ATRA 1989 PRT Report

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PERSONAL RAPID TRANSIT (PRT)

ANOTHER OPTION FOR URBAN TRANSIT?

A Report by the Technical Committee on Personal Rapid Transit (PRT)

of the

Advanced Transit Association, Inc.
1200 18th Street NW, Suite 610
Washington, D.C. 20036

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The Advanced Transit Association exists to focus attention on unmet urban transportation needs and the ways in which advanced transit concepts can help satisfy them. One of these unmet needs results from the gap between the poor quality of transit service in medium and low-density locations within urban areas and the availability of transit technology that can furnish high quality service at affordable costs.

ATRA's objectives, with particular respect to this report, are to:

- Focus public attention on the medium and low density transit problem and the ways in which advanced transit concepts can help solve it;
- Seek wider agreement on the main features that advanced transit should possess to cope with this problem, including such features as cost, service, environmental impact, and ability to respond to passenger and goods movement demand;
- Draw attention to transit systems, or well-developed concepts for such systems, that incorporate the desired features of advanced transit capable of functioning cost-effectively in medium and low density areas while offering high quality service;
- Help define the test and evaluation capabilities that must become available for the demonstration and safety certification of advanced systems and technologies offered by manufacturers.
- Identify solutions to problems that inhibit conceptualization, development, demonstration, and deployment of advanced transit systems and technologies.

This report represents the conclusions and opinions solely of the Technical Committee on PRT, a special committee appointed by the Board of Directors of ATRA to report to the Board on this subject.

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The Advanced Transit Association is grateful to these committee members who, while busy at regular jobs, contributed so much of their personal time and skills to the preparation of this report. Committee members are professionals of high competence and strong opinions. Not every opinion or recommendation expressed in this report, consequently, represents the view of each committee member, but each subscribes to the overall thrust of the report and its conclusions and recommendations. Organizational affiliations, when present, are shown only for identification purposes.

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Chapter 1

INTRODUCTION

The Advanced Transit Association (ATRA) convened a Technical Committee on Personal Rapid Transit (PRT) in late winter 1987. Its assignment was to revisit PRT and update public knowledge about it by:

- Assessing the feasibility and developmental status of the transportation technology called Personal Rapid Transit (PRT); and

- Presenting findings and conclusions as to whether PRT can someday provide economical and high quality transit service in urban[1] areas, especially where today's transit[2] technology is often not capable of offering service economically; that is, in locations where residential or job populations range from medium to low density.

ATRA acted after years of discussion about the merits of PRT, having concluded that communities lack sufficient transit options within low and medium density locations where most of the growth in jobs, services and homes is occurring today in urban areas. The lack of effective transit options to serve the needs of the people of these locations is a key factor in the growth of auto traffic. It also complicates and hampers the access of many persons in these places to jobs, convenient housing, services and amenities. Similarly, people who live in higher density locations but desire jobs in the burgeoning medium and low density areas commonly lack economical transit that will help them gain access to these widely-diffused job sites.

Without cost-effective transit options to meet these trip needs, governments must respond to constant demands for more land, traffic improvements and roads to cope with stifling auto congestion. At the same time, they often are struggling to finance growing subsidies for support or augmentation of conventional mass transit. Its high costs and limited service capabilities sharply constrain its ability to be deployed widely in the under-served locations and, at the same time, provide attractive service.

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[1] The word "urban", when used in this report refers to the entire urbanized area, including the suburbs, in contrast to the term "rural".

[2] The word "transit", when used in this report, refers to transportation service furnished to the general public along an established route in an urban area, or the system/technology that provides such service

Some forms of non-PRT Automated People Movers (APM) are finding a market in airports, major activity centers and denser urban corridors, but they too are too expensive for widespread deployment as transit options within the medium and low density location.

