THE CASE FOR PERSONAL RAPID TRANSIT

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Present systems of urban transportation, private (primarily the automobile) and public (conventional buses or rail transit), have not satisfied the need for transportation. The automobile is expensive and cumbersome for many urban transportation needs. It cannot be used by those who for reasons of health, age, or wealth cannot drive. The conventional transit systems have had declining patronage for many years due to the increased cost of these systems and their inability to provide service competitive with the automobile. It is, therefore, necessary to consider the possible development of new forms of public transportation that can meet the established needs. This paper considers the requirements for, and possible development of, personal transit systems that combine some of the characteristics of the automobile and public transportation. These systems are designed to provide transportation for an individual or a group in an exclusive vehicle, routed directly from the origin to destination by automatic controls. This paper describes the advantages and application of such systems. It includes a preliminary evaluation of the relative areas of application of such systems, as well as more conventional transit systems, and a discussion of possible technical approaches to such systems.

•THE declining acceptance of urban transit, coupled with an increasing demand for transportation, makes it desirable to take a new look at public transportation in order to establish whether more attractive systems can be devised by using existing or advanced technologies, for example, personal transit systems that would provide direct origin-to-destination service for the passenger on a demand basis.

Most public transportation systems transport groups of unassociated people to common destinations on pre-established schedules with frequent intermediate stops. The only personal transit system in significant use today is the taxi, which is routed directly to the passenger's selected destination. This service is provided at a significantly higher cost than an equivalent trip by bus; however, it provides sufficient value such that almost every city, even a very small one, has a viable taxicab service. The same cannot be said of urban transit systems, which are poorly used and rapidly becoming economic liabilities.

A personal transit system would consist of small vehicles (4 to 10 passengers) operating under automatic control on a network of guideways in an urban area. Such a system would provide direct service from origin to destination without intermediate stops. The potential advantages of this type of system would include the following:

1. Lower cost due to light simple vehicles, smaller guideways, and reduced right-of-way requirements;
2. Faster trips due to direct service without intermediate stops and without waiting for vehicles;
3. A more extensive area of service due to the larger network that could be built for the same cost; and
4. A more attractive service due to privacy and direct service provided by the personal transit vehicle.

Sponsored by Committee on New Transportation Systems and Technology and presented at the 50th Annual Meeting.

The objectives of this paper are to review each of the major advantages of the personal transit system and provide evidence, where available, that suggests the order of improvements possible. It is the authors' hope that adequate supporting information has been included in this paper to encourage transportation authorities to make additional comparative studies of personal and conventional transit for major transportation applications and to conduct actual tests and demonstrations of this concept.

STATUS OF PUBLIC TRANSPORTATION

The declining public acceptance of urban transit has been pronounced since the end of World War II and has accompanied the change in the form of the city. It is, in part, a result of the increased discretionary wealth of the private citizen who can choose to purchase amenities (or luxuries) such as a private automobile for his personal transportation.

Usually the transportation planner has only three choices that he can make in planning for the future transportation needs of a city or town:

1. Continued expansion of automobile systems;
2. Introduction (or expansion) of a rail transit system; and
3. Expansion of bus transit, possibly coupled with the use of express lanes or private rights-of-way.

Many cities are looking for improved public transportation, and detailed studies and major plans have been made by a number of cities. For historical reasons that can be readily justified by the transportation authorities and planning groups, these studies have concentrated on conventional steel rail transportation systems (moderately upgraded) that can carry large passenger volumes.

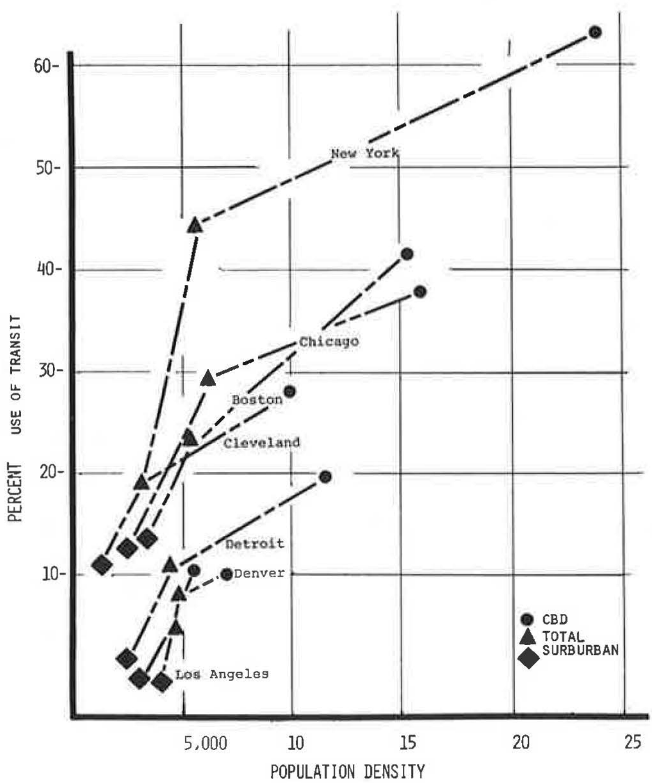

Figure 1. Percentage of CBD-oriented trips by transit system.

The high costs of a rail system can be justified only by service to a high-rate traffic generator. Commonly the CBD is the only such generator in a city. In cities where rail transit has been installed, the transit system does provide a high percentage of the CBD-oriented trips, as Figure 1 shows. However, as cities expand, they tend to become less centrally oriented and less dense. Newer cities may have many centers of activity. For example, in a recent study, Los Angeles was shown to have nearly 30 activity centers of relatively similar importance as traffic generators.

Data on some recent transit proposals and subsequent action are given in Table 1. The percentage of trips is based on the total daily trips in the area. Rail transit systems are usually designed to operate for peak loads rather than to handle the entire traffic demand. Considered on this basis, the Los Angeles rail system should handle about 11 percent of the a. m. or p. m. peak trips equiv-

TABLE 1

RECENT TRANSIT SYSTEM PROPOSALS

City	Length (miles)	Number of Stations	Cost ($ billion)	Trips (percent) Total	CBD	Results
Los Angeles	87	66	2.5	2	6	Voted down (11)
Atlanta	10	—	0.475	5	10	Voted down (10)
Seattle	47	—	1.1	7.5		Voted down (14)
Washington	98	—	2.5	5	10	In planning (17)

alent to 30 or 40 percent of the automobile trips in these hours (23), a very worthwhile reduction in freeway traffic.

Some extensions of existing systems are making notable records. The Lindenwold line in Philadelphia attracts more ridership than predicted, and the airport line in Cleveland attracts a significantly larger ridership than estimated.

Although the reasons for the failure of the proposed systems to obtain the support of the electorate are not fully understood, there are two basic reasons that appear to have an influence in all cases.

1. The rail systems have an image of the 1919 streetcars or the elevated loop and, therefore, appear to many people to be a step backward; and
2. In the best systems, rail transit provides service for only a small portion of the total trips in the urban area.

The preference of trip-makers for the automobile appears to be based on a number of factors. In contrast to public transportation, the automobile can

1. Travel directly from origin to destination (less the requirements for parking at each end of the trip);
2. Be immediately available to its user (who does not have to worry about time schedules or availability of seats);
3. Provide convenient transportation and storage of personal articles (invalids and the infirm can be accommodated with relative ease as passengers);
4. Provide security and privacy (it is not necessary to share the trip with strangers);
5. Almost always provide lower trip time; and
6. Offer pride of individual and private ownership.

