES*

	1977 $		1979 $****	
	$/km.	$/mi.	$/km.	$/mi.
Energy Cost**	0.01-0.06	0.02-0.10	0.02-0.08	0.03-0.12
Maintenance & Repair***	0.02-0.21	0.03-0.33	0.03-0.25	0.04-0.40
Battery Replacement*****	0.06-0.63	0.10-1.02	0.07-0.76	0.12-1.23
Total O&M Cost******	0.09-0.90	0.15-1.45	0.12-1.09	0.19-1.75

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*Source: "State-of-the-Art Assessment of Electric and Hybrid Vehicles," U.S. Department of Energy, January 1978. Data collected from over 800 on-road electric vehicles in use in U.S. and Canada.

**Energy consumption rate ranges between 0.15 and 0.80 kWh./km./1000 kg. curb weight (or 0.10-0.60 kWh./mi./1000 lb.); using electricity cost of 5 cents/kWh.

***Average annual mileage operated is 3,000 miles.

****Consumer Price Index (CPI) used for cost escalation.

*****Life of battery is approximately one year or between 3,000 and 6,000 miles.

******Excluding driver cost.

TABLE D-4 - DERIVATION OF AMTT O&M COST

AMTT Cost Based on Buses/Transit Service

	1976 $		1979 $	
	$/Veh. mi.	$/Veh. km.	$/Veh. mi.	$/Veh. km.
Total O&M Cost	2.10	1.30	2.68	1.66
Less Driver	1.00	0.62	1.28	0.79
Less Energy	0.15	0.09	0.19	0.12
	0.95	0.59	1.21	0.75
Plus Electricity	0.09	0.06	0.11	0.07
	1.04	0.65	1.32	0.82*

AMTT Cost Based Upon AGT

Labor Cost	0.51	0.32
Spares**	0.48	0.30
Electricity***	0.11	0.07
	1.10	0.69*

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*The higher value of $0.82/veh. km. is used as AMTT O&M cost in cost analyses.

**From bus cost.

***Average of four AGT systems.

TABLE D-5 - STANDARDIZED CAPITAL COSTS OF CONVENTIONAL BUSES

Type of Bus	Unit Capital Costs 1976 $*	Unit Capital Costs 1979 $**
Jitney, 5 passengers	8,000	10,000
Bus Wagon, 10 passengers	16,000	20,000
Minibus, 15-20 passengers	28,000	35,000
Midsize Bus, 25-33 passengers	44,000	54,900
Large Normal Bus 40-51 passengers	66,000	100,000 - 120,000***

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*Source: "Characteristics of Urban Transportation Systems, A Handbook for Transportation Planners," by De Leuw, Cather & Co. for UMTA, June 1979.

**The Producer Price Index (PPI) for machinery and motive products (previously called the wholesale price index) is used to adjust the costs from 1976 dollars to 1979 dollars. 1976 carries a PPI of 169.8 and 1979 carries a PPI of 206.9. The following values are used in the cost analyses: $20,000 for small bus, $55,000 for medium bus, and $100,000 for large bus.

***$102,000 for New Look Bus, $116,000 for GMC RTS-II ADB, and $110,000 for GFC 870 ADB. From "Transbus - An Overview of Technical, Operational, and Economic Characteristics," by The MITRE Corporation, 1979.

APPENDIX E

PARAMETRIC ANALYSIS FOR LONG-TERM AMTT AND BUS

The primary difference between the long-term AMTT (designated AMTT-LT in the figures in this Appendix) and the near-term AMTT analyzed previously in this study is that the barriers will no longer be needed for AMTT-LT to avoid conflicting traffic. The long-term AMTT will take advantage of further development and refinement of the present sensor and control system. From examination of the current trend in electronic technology, better sensor and control systems in AMTT-LT will not cost much more than their present counterparts in constant dollars. Therefore, in terms of 1979 dollars, the long-term AMTT unit costs used in this illustration are estimated to be the same as those for the near-term AMTT.

The parametric analysis for long-term AMTT and bus performed in this appendix uses the same approach and same data as the one carried out in Section 3, except for the differences mentioned above. Figures E.1 through E.3 show the equal cost lines and isocost lines for medium-sized vehicles with different route lengths. Within the same vehicle size, the isocost lines and equal cost lines exhibit similar characteristics as those in the previous analysis. But since there are no longer any barriers for AMTT-LT, route length is a less important parameter than it was before. The isocost line does not move much as the route length changes because the guidepath cost (affected directly by route length) is relatively insignificant.