PRT systems are not in public use, and no practical demonstration has been made of their cost and service potential. Within the past 10 years, however, one PRT concept has been the subject of considerable design optimization and analysis aimed, the company says, at reducing both its cost and its visual intrusiveness while achieving its performance goals. Another PRT system completed a development cycle about 10 years ago, and its technology, which would necessarily require updating, is still available for consideration. Within these same 10 years, there has been no systematic evaluation of the status of PRT development, despite the clear public need for transit that would have lower cost and be more widely-deployable.

ATRA considers that the growing urban traffic problem and the critical need for more cost-effective transit options are Bound reasons to conduct a fresh appraisal of PRT. This naturally leads to comparisons being made between PRT and current conventional forms of transit and the non-PRT ATMs. These comparisons, which the committee trusts will not be misinterpreted, are necessary so that features, operating characteristics and costs of the various transit options, including PRT, can be understood better.

Even if PRT becomes a success in urban transit, other transit options will continue to be needed for many years. Experience and detailed planning studies will reveal over time where each mode provides the best balance of costs and benefits in specific applications. The Committee strongly affirms, moreover, that existing transit lines and stations serving a valuable purpose will need to be used for many years and should be well-maintained. If PRT proves itself, one of its early uses would be to furnish better collection and distribution for existing transit networks, thereby improving the overall service and economics of today’s transit.

1.1 Personal Rapid Transit (PRT)

Past confusion about the term “Personal Rapid Transit (PRT)” has led the Committee to offer its own definition of PRT, based on a description of its physical and service characteristics. The widespread adoption of this definition would help preserve clarity during discussion of PRT.

The Committee defines PRT as a transit system that has:

- Fully automated vehicles (i.e., without human drivers).
- Vehicles captive to the guideway, which is reserved for the vehicle

- Small vehicles available for exclusive use by an individual or a small group traveling together by choice. These vehicles can be available for service 24 hours a day, if desired.

- Small guideways that can be located aboveground, at or near ground level, or underground.

- Vehicles able to use all guideways and stations on a fully connected (a “coupled”) PRT network.

- Direct origin to destination service, without a necessity to transfer or stop at intervening stations (i.e., “nonstop” service).

- Service available on demand rather than on fixed schedules.

PRT is one type of “Automated People Mover” (APM). APMs are transit systems in which vehicles are automatically controlled over exclusive guideways. Other frequently used names for APMs are “People Movers” (PM) and “Automated Guideway Transit” (AGT). The committee prefers the term “Automated People Mover” (APM) and encourages others to use it for this class of transit. APMs have also been called such names as “Downtown People Movers”, and APMs have also been given local names such as “Metromover” (used for the Miami, Florida APM).

1.2 Technical Committee Objectives

The Committee met as full committee a number of times, including a meeting to hear presentations from PRT system developers, with the following objectives:

- to review PRT state of the art, taking into account its physical and service characteristics;

- to identify the conditions that must be satisfied to develop and implement PRT systems for practical use in urban settings;

- to identify the factors that decision makers would weigh in considering PRT for transit service in urban areas, especially in fulfilling needs for transit in underserved locations;

- to suggest further steps, if any, that need to be taken to make PRT a practical option for decision makers; and

- to develop strategies to bring the Committee’s findings and conclusions to the attention of private and governmental policy makers, and others who are concerned.

These objectives were achieved by the committee, working part-time as volunteers, only in varying degrees. Much remains to be done, but the committee feels that this report represents an important first step.

The Committee focused on current PRT development activity. As worthwhile as it might have been to evaluate the many interesting PRT ideas that had been conceived through the years, such an effort was beyond the scope of the committee’s work.