Conventional transit systems (rail or bus) have not competed effectively with the automobile for a number of reasons.

1. Trips generally are possible only along major corridors (some method of access is usually necessary at one or both ends of the trip, and transfers are frequently necessary thereby reducing speed and convenience);
2. Public transit systems operate on a schedule (the service frequency is seldom shorter than every 2 min, may be 15 min to an hour during the day, and may not exist during certain time periods);
3. Vehicles are frequently difficult or inconvenient for the aged or infirm to use (buses have high steps, and rail systems have long difficult stairs);
4. Increasing labor and material costs make even relatively popular runs unprofitable;
5. Inadequate amenities exist for the passenger (seats are hard and crowded, and all classes of passengers must mix in the same compartment); and
6. Low average speeds are typically less than one-half the actual en route speed (a transit system trip may be several times as long as an equivalent trip by automobile).

Limitations of the Automobile

Although the automobile is a very effective means of transportation in general, its major advantages are outstanding in moderate- or low-density areas where other forms of transportation are uneconomic or nonexistent. In large urban areas, the advantages of an automobile used for commuting to the center of the city are diminished by excessive distances, inadequate and crowed roads, and expensive parking facilities. The cost of building additional facilities is often significantly more expensive than the cost of providing equivalent transportation capabilities by use of public transit systems. Although we do not expect new forms of transportation systems to replace the automobile or existing conventional transportation modes, we have emphasized the comparison of the transit systems and the automobile because the car is the standard by which most Americans judge their transportation service.

PUBLIC TRANSPORTATION REQUIREMENTS

In evaluating future transportation needs, one must understand the factors that influence the magnitude and nature of the transportation required. An evaluation of future transportation systems must consider (a) changes in population and urban density, (b) changes in rate of travel and travel requirements, and (c) availability and attractiveness of alternative modes of transportation

The requirements for transportation of people and goods are based on both social and economic factors, the locations of centers of population and industry, the areas of residence and recreation, the location of service activities, and the geographic constraints of the area in which transportation is to be provided.

Changes in the number of people and the form of community organization will bring changes in the requirements for transportation. The increased time available for recreation and sports will increase the need for transportation. Larger cities with lower population densities will make the movement of people by conventional transit systems less competitive with the private automobile.

The design of transportation systems and vehicles (whether public or private) is related to the movement of people and how their needs may change in the future. The extreme transportation need of this country is demonstrated by the 1966 figure for the movement of people—almost 1 trillion passenger-miles (approximately 80 percent in automobiles). On this basis the per capita average was nearly 5,000 miles.

A primary factor in establishing whether a specific trip will be taken is travel time. With increasingly effective transportation modes, the distance between residence and place of employment increases. The 1-day trip across the continent for a business meeting is not uncommon today.

The rate of travel is anticipated to increase even more rapidly than the population; for example, in one eastern town where a new rapid transit system is being considered, the number of trips per capita is expected to increase 25 percent between 1960 and 1980. The total mileage per capita is expected to more than double, and the number of automobiles is expected to increase by 50 percent (7).

Availability of a Car

Urban mobility requires a dependable, available transportation system. The modern passenger car has satisfactorily provided this for a large number of people. However, to use a car, one must have

1. A license,
2. Adequate funds to buy or rent a car,
3. Adequate physical health and skill, and
4. An adequate and available road system.

There are large groups of people who cannot meet all of these conditions. In 1967, 22 percent of United States families did not own a car, and in a substantial majority of families only one car was available. Car ownership in urban areas varies from 71 percent of the family groups in the Northeast to 84 percent in the West. Many who need transportation are not qualified to drive because of age, health, or legal restrictions.

The percentage of those who are unable to drive because of lack of licenses is shown in Figure 2. Over half of the eligible men under 17 and above 70 are not licensed to drive; at best, between the ages of 25 and 40, barely 50 percent of the women are licensed to drive.

Studies have shown that most users of public transportation systems are captive riders and have not made a free choice between public transit and an automobile. The typical reasons for using public systems are (a) car is not available; (b) user is unqualified to drive; (c) user is aged, infirm, or too young; and (d) there is no other way practical to reach destination, for example, commuting to Manhattan and, to a lesser extent, Chicago.

The captive nature of public transit users is borne out by the relationship of transit use and automobile ownership as shown in Figure 3 for 15 major United States cities (12). The relationship for work trips is almost directly proportional to automobile ownership. What is not clear is whether the presence of a transit system led to low automobile ownership, as the cities with the largest transit usage are the older, denser cities.

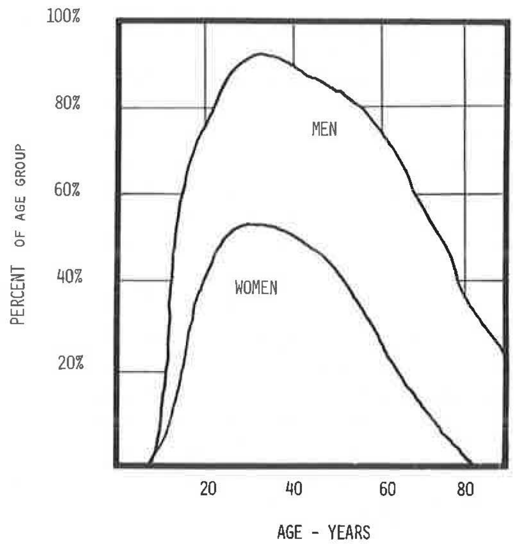

Figure 2. Percentage of population licensed to drive by age.

Many authorities, in particular the environmentalists, expect urban transit to make a significant inroad into the use of the private automobile. However, the demand for transportation is increasing so rapidly that even the most optimistic assumptions of the use of public transportation do not indicate a decrease in the use of the automobile. Table 2 gives the range of prediction of the use of public transportation based on a number of logical projections (12). The most significant is an increase of about 33 percent in the use of public transportation. This would result in only a slight decrease in the use of the automobile.

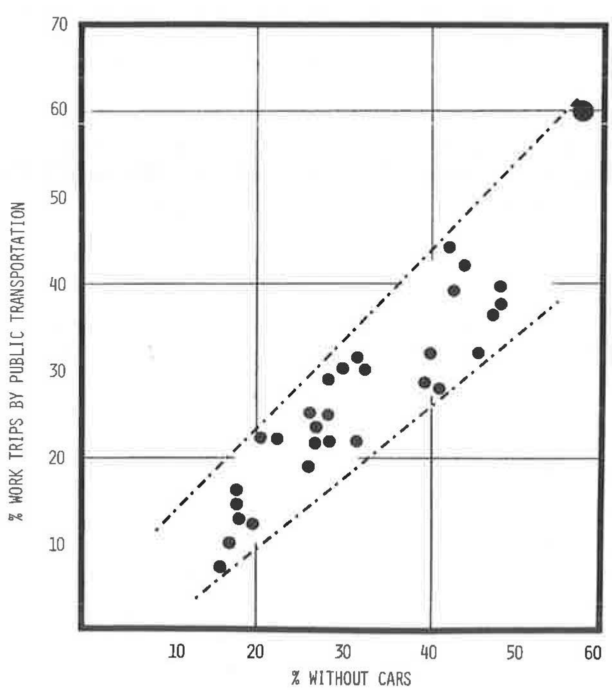

Figure 3. Relationship of automobile ownership and transit trips.