Generally, when the route length is short (e.g., 2 km.), there is not much difference between the isocost lines developed for AMTT-LT vs. bus and those developed for near-term AMTT vs. bus. As the route length increases, the difference increases: the isocost lines for AMTT-LT vs. bus move toward the lower right hand corner of the graph relative to those for AMTT vs. bus. This means that the AMTT zone increases in size, making AMTT a more cost-effective mode than bus. (Compare Figures E.1 and 3.2.a; Figures E.2 and 3.2.c; Figures E.4 and 3.1.c; Figures E.5 and 3.3.c.).

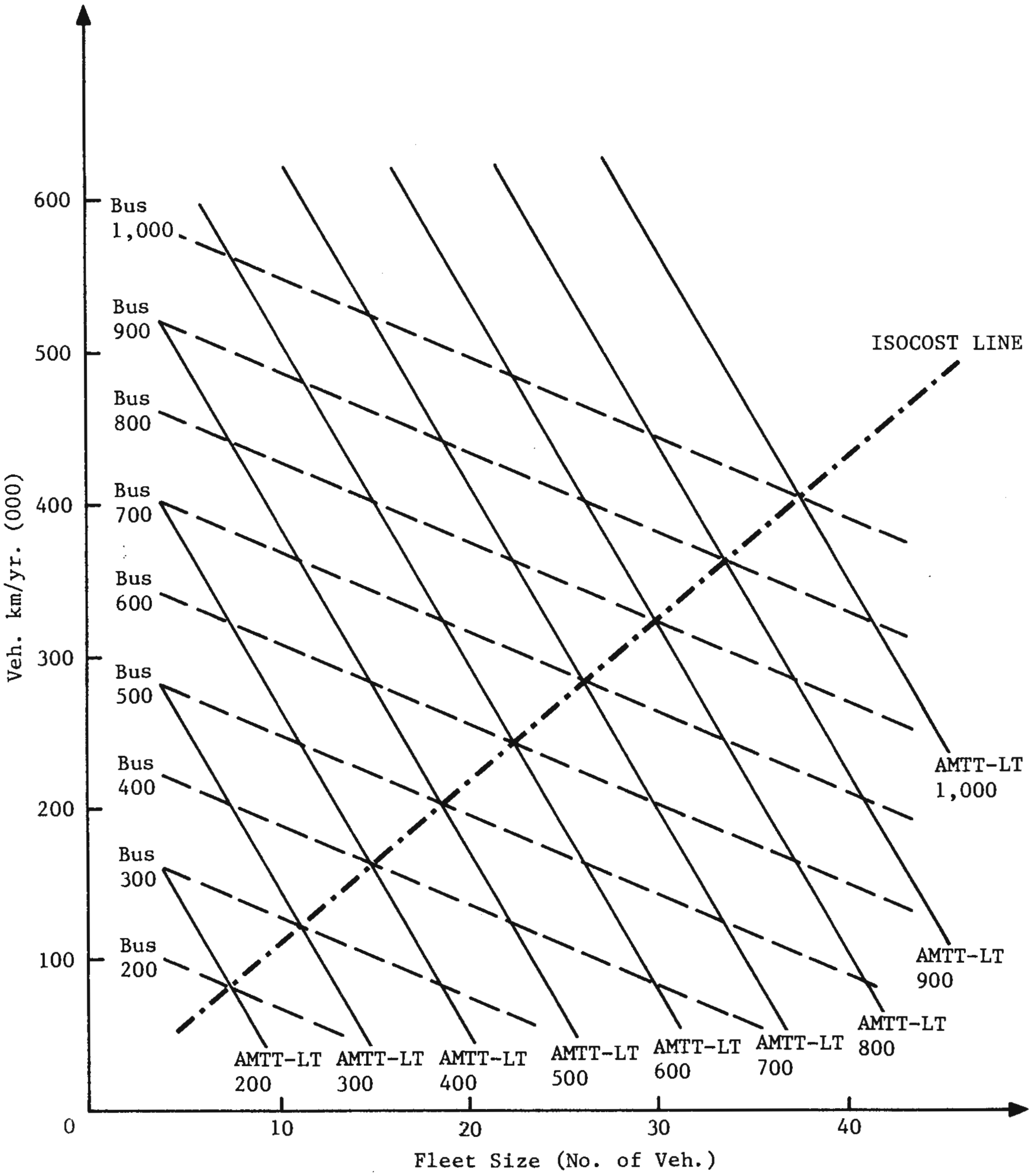

FIGURE E.1 EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) FOR LONG-TERM AMTT VS. BUS —MEDIUM VEHICLES, 2 KM ROUTE LENGTH .