1.3 Evaluation Criteria

The Committee felt that decision-makers examining PRT would apply evaluation criteria within the following categories, and therefore considered these in producing this report about PRT:

- Categories that include features critical to whether PRT is “market ready”
    - system safety and personal security (e.g., prospect for system-caused death or injury, personal threats and vandalism, and damage to property of others); and
    - performance (e.g., capacity, minimum speed and travel time, service availability, threshold standards of ride quality, and system reliability).
- Variable categories, subject to customer desires, site-specific needs, economic capability and varying legal requirements - categories that affect PRT “market potential”:
    - quality of service (e.g., maximum speed, travel time, average walk distance to stations, ride comfort);
    - accessibility (e.g., for elderly, handicapped, adults with small children, and for carried luggage and groceries);
    - environmental (e.g., noise, visual impact, amount of land used, and siting of guideways, stations and other facilities);
    - economic and financial (e.g., cost-benefit ratios, cost-effectiveness ratios, capital, operations and maintenance life-cycle costs, insurability, and revenue generating potential);
    - sources of funds, including subsidies; and
    - institutional arrangements for building, owning and operating PRT systems.

1.4 System Presentations

The Committee announced publicly its desire to receive information from all developers of PRT. Only two companies responded, TAXI 2000 Corporation, Revere, Massachusetts and Cabintaxi Corporation, Detroit, Michigan. Both requested and received an opportunity to appear before the committee. Rumors that other PRT activity is underway could not be confirmed, much to the regret of the committee.

The representatives of these companies were asked for the following:

- a general description of their system - its projected capacity, cost, and safety/security features, including data to support their claims;
- the status of the system's development;
- system design for removing passengers from disabled vehicles, clearing guideways of inoperable vehicles, and restoring service on damaged guideways;
- comments about the feasibility of short headways;
- plan for prospective subcontracting;
- power requirements and means of achieving them;
- requirements to demonstrate a PRT system;
- conditions necessary to gain approval of certifying agencies for safety, personal security, liability insurance;
- answers to the following market questions: (a) why have no PRT systems been built yet? (b) why have major U.S. and non-U.S. companies or governments stopped PRT development?
- steps needed to overcome negative perceptions of PRT; and
- what they think the Advanced Transit Association should do to encourage more attention to PRT.

TAXI 2000 provided oral and written answers to many of these questions, based on current research and development activities.

Cabintaxi Corporation provided a 1979 German-language document and showed a video tape reporting on the development status of its PRT concept at that time, and acknowledged that no current development is underway, or has been underway during most of the 1980s. The Cabintaxi video, showing mergings of PRT vehicles at 2.5-second headways (i.e., spacings), was most interesting. The company's President devoted his oral presentation to discussing how Cabintaxi systems, offered in various vehicle sizes ranging from 18-passenger to 3-passenger vehicles, could begin service with 12-passenger vehicles in non-PRT mode and evolve into PRT mode, using the same guideways and stations, ultimately using 6-passenger vehicles in mostly-PRT mode as passenger demand increased and the network expanded. He also described the non-PRT automated system called Cabinlift that the German companies, Demag and KesserschmittBolkow-Blohm (MBB), installed at a hospital in Ziegenhain, Federal Republic of Germany (West Germany), in 1976.[3] 3

The committee felt that it should call attention to Cabintaxi. Major work and testing was done on this PRT system in the 1970s, and a company still exists to market transit systems based on that earlier development of Cabintaxi, which culminated with West German designation of the Cabintaxi system as ready for urban application.

However, in that the committee's task was to concentrate on <u>current</u> PRT development activity, a decision had to be made whether to base the committee report largely on the current work and claims of one company, TAXI 2000. The committee decided to press ahead, concluding (a) that the lack of competing developmental activity currently did not diminish the need to re-examine PRT and (b) that the work of even one company that was making a current comitment to the further development of PRT deserved to be examined.

The discussion of PRT in the remainder of this report relies heavily on the TAXI 2000 concept because, as noted earlier, it is the only PRT concept for which the committee received extensive testimony and written documentation based on work <u>currently</u> underway. This decision does not reflect a bias toward TAXI 2000. We reiterate that the committee's assignment was to examine current activity in the world of PRT as it is; not as we hoped it might be. Moreover, it would have been grossly unfair to the TAXI 2000 Corporation for the committee to abandon its investigation because only one current developer emerged.