Although we cannot fully substantiate these assumptions (and reductions in automobile purchases would be anticipated by some authorities), they do indicate that expanded use of conventional transit will have little influence on the use of the automobile.

CRITERIA FOR IMPROVED PUBLIC TRANSPORTATION

A superior public transportation system should provide (a) short trip times, (b) extensive coverage of urban area served, (c) adequate system capacity and expansion capability, (d) privacy and safety, and (e) minimum impact on the urban environment.

TABLE 2

ESTIMATED FUTURE CHANGES IN TRANSIT USE IN THE UNITED STATES FROM 1960 TO 1980

Method of Projection	Percentage of Change
1. Extrapolation of existing transit riding trends	-21
2. Projection based on extension of composite trends reported in origin-destination studies for selected urban areas	+4
3. Extrapolation of existing trends increased 33 percent for service improvements[a]	+5
4. Projection based on stratification of nation's urban residents according to urban population, and estimated transit riding in each grouping	+14
5. Extrapolation based on general relationship between automobiles per capita and transit rides per capita	+30

[a]This value is based on reported gains in patronage resulting from selected service improvements.

A successful urban transportation system must meet many needs. It must, at the least, provide transportation for those who are unable to afford automobiles or unable to drive from their residences to work, recreation, or shopping. However, in our affluent society, a system designed for only the indigent and infirm will not have sufficient patronage to be economically successful. The system must also attract those who can afford to pay for the services and therefore must provide more extensive, better service than could otherwise be obtained.

Studies of rubber-tired transportation systems indicate that a significant number of people are willing to pay a higher fee for a system that will provide rapid, personalized service. For example, in New York, nearly 20 percent more passenger trips are made by taxicabs than by subway and commuter rail.

Personal Rapid Transit Systems

It has been proposed that a tracked system can be devised that bears the same relationship to a rail system as the taxi bears to the bus. This type of system would provide direct service for a traveling group and improved and possibly more economical service.

Such systems must be greater in extent than conventional rail systems and provide more frequent terminal locations. It must be possible to install them with a minimum disturbance to existing buildings or to the appearance of the city.

Although taxi and bus data indicate that many people would be willing to pay a premium price for individual or personal rapid transit (PRT) type of service, there are to date very few data to indicate the importance of service in attracting additional patronage.

Trip Times

For many trips, personal transit systems operating at moderate speeds (i. e., less than 60 mph) will provide shorter trip times than other modes of transportation, including the driver-operated car. The personal transit system will provide an average speed approaching the line speed of the system when operated to a significant distance. There are no intermediate stops for stations, no stoplights, and no slowing of speed for traffic. Vehicles would be immediately available in the stations.

Other modes of transportation are inherently slower than their running speeds. For example, Table 3 gives the average trip speed for the more commonly used modes of transportation for five major cities (12). Only the automobile exceeds an average speed of 10 mph. The automobile speed is influenced significantly by the length of the trip and the availability of a suitable road system.

Comparable trip speeds for PRT systems, assuming a 5-min walk to the station, a 30-sec station delay, and 0.3 g acceleration, would be as given in Table 4 (12). Even including the 5-min walk (¼ mile), the average trip time for an 8-mile trip by PRT would

TABLE 3

RELATIVE PORTAL-TO-PORTAL SPEEDS (MPH) FOR VARIOUS MODES OF TRANSPORTATION

Mode	Chicago	Philadelphia	Detroit	Pittsburgh	Philadelphia Center City
Automobile driver	11.1	11.4	8.9	13.6	10.0
Automobile passenger	10.4	11.3	8.9	13.6	10.1
Bus	6.2	5.4	6.0	7.4	5.7
Rapid transit	8.9	7.4	—	—	7.5
Commuter railroad	14.4	13.4	—	—	13.1
All	—	10.0	8.1	—	8.5

Note: Based on comprehensive origin-destination studies in each urban area.

range from 12 to 18 min. The equivalent trip would require 18 to 22 min, not including station waiting times; by automobile this trip would require 20 to 35 min depending on the available roads. Thus, the average time to complete a trip can be significantly lower by PRT than by other modes of transportation.

Line Capacity

Personal transit vehicles operating at typical automobile load factors (i. e., 1. 6 passengers per vehicle) can satisfy most of the real demands of passenger service. Typical peak-hour passenger requirements, actual or predicted, on rail transit systems in New York, Los Angeles (11), and Seattle (14) are as follows

City	Passengers per Peak Hour
New York	12,000 to 72,000
Los Angeles	12,000 to 24,000
Seattle	2,000 to 7,000

In many cases, these peaks exist only because the passenger load has been forced into channels to permit the economic operation of the rail system. PRT systems that are economic at a lower capacity would provide for alternate or parallel routes that would reduce the capacity required significantly while improving service.

The line capacity of a personal transit system depends on the control and braking technologies assumed and the conditions against which the system is to be protected. The technology exists today for a vehicle line capacity of 250 to 600 vehicles per hour (1,500 to 3,600 passenger-seats per hour for a six-passenger vehicle). A conventional rail transit system by contrast provides for 40 trains per hour (90-sec headways).

It is logical to assume that the technology will be developed to permit much higher capacities that approach the theoretical limits. For example, at 40 mph with 0.5-g (11 mph/sec) braking capability by the vehicle, the theoretical peak capacity of the line flow would be more than 2,000 vehicles per hour. This capacity assumes that there is a continuously monitoring control system and protection for the trailing vehicle against the improbable condition of an instantaneous stop of the lead vehicle. A 0.5-g stop is slightly lower than the maximum braking rate of a typical passenger car on dry pavement. The line capacity would increase with increased braking capability. For example, at 1.0-g braking the theoretical line capacity would exceed 4,000 vehicles per hour as shown in Figure 4.

TABLE 4

AVERAGE TRIP SPEED OF PERSONAL TRANSIT SYSTEM

Distance (miles)	Line Speed		
	40 mph	60 mph	80 mph
1	10	10.6	11.1
2	15.5	17.6	18.6
4	21.0	26.6	30.0
8	28.4	36.8	44.0
16	33.7	45.5	56.5

Note: Times include 5-min walk and 30-sec station access time.

Several possible approaches could be used to increase significantly the actual capacity after experience is obtained and safety ensured. For example, if it is found that the worst condition requiring protection is a 1.0-g stop by the lead vehicle, the capacity with a 0.5-g vehicle braking capability would again be more than 4,000 vehicles per hour. At higher deceleration rates (i. e., 0.8 g), which may be tolerable for emergency conditions, the capacity could theoretically be as high as 14,000 vehicles per hour.

Such capacities will probably never be obtained or required in practice. Practical control considerations will significantly reduce the actual vehicle capacity. Figure 5 shows the effect of various block lengths on the vehicle capacity that provides protection against a 1.0-g stop by the leading vehicle. A 30-ft block reduces the line capacity by more than 30 percent. Note that the effect of speed is such that with small blocks or continuous monitoring the capacity drops off exponentially with speed. At 80 mph the line capacity is half of the capacity that exists at 40 mph.