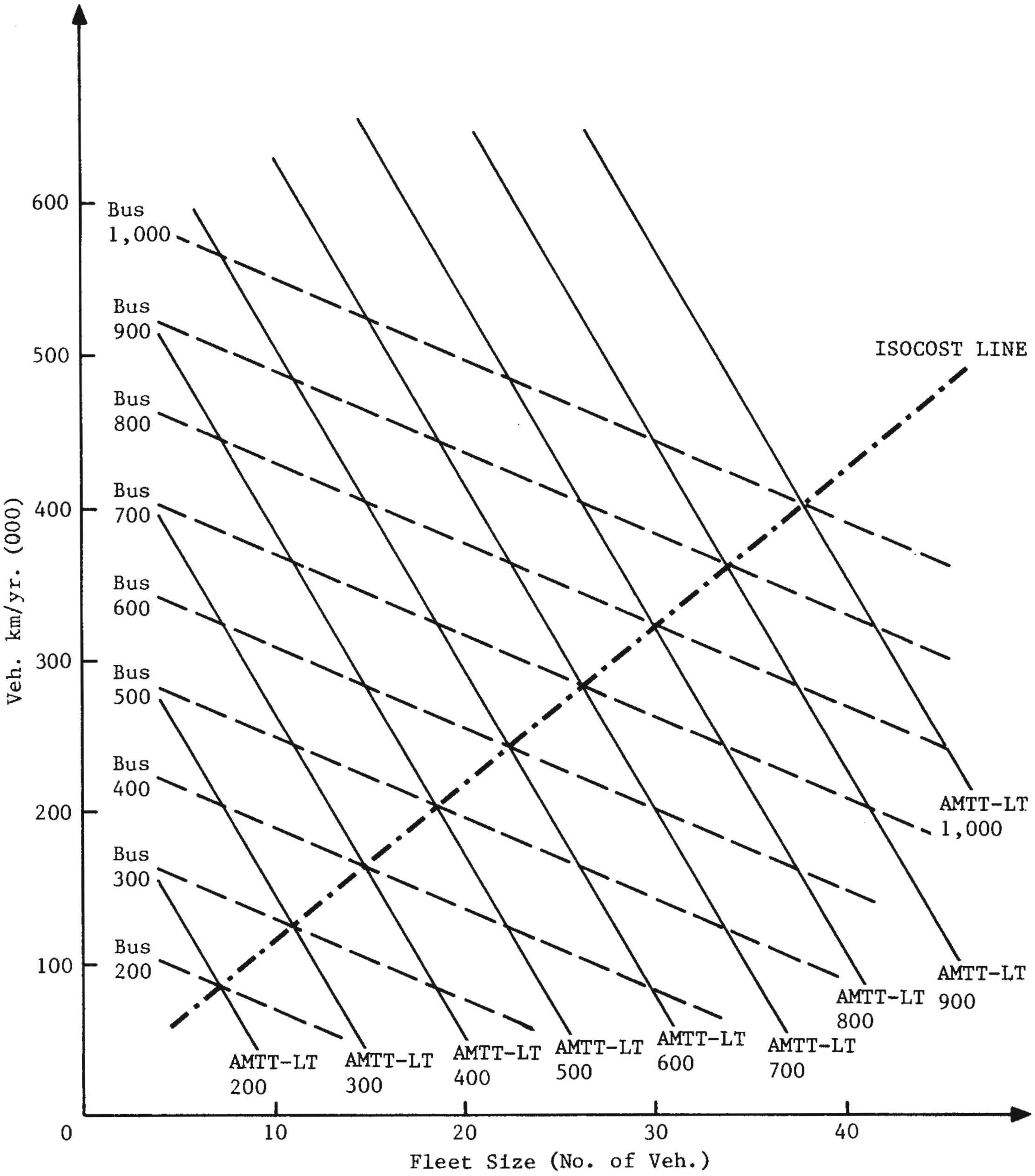

FIGURE E.2 EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) FOR LONG-TERM AMTT VS. BUS —MEDIUM VEHICLES, 10 KM ROUTE LENGTH.