Our decision to concentrate on TAXI 2000 should not be interpreted as a judgment that the Cabintaxi concept deserves no futher consideration - to the contrary - for Cabintaxi remains the most thoroughly tested PRT system, and therefore should be included as a PRT candidate system in future site-specific alternatives analyses, if the Cabintaxi Corporation elects to offer a proposal or quotation for that specific site, even though further development would be required today for a Cabintaxi system to become market-ready.

Nor should our decision to give attention only to TAXI 2000 and Cabintaxi in this report be interpreted to deny the possible validity of other PRT concepts or configurations that may come forward, based on past or new ideas. Rather, we hope that this report will encourage others to invent, innovate and experiment.

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[3] The Ziegenhain "C-Bahn" system, a standing passenger system (except for patients), has operated successfully and economically since 1976, and been overhauled recently. It carries patients and staff on an 2.000—foot (609m) shuttle in 12—passenger vehicles.

The report in the following chapters is based on Committee objectives, PRT definition and criteria, and the company presentations described above.[4]

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[4] Henceforth, the pronouns "us", “our”, “us”, etc. are frequently used when referring to the Committee.

Chapter 2

URBAN TRANSIT CHALLENGE AND RESPONSES

There is a large and growing disparity in most urban areas between unmet travel needs, which often should be satisfied by transit, and the fact that current mass transit technology is not capable of satisfying these needs at reasonable cost with high quality service. Government and private investors are doing little to reduce this disparity. Worldwide, only minuscule investments are being made in research, development, and demonstration to advance transit technology conceived to serve these unmet travel needs.

This disparity has its origins in the outward spread of urban areas. When this urban “sprawl” began to increase rapidly after World War II in the United States and a little later in other countries, the problem of insufficient transit technology options was not immediately apparent. The earliest suburbs were usually bedroom communities with only small shopping and service facilities. The jobs and services for suburbanites continued to be mainly in the “center city.” Transit service — furnished by light or heavy rail cars and buses — radiated out from center city to bring travelers in and take them out again, performing a function that such mass transit had traditionally performed.

During the first half of this century in foreign metropolises such as London, Paris, Moscow, or Toronto, heavy rail systems were extended into some of the suburbs, and light rail networks were expanded as well. In the United States, street and interurban railways experienced a boom from about 1890 to about World War I. Strong municipal interest in building subways lasted somewhat longer, but by the 1930s, the main governmental emphasis (local, state and national) was increasingly on road programs that facilitated the rapid expansion of automobiles which cut into the demand for transit service.

Gasoline and other direct taxes, as well as the prices paid by consumers for the purchase and upkeep of their cars, paid some of the costs of this rapid expansion of the automobile, but large subsidies in various forms (financial and non-financial) provided an additional strong boost to it. Unlike governments in a number of other countries, U.S. governmental units did not tax automobile purchase and use heavily to try to recapture the full costs of the automobile to society. Faced with this intense competition from the automobile, transit went into a decline.

Two trends, to a degree conflicting, began to evolve after World War II, especially in the United States:

- one trend was that many places outside center city became major locations for jobs, shopping and services. A growing number of trips for work or other purposes occurred solely within these locations, where population densities were usually too low to justify financing heavy and light rail systems to serve the "local" (i.e., non-radial) trips. Moreover, as a growing number of transit companies were bought by investors interested only in bus-based transit, street and interurban rails were torn up, even in the more densely-traveled corridors, and their service abandoned;

- another trend, nevertheless, was a renewal of interest in renovating, expanding and building heavy rail transit, and later light rail transit, mostly to connect the center city better with its suburbs. In the United States in the 1960s, aided financially by the Federal Government, a rapidly-growing number of failing private transit companies were replaced by public authorities, financed with tax money and managed by appointees of state and local governments. Capital subsidies, and eventually operating subsidies, began to flow to these authorities in a growing stream of money, which continued until the early l980s.