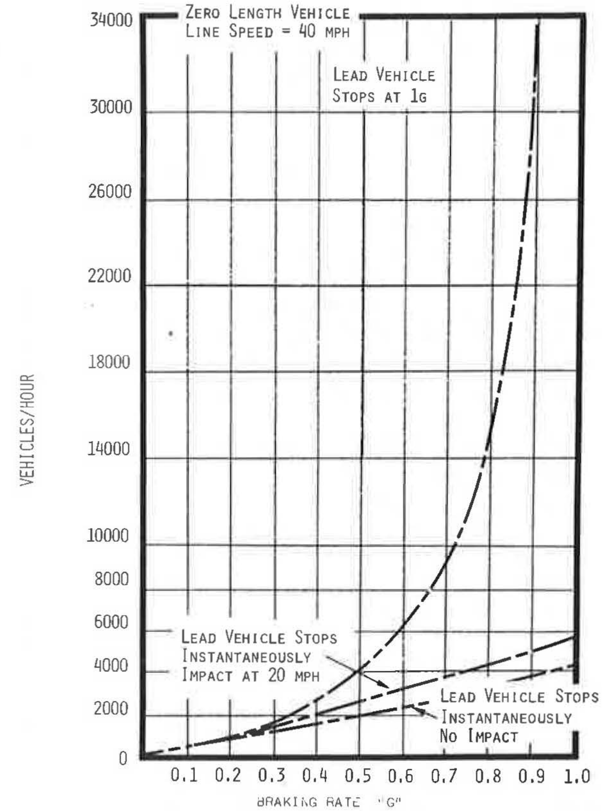

Figure 4. Line capacity and braking rate relationship.

Station Capacity

The limiting capacity of most systems, however, is established by the terminals. The random access or docking terminal provides unique advantages in this aspect, as follows:

1. The dock provides for loading the vehicle "off line" and thus permits vehicles to bypass the station;
2. Capacities equivalent to large vehicle systems can be provided with small personal transit vehicles; and
3. By having some docks occupied by empty vehicles, the passenger is assured of immediate service on entering the station, and holding up a single vehicle need not impair total system performance.

If six-passenger vehicles are used, a single gate can handle approximately 70 passengers per hour. On this basis, an eight-gate station (approximately 90 ft long) would be capable of handling 5,600 departures per hour if the vehicles were fully loaded. However, it may be expected that there would be an average passenger occupancy of 1.5 to 2.0 passengers per vehicle during most times of service, resulting in a flow of 1,800 passengers per hour—adequate for most urban needs. In places where lower passenger requirements are anticipated, fewer docks would be used; for example, two docks (24 ft total length) could handle over 1,000 passengers per hour.

A conventional transit system requires a loading platform equal in length to the vehicle; a 90-passenger vehicle, for example, requires approximately a 140-ft platform.

If a 90-sec headway exists, such a vehicle could handle the same volume as the eight-dock terminal.

Vehicle Management

The regulation of the vehicles in a personal transit system can be accomplished by using several modes. The choice of mode depends on the size of the system and specific requirements. The examples of possible modes of vehicle management include individual single-vehicle demand, transit or batch and scheduled sequential demand.

The single-vehicle demand mode would provide a vehicle for each traveling individual or traveling group. The vehicle would be dispatched for the specific trip only. Vehicle management would provide control of the path of the vehicle through the system network in a manner producing the minimum time for the system and existing demand. A secondary requirement of the vehicle-management system would be the supply of vehicles to the stations in response to the actual or anticipated demand. Where inadequate return service exists, empty vehicles would be scheduled to the stations. Such systems have an upper capacity limit per line due to the constraints discussed previously. However, in a large network system there will usually be adequate alternate routes to permit the vehicles to be scheduled to their destinations even where the peaks exceed the capacity of the most direct route.

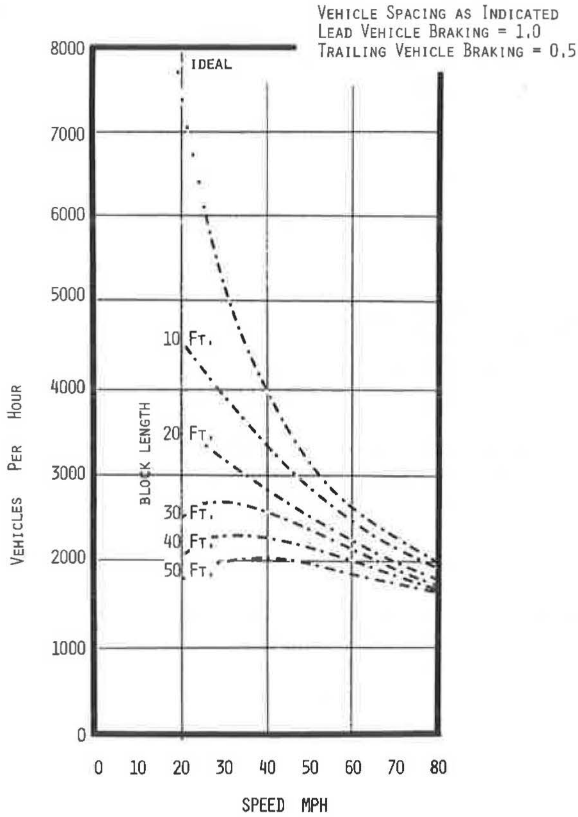

Figure 5. Line capacity and vehicle speed relationship.

Where higher capacities than can be provided on a single line are required, a batch mode of operation can be used on the same system. This could be provided by the incorporation of larger vehicles, each scheduled to specific destinations. In a terminal, a given dock could be identified for specific destination or route of destinations to provide efficient grouping of passengers. An alternate method of providing the same type of capacity would be to group vehicles in small trains with each directed to the same destination, or sequential destinations, such that the vehicles could be disconnected from the train at appropriate stops.

A simple circulation system may involve two to ten stations and several miles of track with few alternative paths between destinations. These systems are compatible with a number of basic vehicle management logic concepts and could be implemented in a relatively short period of time. More complex networks, as in a large city where there may be hundreds of stations and several alternate paths for almost every origin-destination pair, require more complex vehicle-management concepts. A number of approaches to these problems have been evaluated. The most attractive at this time are based on the use of a central computer that has full control of the velocity and position of each vehicle in the system. It is reasonable to assume that the problem of design of such a complex network can be resolved. Studies indicate that with proper vehicle management the peak-hour waiting times should still be less than the delays due to schedule frequency for conventional systems (13).

Passenger Service

The personal transit concept provides a class of service that cannot be provided by conventional transit systems. The small (4- to 6-passenger) vehicle will transport a single individual, a family, or a business group directly to the selected destination. The passenger can read, listen to music, work, or converse during the trip. It provides an environment equivalent to the private car but does not require attention and skill of the passenger. Children, the aged and the infirm, and those not qualified to drive can use this system.

Although there are few data on the actual use of personal transit vehicles, or the rider preferences, some studies have been conducted (28) to survey the preferences of possible rider groups for various typical system characteristics. The reference study indicated that the 5 most important characteristics out of more than 30 considered were as follows:

Characteristic	Rating
Arriving when planned	1.8
Having a seat	1.65
No transfer	1.56
Calling without delay	1.45
Shelters at pickup	1.42

It is very possible that the relative privacy of the personal transit system will attract a significant portion of the riding public who now use their private cars. V. B. Hammett, of the Psychiatry Department of the Hahnemann Medical College in Philadelphia, points out that there are many people who have an intolerance to being lumped in a group and who have a great need for privacy. He observes that, even in a traffic jam, these people have real privacy when driving their cars. They do not have to rub elbows with anyone. The independency and privacy are worth it to those who are willing and able to pay extra for it.