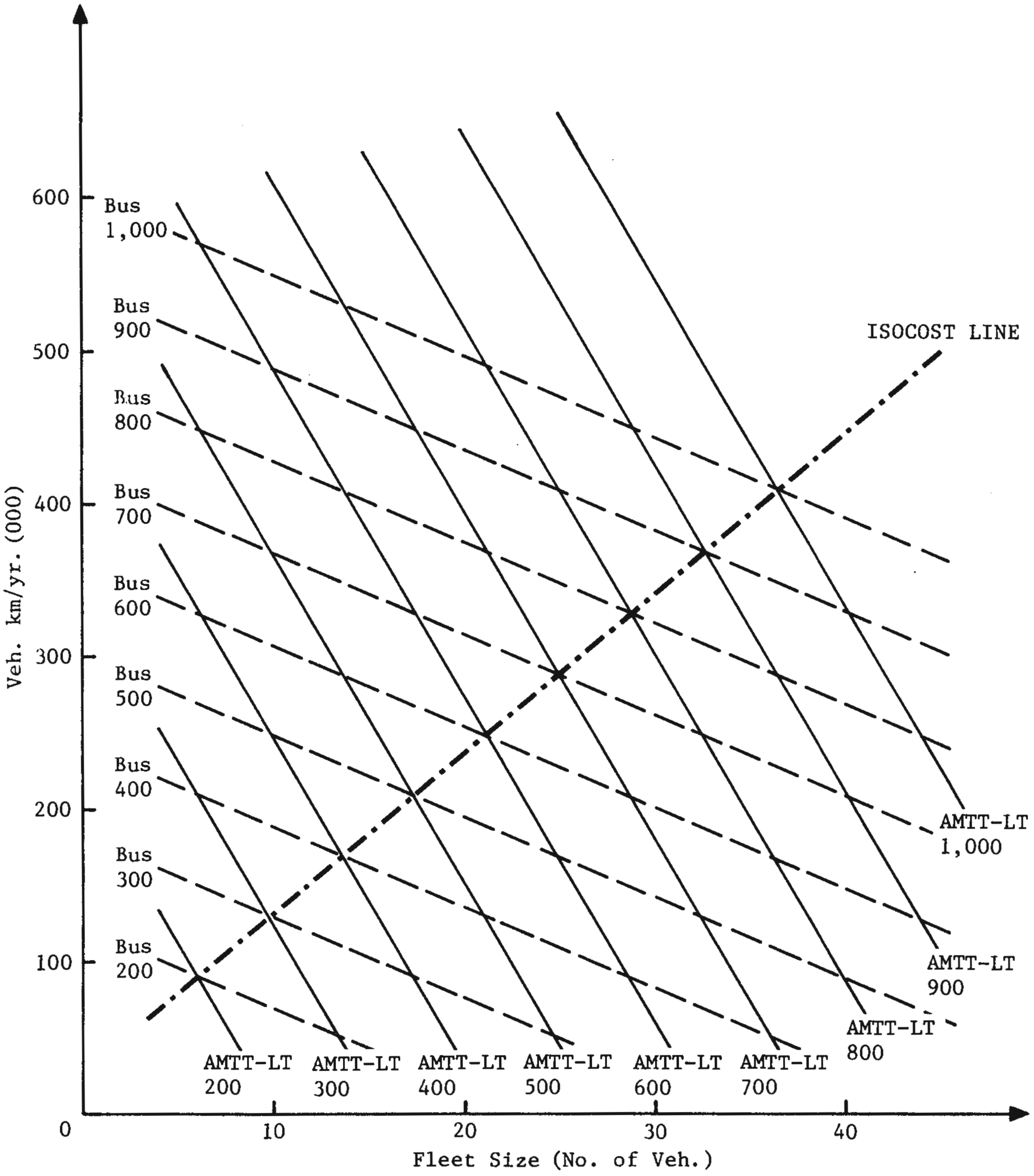

FIGURE E.3 EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) FOR LONG-TERM AMTT VS. BUS —MEDIUM VEHICLES, 30 KM ROUTE LENGTH.