Both trends surfaced as responses to a new but relatively informal "coalition" of downtown business interests, suburban real estate developers, some local planners and officials, and some distressed transit owners and operators. In different degrees, its participants wanted to foster urban renewal, reduce parking demand, ease circulation in downtown cores, and promote greater density and higher property values in corridors that linked revitalized urban cores with growing suburban centers.

One way to accomplish these goals, the coalition thought, was to build and upgrade heavy and light rail systems. An additional means was to develop automated people mover systems within the downtowns as circulators.

2.1 Rail Transit (HRT and LRT)

Downtown business leaders and suburban developers joined with local government officials in some communities to promote the construction or modernization of heavy rail systems. Heavy rail, they said, had the twin advantage of being able to serve large passenger loads efficiently and of being paid for by the increased number of passengers that high density real estate developments would bring.[5] The advocates of heavy rail, including some consulting engineers and other specialists in transit, felt that modern rail systems would divert enough persons from autos to ease both road congestion and parking problems, and would reduce air pollution.

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[5] The newer heavy rail cars have a passenger capacity, on the average in the United States, of about 150 seated and standing passengers; light rail cars, about 100—125 passengers.

Promoters of rail projects also maintained that rail transit would encourage people to live and work in higher density developments, thereby reducing commuting distances and encouraging people to live near their workplaces. Bus feeder routes would bring people to rail stations.

An example of one of these modern and attractive heavy rail transit systems is shown in Figure 2.1.

Figure 2.1: New Heavy Rail System in Washington, D.C. Metro Area

Most communities have concluded that heavy rail is too expensive for them. Light rail, a modern version of the streetcar, has been one alternative for some localities. A new light rail installation can sometimes use abandoned railroad or former interurban rights-of-way and tunnels, and even old but upgraded trackage. Adopting of light rail seemed to be a relatively quick and efficient way to furnish transit service in a corridor and reduce auto use. Some national governments encouraged light rail installations, and the U.S. Congress provided funds to assist a number of such projects.

Costs of light rail vary considerably. With the use of existing rights-of-way and stations, added costs are usually limited to roadbed and track improvements, station modernization, the purchase of new vehicles, and liability insurance. In such instances, operation can be fairly economical for a particular corridor. In other instances, where rights-of-way must be acquired and new tracks, stations, platforms, and grade separations must be built to create safe operating conditions, the justification for light rail is less clear. Costs can approach those of heavy rail systems. Figure 2.2 shows a vehicle in a special transit mall for one of the most recently-built and more expensive types of light rail systems in North America.

Figure 2.1: New Light Rail Car in Transit Mall, Buffalo, New York

Large sums have been spent on both heavy and light rail, and during this period a number of city centers have stabilized or reversed their decline, perhaps affected by the rail upgrading programs. Yet, urban sprawl is continuing at a rapid pace, auto use and parking demand are still increasing, and commuting distances are growing. In general, rail transit has not altered these fundamental trends in most urban areas, even where it has been beneficial in other ways. Automobile-based transportation continues to receive the lion's share of money for capital and operating costs in the United States, offsetting any opposite effects that the relatively small investments in transit may have.

Few rail systems cover a major portion of their operating costs from the farebox; therefore, they lack capability to recover capital costs. Even in the non-U.S. cities where there is an well-developed network of heavy and light rail lines, sometimes penetrating well into the suburbs (where auto ownership is not yet as widespread as in the United States), urban areas have sprawled beyond easy access by these conventional mass transit systems. Accelerating auto use is creating its trail of problems for decision makers nearly everywhere.[6]

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[6] Comparisons of the costs of transit and automobile transportation often conclude with the assertion that whereas automobiles "pay their own way" with gasoline and other direct taxes, transit requires subsidization by the general taxpayer. This erroneous conclusion about automobile financing leads to unreasoned decisions to reduce taxpayer funding of transit service more than is usually justified by the facts.