The significance of the degree of privacy on ridership is difficult to evaluate. One experiment that could be conducted with a demonstration PRT system would be to compare large transit vehicles with small personal transit vehicles (perhaps with a fare differential). This could be done in parallel with both classes of vehicles in the system or sequentially with the entire system dedicated to one or the other class of transit for a significant period of time.

The personal transit system provides a higher level of personal security than do conventional transit systems. Because each trip is made to a selected destination, the passenger can select his traveling companions. The station will be under continuous manual or TV monitoring, and a problem can be identified with appropriate corrective action taken. In most cases the vehicle would be held in the dock until authorities could investigate. This is in contrast to the situation in large transit vehicles where it is frequently necessary to maintain security guards.

Urban Development and Land Use

The PRT systems will have a somewhat different influence on the land-use pattern of a community than would a rail or all-automobile approach. The rail systems tend to force transportation into narrow channels and place a high premium on the value of the land most accessible to the individual stations. The decision as to the route, and particularly the station locations, is a significant one in determining how the community will develop and what form it will take.

The automobile provides relatively similar access to all locations in the community, thus tending to level land values. In part, as a consequence of this ease of access, the community will tend to grow in a scattered, disorganized pattern with industrial, commercial, and residential facilities intermixed.

The personal transit system, much as the rail system does, will tend to enhance the value of areas adjacent to the stations. However, because of the much greater number of stations, the effect will be less pronounced. The PRT system does provide many of the same advantages in urban development as does the rail system. Some stations will be placed in commercial areas and others will be placed in industrial, educational, and recreational areas. Stations located primarily in residential areas will tend to become the centers of small local communities and for that reason should be located in or adjacent to schools and other community facilities.

System Cost

Personal transit systems (using small, light, low-cost vehicles) should cost significantly less per route-mile and per station than conventional transit systems. PRT networks can be installed through places where the use of conventional transit systems would be impractical. The light weight and low noise of the vehicles should permit the systems to be routed through buildings and installed in locations that would be unacceptable for other forms of transportation.

In dense central business districts, for example, the system can be routed through existing buildings, and stations can be provided in the buildings much in the manner of an elevator. Surveys in several major cities have indicated that merchants and building owners would be willing to consider such installations in their buildings in exchange for the direct access it would provide.

The small vehicle guideways can be fabricated of conventional materials and erected with normal construction tolerances. They are small in cross section (4 to 6 ft wide total) and, because of the light weight of the vehicle, can be designed to be aesthetically pleasing.

The personal transit system concept can be implemented with a number of different technological approaches. Small individual-rail, rubber-tired, or air-supported vehicles can be designed, and a number of variants have been proposed. Although the actual cost figures for these systems are for the most part proprietary, some comparative cost data have become available in the literature. For the purpose of the study, the costs given in Table 5 were used. Individual differences in the cost per mile of elevated rail systems have varied significantly, and it may be anticipated that the ratio of cost for PRT systems may be even greater as they are more significantly influenced by line density and use of existing building structures.

A number of studies have been made to establish the relative economics of various forms of transit systems, and, although each application is a specific and unique case such that generalizations are suspect, it is convenient to consider the costs of competitive transit systems for the same type of service.

A previously published study by Transportation Technology, Inc., was based on a 10-mile route of uniform density. Bus, rail, and personal transit costs were compared directly with the operating costs of a conventional transit bus on the city streets. The

TABLE 5
REPRESENTATIVE TRANSIT SYSTEM COSTS

Item	Bus	PRT	Rail
System design, dollars	250,000	500,000	500,000
Engineering services, percent	15	20	20
Vehicle			
Capacity, passengers	52	8	80
Unit cost, dollars	50,000	10,000	250,000
Average right-of-way costs per lane-mile, dollars	400,000	200,000	400,000
Cost of guideway			
On-grade, dollars	25,000	300,000	300,000
Elevated, dollars	2,000,000	900,000	2,500,000
Average cost of stations, dollars	250,000	300,000	2,000,000
Cost of controls and electrification per mile, dollars		300,000	250,000
Cost of service facility, percent		5	10

study considered only the costs of moving a number of passengers, not the speed, attractiveness, or other considerations of importance to the passenger. In this study, the effect of peak-line requirements was evaluated, and each system was evaluated at a number of demand levels. To provide a basis for generalization and to minimize local effects, we normalized all costs to the cost of operating a city bus on city streets. The results of this evaluation are shown in Figure 6. The capital recovery cost was computed on the basis of 6 percent annual interest. In addition, operating costs were considered.

These results indicated that the PRT concept selected was competitive with the conventional bus on city streets down to an average line capacity of 1,000 seats per hour depending on the specific system. This is approximately one-half of the seat-mile cost of a bus operating on a route with a separate right-of-way, the next lowest cost of the systems evaluated.

Although the PRT system is capacity limited (approximately 7,000 seats per hour assumed in this case), it was shown that by the use of parallel lanes (perhaps a block apart) the total system capacity would be increased to the equivalent of the transit system at a lower total cost.

Network Size

The ratio of cost per mile between a conventional rail transit system and a personal transit system is of the order of 3:1 to 10:1 depending on the technology used, frequency of service, and similar factors. For an equivalent initial cost, the personal transit system may have three times or more route mileage and several times the number of stations per route-mile. This will provide easier access to the system, particularly by those walking. People ½ mile from a transit system will use the system less than half

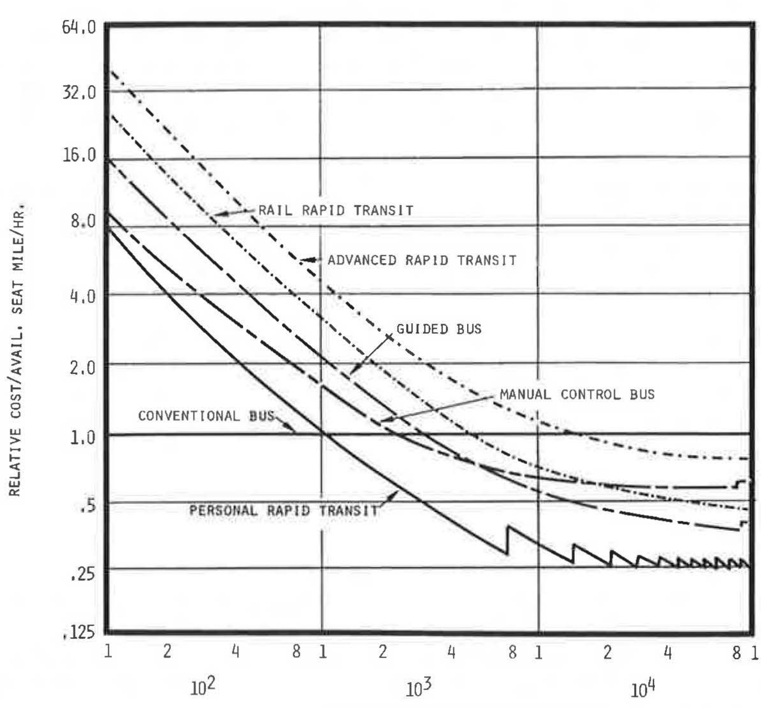

Figure 6. Transit cost comparison.

as often as those ¼ mile or less. A recent study (22) showed that the average walking trip was 0.20 mile in both Dallas and Chicago and that there were only a negligible number of walking trips longer than 0.60 mile.