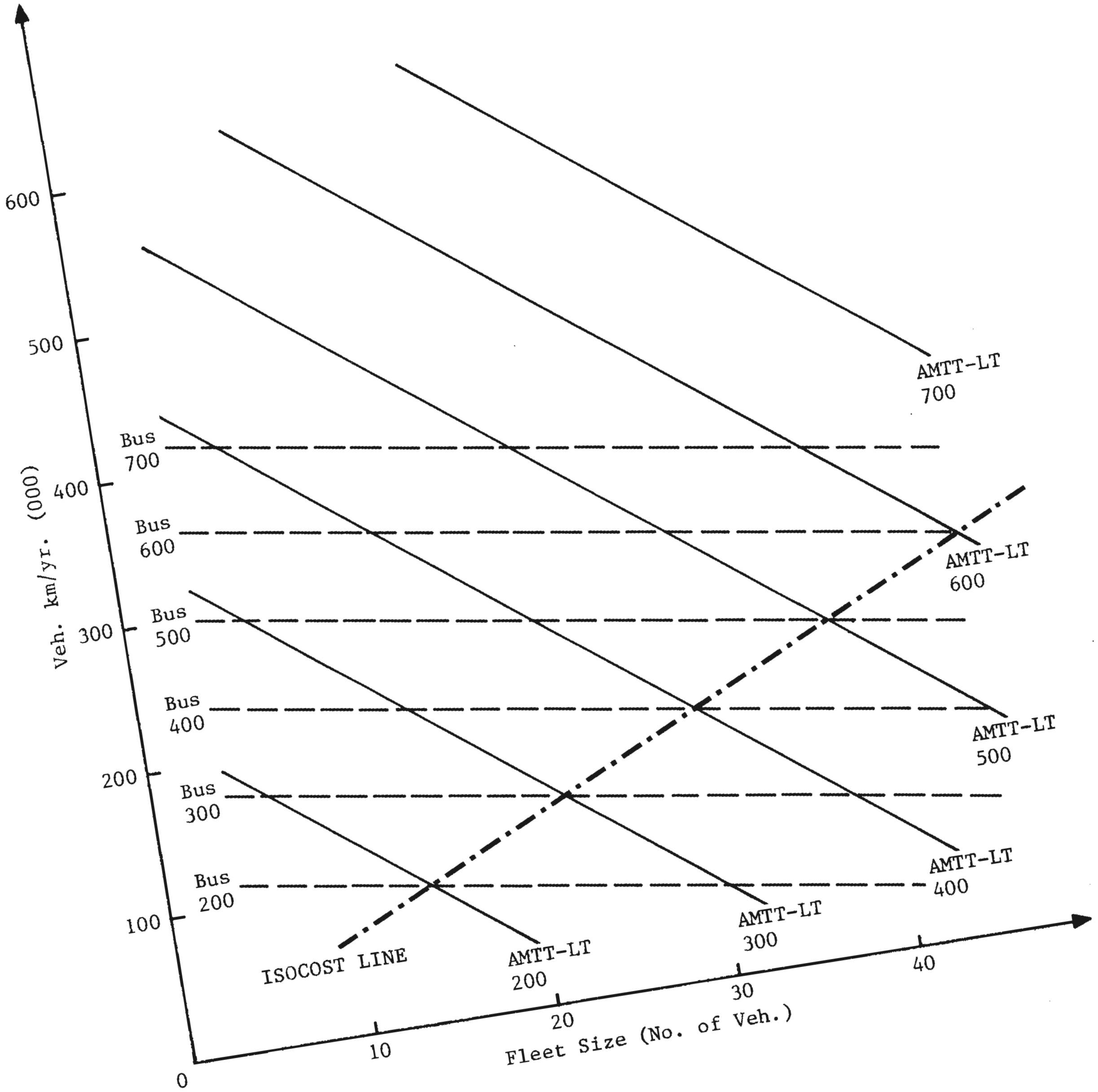

FIGURE E.4 EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) FOR LONG-TERM AMTT VS. BUS —SMALL VEHICLES, 10 KM ROUTE LENGTH.