Nearly all the costs of the construction and operation of a transit system are usually apparent on the public record (although buses use roadways nearly free of charge), as are the fares and other revenues that the system receives for its services. Thus, the difference between these costs and revenues is not only visible to the public but is nearly always unfavorable to transit, requiring some kind of taxpayer subsidy to cover the loss.

In contrast, many of the costs of building and operating the automobile—based transportation "system" are not apparent. They do not show up in a "budget" of a "system" owner/operator, but rather are scattered across many budgets, private and governmental. Examples are businesses' provision of "free" parking for workers and shoppers, many of the police and traffic control costs, many of the negative environmental impacts of automobiles, and taxes lost because of land takings for roadways and parking facilities. Gasoline and other direct taxes do not cover many of these costs, which means that the public is also providing subsidies —thought to be quite large — to the automobile transportation "system", although they rarely realize it.

In the United States, some communities that have recently built or expanded rail mass transit systems have committed a large share of their total transportation funding capability to service this debt, in spite of major financial assistance provided by the Federal government, and few have budgeted properly for long-term upkeep and replacement costs. They face growing taxpayer subsidization of these conventional mass transit technologies, especially if Federal government subsidies continue to decline.

Neither heavy nor light rail modes, unfortunately, have been able to cope economically with the new transit needs of the increasingly-dispersed urban areas of today. The capital and operating costs of these modes are too high, compared to the service they provide, to permit their track and stations to be intensely and widely deployed, easily accessible to riders, in medium and lower density locations. Any attempt to offer satisfactory service in these locations with either heavy or light rail requires public subsidies that are politically unacceptable. This transit deficiency has denied individuals without autos (including growing numbers of older people and workers without autos who need jobs) a satisfactory mobility. They are either marooned or dependent on others for transportation. Those who can afford autos usually have to operate two or more to satisfy the needs of their family. The inability of rail systems, and the possible potential of PRT systems, for meeting some of these critical unmet needs is what has provided the focus for the committee’s appraisal.

2.2 Buses — The Urban Workhorse

Buses are the work horses of urban mass transit, carrying more transit riders than any other mode, including rail, and providing the only transit service in most smaller communities. They have relatively low initial (i.e., capital) costs and adapt fairly easily to changing travel demands and routes. Their disadvantages are well-known — high operating and maintenance costs, uncertain and sometimes long wait times, unsatisfactory shelter while waiting, uncomfortable rides, low average speeds (except for some express buses), excessive noise, visible emissions, and poor image with the public. Their total operating costs, moreover, contain a high proportion of labor cost (about 70 percent typically), which weighs heavily against any attempt to improve bus service by, for example, increasing the frequency of service on routes or adding more routes, especially during off-peak travel periods.

Using buses as connectors to rail stations has been successful some places. Perhaps more can be done to facilitate these connections, yet most travelers dislike transfers. Travelers who have a choice usually prefer autos to reach rail stations, despite their higher costs, including parking charges.

Buses can meet some of the travel needs of the underserved locations within urban areas but their ability to furnish expanded and high quality service economically is limited. Although buses have relatively low capital costs, their high labor costs make it economically difficult for them to offer reliable and frequent service outside the peak periods. Most buses are poorly patronized in non-peak hours, and even during peak hours on lightly-traveled routes. Generally, therefore, bus transit is heavily subsidized with tax funds (sometimes supplemented by local business contributions) in localities that provide widespread route coverage on fairly convenient schedules.

Buses on heavily-traveled or express routes sometimes furnish satisfying transit service, but buses usually offer a slow and inconvenient way to travel. Persons who have choices, therefore, rarely use them. Yet the low capital cost and flexibility of the bus, in spite of its service weaknesses, mean that any proposed guideway system, including PRT, will find that bus mass transit is its primary competitor for the funds available to invest in transit. This is particularly true if the location under consideration is widely served currently by bus transit.