An evaluation of the influence of the increased number of stations available to a passenger in a stated distance or period of time indicates that the number of trips should increase exponentially with the probability that a suitable destination will exist.

Balanced Transportation

The PRT transportation systems, as envisioned by the authors, will probably never provide all or even a majority of the transportation in an urban area. Other forms of transportation will be required to meet the specific needs of the area or the traveling public. The automobile will probably continue to provide for the majority of the transportation needs of the community. It can serve low-density areas where no other form of transportation is practical. The taxi, as the rubber-tired version of the PRT, will continue to have broad application for special nonrepetitive trips. The conventional bus (upgraded in appearance, technology, and operation) will provide service to areas where the cost of a fixed-route system cannot be justified because of low demand or infrequent needs for service. It is very probable that the rubber-tired bus will continue to be the largest supplier of public transportation. Large conventional rail (or rail-like) vehicle systems will continue to be used in high-density corridors where there are existing facilities or where high demands exist.

In addition, there will be need for special systems, multimodel devices combining one or more of the characteristics of other vehicle systems, and moving sidewalks, or an equivalent, for relatively short trips.

COMPARATIVE SYSTEM EVALUATIONS

An accurate evaluation of the relative usefulness and advantages of a personal transit system in a specific urban area will require a comprehensive study in which at least four system alternatives are considered (automobile only, bus including exclusive express lanes, conventional rail, and personal transit). Such a detailed study would require consideration of the actual needs of the area, established trip patterns, and the influence of changes in transportation service on future transportation patterns. To make a direct comparison, the evaluator would have to quantify at least the following:

1. Relative costs of the competitive systems;
2. Effect of system parameters on attraction, e.g., trip time, en route delays (i.e., transfers and parking), user perceived cost, user actual cost, access provisions, distance to parking lots, and convenience and privacy; and
3. Effect of network size and configuration on actual ridership (i.e., riders per dollar investment).

Existing modal-split and passenger-assignment models cannot accurately make such studies for new and unconventional transit concepts. For example, there is no information to quantify the effect of convenience and privacy on the actual ridership. A comprehensive study of this nature is beyond the scope of this paper; however, the authors did consider a number of possible applications of personal transit and have made qualitative evaluations of representative systems.

PRT Applications

One significant advantage of the personal transit systems is the fact that they can be developed on an evolutionary basis. Relatively small activity center systems can be built where there is adequate demand; these can be extended to serve larger areas as demand increases. Several isolated activity center systems can then be linked by relatively high-speed (60 to 100 mph) routes, and the overall systems can be expanded as the need and finances permit.

PRT systems can be applied to a number of specific transportation needs, such as for access from remote parking to activity centers; for access to, and circulation through, large airports; for distribution of trips in a central business district; and for urban transportation throughout an urban area.

Remote Parking

Small versions of personal transit systems can be used to connect parking facilities with commercial buildings, campus areas, recreation facilities, or industrial plants. Studies have indicated that in many cases the savings in cost of land or construction by providing remote parking facilities will more than offset the cost of the transportation system required to provide access between the parking area and the facility being served.

Cost studies indicate that systems of this general class can be built to operate profitably at a fare that is acceptable to the using public, i. e., 10 to 50 cents. In many developments it may be possible to pay for the system by a slight increase in the rental cost of the facilities being served.

Airports

The application of modified versions of the PRT system to airports may greatly improve passenger circulation from the parking lot, or other point of access, to the terminal activities and on to the aircraft. Not only does this permit location of major parking facilities in low-value land areas (approach zones, for example) some distance from the terminal, but it also provides a basis for improvements in the utilization of the airport facilities themselves.

Central Business Districts

Small individual vehicle systems are particularly applicable to the transportation needs of central business districts. The CBDs in most of our major cities are in serious trouble because of the difficulties associated with travel to and through them. Parking is difficult to find and is expensive, distances walked are long and undesirable in inclement weather, and personal safety is uncertain in the evening and off-hour times.

Personal transit systems provide an opportunity for overcoming some of these problems. Parking can be remotely located at the fringes of the central business district and thus more easily reached. More area can be made available for parking facilities. Passengers in personal transit vehicles are protected from weather and from the more serious crime problems. Access stations can be monitored by television from a central location to spot potential problems. As a result, the passengers will be safer than in their own cars.

The lightweight, small guideways can be installed in existing urban areas and can penetrate buildings if required. The installation of stations in existing commercial buildings may be attractive to building owners; the improved access to an upper floor can make the building more valuable to tenants; and higher rentals can be charged.

A study by General Motors (23) described such a system for a large, eastern town. The system provided distribution service between the commuter rail terminals and peripheral parking areas to the major buildings in the 2-sq-mile CBD. It had an anticipated 1980 ridership of 100,000 passengers per day (approximately 50 percent of the local trips within the CBD). The system incorporated 11.7 miles of track and 138 stations. It had 3,000 four-passenger (adult) vehicles.

The analysis indicated that the cost per passenger trip (including operating and capital recovery costs) would be in the order of 4 cents per trip. The average trip time was only 2 min for a trip of 0.6 mile.

Area-Wide Systems

The PRT systems can, of course, be expanded from such bases as described to cover an entire city. The vehicles would operate at speeds appropriate to the length of the trip (up to 60 to 80 mph in most cities) and would provide a degree of service not possible with conventional rail transit. Although such diverse systems may not be built for a number of years because of technical, economic, and political factors, the fact that they can evolve from smaller systems should result in the near-term development of smaller activity center systems or the equivalent.

A brief comparison was made for selected city A of a proposed rail transit system and the possible rail applications of a personal rapid transit system for the same relative cost. The proposed rail transit system is shown in Figure 7. It consists of 160 miles of two-way rail track and 87 stations. The system would cost $1.5 billion and would provide 450,000 daily trips or 3 percent of the total transportation demand of the area.

The city is a relatively low-density urban area of 3,500,000 population plus major suburbs. It is largely dependent on the automobile for transportation, although bus systems currently provide 5.2 percent of the total daily trips. The proposed rail system will serve six major corridors and will be oriented to the CBD (Fig. 7). The average distance between stations will be 1.3 miles; thus, each station serves an isolated area approximately 1 mile in diameter as shown in Figure 8. These ½-mile radius areas cover 14 percent of the urban area.

This system will not provide adequate capacity to reduce the use of the automobile in this area. Between 1970 and 1990 the use of the automobile is expected to increase 230 percent, and the relative use of public transit is expected to decrease from 5.2 percent (all bus) to 3.0 percent, approximately half of which is rail. The performance characteristics and estimated costs of the system are given in Table 6, where the planning agency estimated a cost of $1½ billion for the system, approximately 4 percent higher than that estimated by the authors using Table 5.

A PRT system was postulated for the same area at the same price (note that a contingency of 25 percent was used for the PRT versus 10 percent for the rail transit). This system provides a grid network of one-way lines across the city. The total length is 382 miles and there are 410 stations. The system route network is shown in Figure 9. All of the routes are single track, which minimizes the impact on the environment in each area. The one-lane guideways can be easily incorporated into marquees, pedestrian shelters, or freeway medians, and can penetrate buildings. The cost is, of course, greater for two single-lane routes than for a two-lane route. However, the area served is greatly increased, which attracts additional patronage and offsets the

Figure 7. Proposed rail transit system.