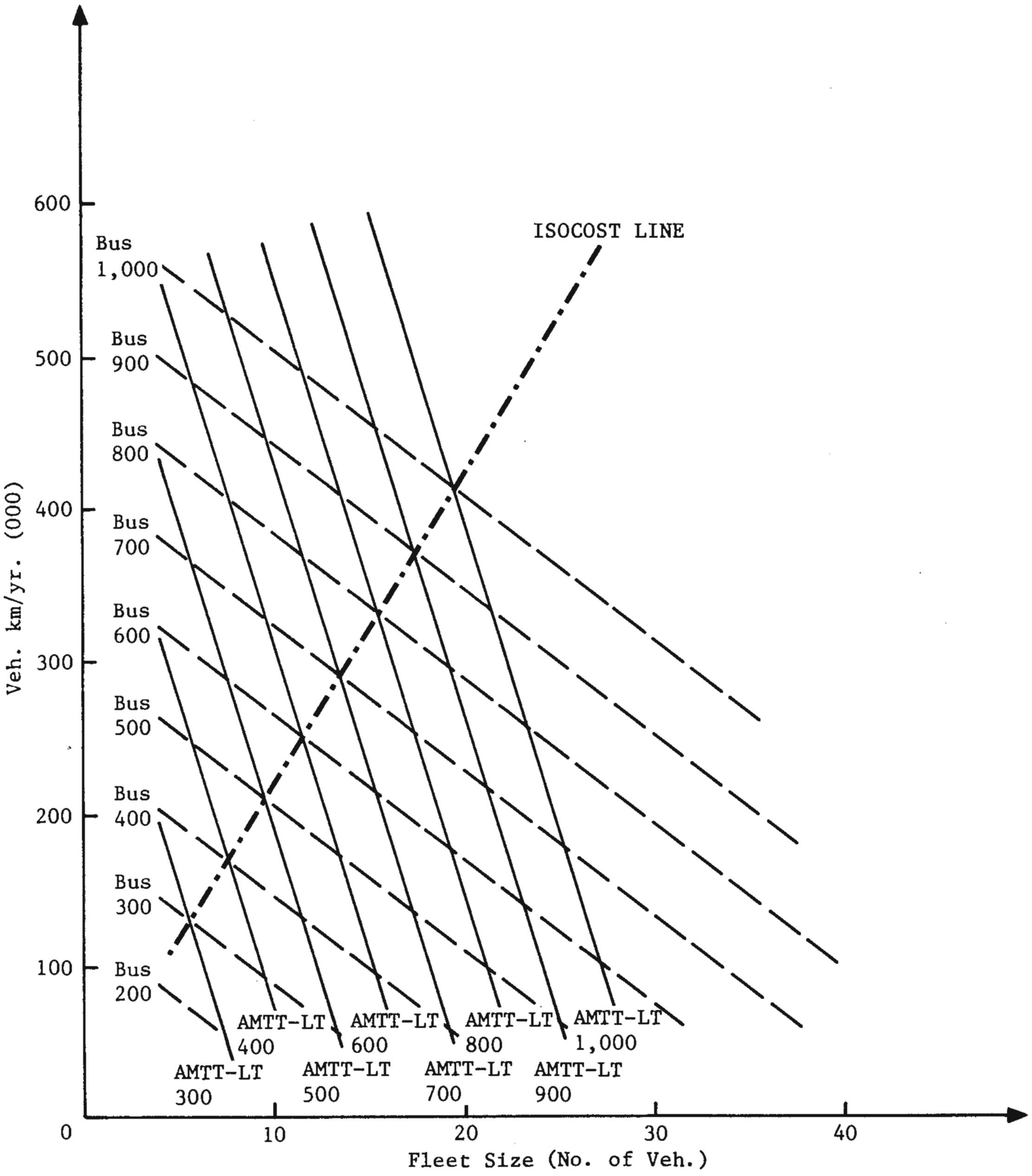

FIGURE E.5 EQUAL COST LINES SHOWING ANNUALIZED TOTAL COST (THOUSANDS OF 1979 $) FOR LONG-TERM AMTT VS. BUS —LARGE VEHICLES, 10 KM ROUTE LENGTH.

The market penetration potential for long-term AMTT improves due to lower annualized total cost. Table E.1 shows potential long-term AMTT market penetration based on cost comparisons with conventional bus. The improvement in market penetration is more significant in cases where the route lengths are relatively long, as illustrated by retirement communities and long route length cases of universities and CBDs. The average market penetration potential of the long-term AMTT increases by approximately five to 25% in most application areas when compared with that of the near-term AMTT.

TABLE E-1 - POTENTIAL LONG-TERM AMTT MARKET PENETRATION BASED ON COST COMPARISONS WITH CONVENTIONAL BUS*

	Vehicle Size		
Application Area	Small	Medium	Large
Universities	--	80-90%	50-55%
CBDs	--	95-100%	70-80%
Airports	100%	100%	--
Medical Centers	100%	100%	--
Retirement Communities, New Towns, etc.	100%	90-95%	--

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*Based on results of parametric analysis performed in the appendix and ranges of transportation requirements and service characteristics prescribed in Table 5-1.

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