2.3 Automated People Movers (APM)

First generation APMs in the l960s were offered as an alternative to heavy and light rail and, in some case, buses. Few localities or transit specialists adopted them. Indeed, during the 1960s, ‘70s and ‘80s, municipal leaders have usually backed the construction or upgrading of conventional mass transit systems. Nevertheless, a fair amount of government and private investment went into the development of APMs between the early l960s and the early l980s.

Non-PRT APMs began to attract special interest for urban transit purposes during the 1970s. The U.S. Urban Mass Transportation Administration (UMTA)7[7] started to concentrate its resources on what it called “Downtown People Movers”, encouraging demonstrations in “downtowns” and other major activity centers. Many American cities applied for Federal money to participate in the Downtown People Mover program, and several received assistance. One of these cities was Miami, whose Downtown People Mover, an APH, is shown in Figure 2.3.

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[7] One of the principal agencies of the U.S. Department of Transportation.

Figure 2.3: “Metromover” APM on Aboveground Track, 2nd Story Level, Miami, Florida

APMs took several forms, the merits and demerits of which sometimes led to considerable debate. Experts and others took sharply contrasting positions. PRT was caught up in this debate, but it mostly revolved around the other types of APMs.[8]

The non-PRT APM designs that received the most financial support from government and industry had vehicles that ranged from a capacity of about 12 riders up to as many as 100. seated and standing. The largest of the current non-PRT APM vehicles is a little larger than a “standard” 40-foot [12 ml transit bus. The smallest of the non-PRT APM vehicles is about the size of the average motel/airport van. Thus there is a broad spectrum of sizes among these early non-PRT APMs.

Guideways for non-PRT APH systems are usually aboveground and about 7 to 10 feet wide [2 to 3 ml. The vehicles can be operated either singly or coupled. Like conventional mass transit, the non-PRT APMs typically load and discharge passengers at on-line stations along a route, operating on a fixed schedule. Vehicles in the earliest installations, such as within airports, shuttled among a few points, sometimes between only two (for example, connecting the main and a satellite terminal).

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[8] Generic names given to types of APMs have fluctuated over time. A 1975 report of the U.S. Congress’ Office of Technology Assessment, Automated Guideway Transit: An Assessment of PRT and Other New Systems, in an effort to standardize terminology, defined three types, progressing from the simplest to the most complex: Shuttle-Loop Transit (SLT), Group Rapid Transit (GRT), and Personal Rapid Transit (PRT).

The first APM placed into service more characteristic of urban transit was the system in Morgantown, West Virginia. It is mainly a circulation system for the large and fragmented campus of the University of West Virginia, but it also provides service into the Morgantown central business district. The System is owned and operated by the University rather than a transit agency, but was financed almost entirely by the Federal government. System demonstration began in October 1972 with 5 vehicles and 3 stations. Regular service began in September 1975 with a Phase I configuration having 45 vehicles. Phase II of the Morgantown System, completed in July 1979, ended with 73 vehicles that continue in service today over 8 single-lane miles of guideway with 5 stations. It can function safely with as little as 5-second spacing (i.e., “headway”) between vehicles, which are not coupled, but normally operates at 15-second headways. Vehicles carry 8 seated passengers and up to 13 standees.

The system operates successfully and relatively economically today (in O&M costs), providing a needed transportation service for the community and university. It operates in near-PRT and mass transit line-haul modes. During periods of high demand (the school day) it typically employs a near-PRT mode, which raises passenger-carrying capacity and also improves service to passengers. “Near-PRT” mode, for this system, means that the system fulfills all PRT criteria except that of assuring a private ride for the passenger (i.e., the right to ride alone or with persons of his or her own choosing). Vehicles are controlled automatically, stations are off-line, and vehicles in the near-PRT mode travel nonstop between origin and destination stations. Upon arriving at the station entrance gate, passengers signal their desired destination stations. After a maximum wait of 5 minutes, they and other waiting passengers going to the same destination board the arriving vehicle which is designated for nonstop service to that station.