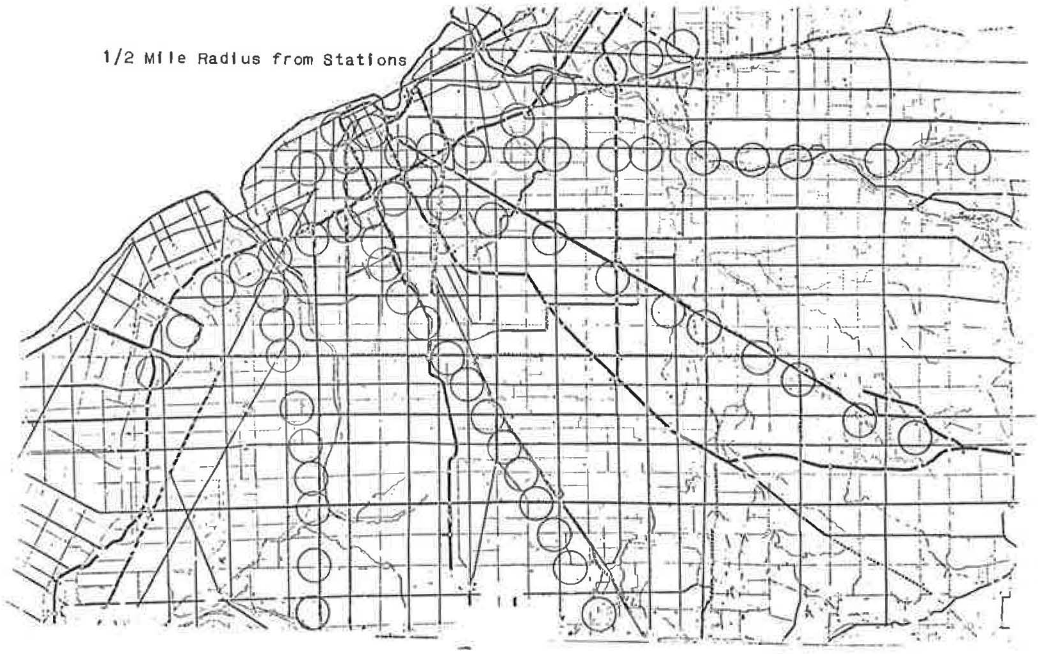

Figure 8. Rail transit service areas.

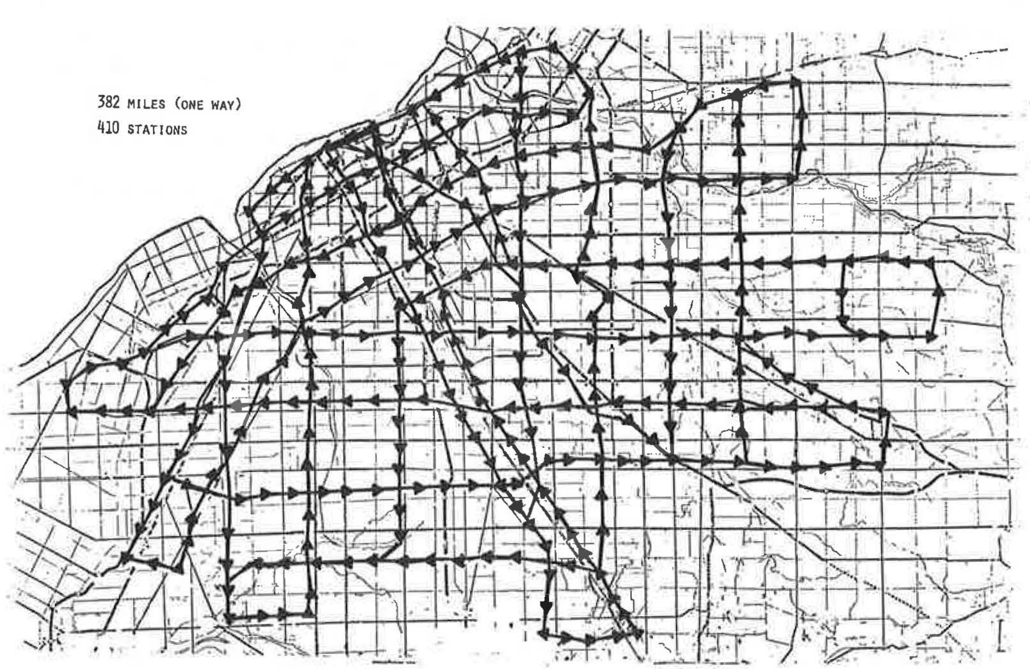

Figure 9. Personal rapid transit system.

TABLE 6

ESTIMATED COSTS OF RAIL RAPID TRANSIT SYSTEM

Element	Amount	Unit Cost ($)	Total Element Cost ($)	Percentage of Total System Cost
Track	226 mi	2,500,000	580,000,000	44
Stations	87	2,000,000	174,000,000	13
System design	1	500,000	500,000	
Right-of-way	226 mi	400,000	90,000,000	7
Control and electrical	226 mi	250,000	59,000,000	4
Subtotal			903,500,000	
Engineering and service facilities, 30 percent of facilities			274,050,000	21
Vehicles	565	250,000	140,000,000	11
Subtotal			1,317,550,000	
Contingencies, 10 percent			132,855,000	
Total			1,450,405,000	

small increment in cost. The direction of vehicle flow is represented by the position of the triangles, which indicate the location of the stations. In some cases, where there is a very high demand, parallel reversible guideways are installed to accommodate peaking requirements. These are shown by the dotted lines near the CBD (Fig. 9). Table 7 gives a summary of the cost estimates for this system. Note that the share of the cost for the control and electrical systems and for the vehicles is higher than for conventional systems.

Figure 10 shows the significant improvement in accessibility made possible by the PRT class of system. Approximately 65 percent of the urban area is within ½ mile (walking distance) of a station. Because many of the stations are less than 1 mile apart, the maximum walking distance in many activity centers (such as the CBD) is less than ¼ mile.

The conduct of a demand analysis for this system was beyond the scope of this paper; however, there are certain improvements in service and performance that can be shown to have a significant effect on the probable use of the system.

1. The increased number of stations significantly increases the areas of the city within walking distance to transit service (65 versus 14 percent);
2. The trip time for an average length trip (4.5 miles) is reduced significantly (from 9 to 6 min); and
3. The convenience of the vehicles is significantly improved.

TABLE 7

ESTIMATED COSTS OF PERSONAL TRANSIT SYSTEM

Element	Amount	Unit Cost (dollars)	Total Element Cost ($)	Percentage of Total System Cost
Track	390 mi	900,000	351,000,000	31
Stations	410	300,000	123,000,000	11
System design	1	500,000	500,000	
Right-of-way	390	200,000	78,000,000	7
Control and electrical	390 mi	300,000	117,500,000	10
Subtotal			670,000,000	
Engineering and service facilities, 25 percent of facilities			167,000,000	15
Vehicles	30,000	10,000	300,000,000	26
Subtotal			1,137,000,000	
Contingencies, 25 percent			284,250,000	
Total			1,421,250,000	

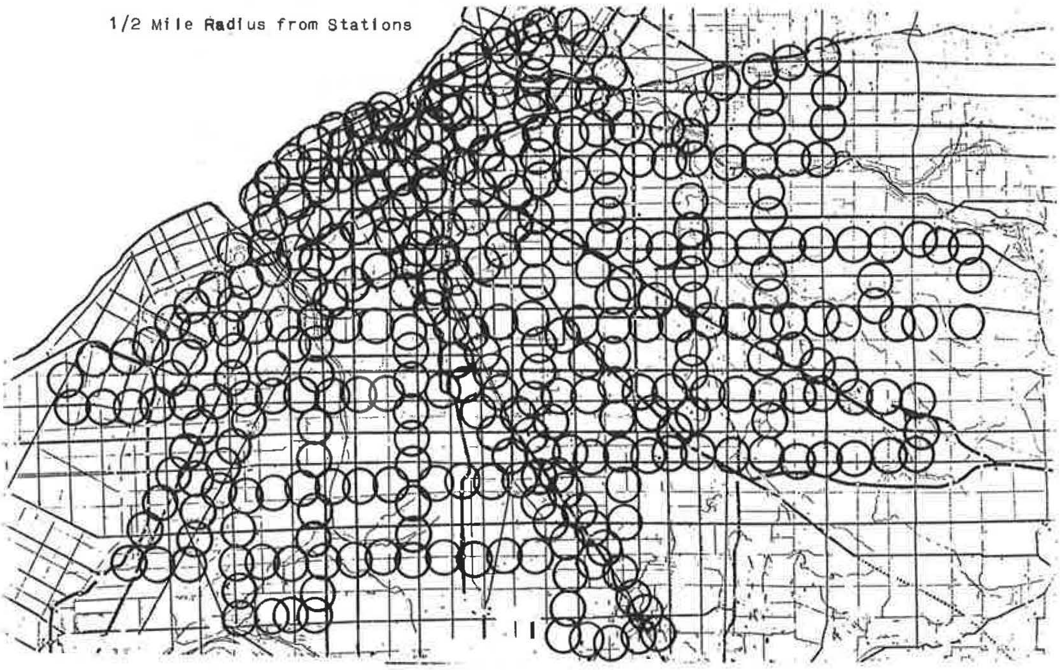

Figure 10. Personal transit service areas.

The actual increase in use of the PRT system as compared to the rail rapid transit system would require a definitive study; however, by inspection we would expect the ridership on the PRT system to be 5 to 10 times greater.

A common criticism of small vehicle systems is that they do not have adequate capacity to meet the demands of the system. It is true that the single-line capacity is less, but there are a sufficient number of alternate paths so that the total daily trip capacity (even assuming low load factors for the vehicle) is more than 10 times the predicted peak ridership of the rail transit system.

It should be noted that a greater effective use of PRT than of rail vehicles can be anticipated. Because of the diffuse nature of the trips in this area, it is probable that during the peak hour there will be fewer "deadheads" or low-load factor vehicles being returned for additional passengers on the PRT than on the rail system.

Figure 11 shows the differences in the potential service provided by the two systems. In this case the number of stations that can be reached from an average station (rail or PRT) is plotted against trip time. The actual distance is also shown. The two speed lines for the rail represent the average of existing system speeds and the proposed average speed for new systems with the same station spacing. The PRT system is shown for three line speeds: 40, 60, and 80 mph. This figure shows that even at 40 mph the PRT system will provide better service than the conventional rail system operating at the highest practical speeds.

Similar results were found in other studies of personal transit systems. For example, in a study of a large automobile-oriented city in the South (21), it was shown that a PRT system equal in length to a rail system would cost only 45 percent of the rail system but (primarily because of the shorter trip times) would attract 60 percent more riders, thus attracting 3.5 times the patronage per capital dollar of the rail system. In this case the rail system would attract 8 percent of the total person trips in the area. A network triple the size of the rail system would attract more than 20 percent of the total trips in that area.

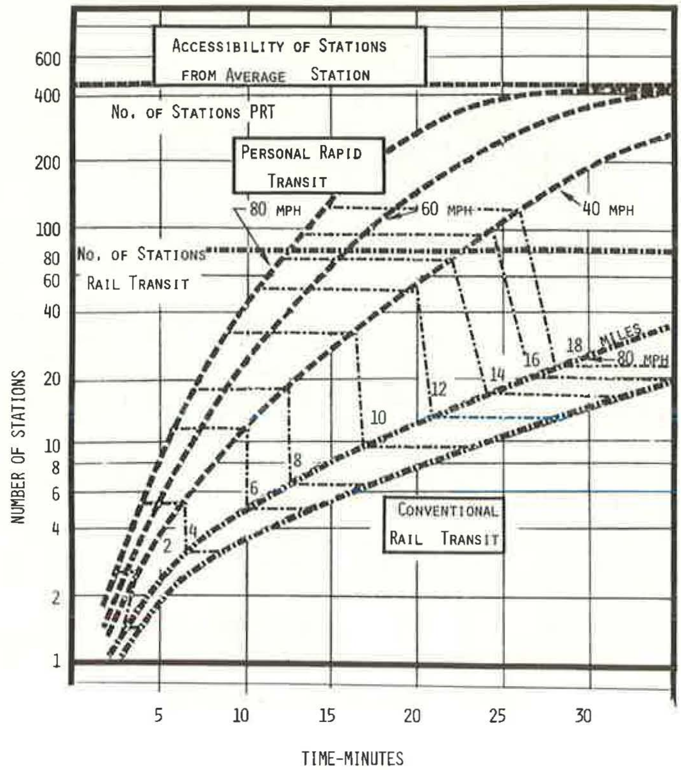

Figure 11. Comparison of potential service provided by personal rapid transit and conventional rail transit.

CONCLUSIONS

Although full-scale PRT systems may not be built for a number of years because of technical, economic, and political considerations, the fact that they can evolve from smaller systems should result in the near-term development of smaller activity center systems or the equivalent. Because of this possibility, transportation planners should be familiar with such systems.

PRT systems are not necessarily the best answer for all transportation needs. They will not replace bus systems in low-density areas or rail systems in high-demand, high-speed corridors. When their advantages are fully exploited, however, the PRT systems will permit the development of new urban forms. Greater use of parks and greenbelts between areas of the city can be provided within the normal trip time limits; basic services of a common nature can be lumped together in specialized areas (e.g., recreation, banking, and education)—all accessible from residential and other areas in an acceptable period of time; and large residential areas, apartment complexes, and similar areas can be designed without any provision for automobiles except in an emergency mode (i.e., fire and construction).

The use of a system of personal transportation should be significantly higher than that of a conventional transit system because of the following factors.

1. The total trip time can be lower than that of the automobile, thus attracting patronage that would otherwise use private automobiles;
2. The vehicle would provide privacy, safety, and comfort at least equivalent to an automobile and therefore would be attractive to passengers who avoid the transit vehicles;

3. The lower cost of guideways and compact terminals will permit the construction of more extensive networks for the same capital cost, thus providing wider service and more destinations for the passenger;

4. The low noise and pleasing appearance of the vehicle and system will permit installation of the system with minimum impact on the environment (in many cases, the vehicle can be routed through and stations located in existing buildings);

5. The system can be developed in economic stages, starting with activity center systems and gradually expanding to serve entire urban areas; and

6. The mechanical simplicity of the system and the use of automatic controls should provide low operating costs that permit economical fares.

The potential of this class of personal transportation has been established by preliminary analysis and engineering design studies. However, its acceptability to the public, the influence of the system on a specific urban area, and its implications in design freedom for the urban planner and architect can only be established by more extensive studies and demonstrations.

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