The Morgantown system became heavily embroiled in political controversy during construction because of capital costs that greatly exceeded expectations and the Federal government budget provisions (being an experimental and demonstration technology, and for other reasons). This controversy seriously damaged the advancement of transit technology, and it led to misunderstandings about the potential value and economics of other PRT design concepts and systems. The system was indeed costly, if compared to current PRT cost expectations, but not exceptionally costly if compared to the costs of light rail or other APM systems.

Another unfortunate consequence of this controversy was that the Morgantown system was, in effect, abandoned by the U.S. Government, and therefore ultimately by its contracted supplier. It became a one-of-a-kind installation without either government or supplier commitment to long-term support or improvement, facing continual difficulties in securing spare parts and upgrading equipment in spite of its current excellent operations. As an historical step toward PRT, Morgantown is important. It deserves more serious and dispassionate study than it has received by the established transit industry.

Since Morgantown, only a few APMs have been installed in North America in typical urban transit service; all in the mid-1980s and all with mass transit line-haul configurations, having stations on-line and vehicles stopping at each station. One of these, Detroit **"CATS",** is a one-way loop system. The two others in Miami ("Metromover") and Vancouver, have a dual-track configuration similar to mass transit rail systems.[9] A dramatic display of several forms of mass transit, heavy rail, bus and APM - interacting with each other - is shown in Figure 2.4.

Figure 2.4: Heavy Rail, Bus and APM at a Transfer Point in Miami, Florida

The new Reagan Administration in 1981 opposed the strong Federal financial support for transit in general, and transit hardware research and development in particular. It quickly began to terminate Federal support for most hardware R&D, including that for APMs. Although the Detroit, Miami and (to some degree) Jacksonville (Florida) downtown people mover projects managed to survive, no other projects have been programmed or financed. In Canada, vigorous support by Provincial governments enabled some APM activity to proceed, leading in particular to the Vancouver installation, built in connection with a major exposition held in that city.

U.S. urban areas continue to evaluate APMs for various transit applications, but, without the considerable Federal Government support that they once received, little local demand has emerged for them thus far, even for center city circulation. Other reasons why cities abandoned

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[9] True urban systems outside the United States include the Kobe Port Island System (Japan), Lille "VAL" System (France), and the Osaka-Nando Port Island System (Japan), to mention the most important.

downtown people movers included "…the cost of building heavy guideways for the present generation of hardware and the visual bulk of the structure…".[10] Outside the United States, on the other hand, the application of these APMs to urban transit for heavily-used corridors is increasing. Nevertheless, current non-PRT APMs, like rail mass transit, have relatively high costs and limited flexibility. As a result, they cannot be regarded in their present configurations as serious options for the underserved transit needs of medium and lower density locations.

Non-PRT APMs have had, on the other hand, a steadily growing market in specialized applications such as for circulators within airports and large real estate developments, and for short links between major activity centers and other facilities such as parking locations. The first non-PRT APM system installed in an airport was in Tampa in 1971. Since then a number have been installed, and many more airports, as well as other major activity centers, are studying APMs.

There is an active construction activity, as well as planning, for non-PRT APMs today. Figure 2.5 identifies the extent of this construction around the world in late 1988.[11]

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[10] Boris Pushkarev and Jeffrey Zupan, Urban Rail in American: An Exploration of Criteria for Fixed-Guideway Transit, Regional Plan Association, Inc., 235 E. 45th Street, New York, NY 10017, report to the Urban Mass Transportation Administration, November 1980.

[11] Source: TransitPulse, P.O. Box 249, Fields Corner Station, Boston, MA 02122, January/February 1989, p.2.

PEOPLE MOVER CONSTRUCTION FALL 1988

Site	*Expected Service*	*Configuration*	*Cost ($m)*	*Supplier*
People Movers of Architectural Scale				
Singapore	1989	1km airport shuttle	26	Westinghouse
Chicago, Ill.	1990	5km airport line	143	Matra
Orlando, Fla.	1990	3rd airport shuttle	24	Westinghouse
People Movers at Institutional Scale				
Jacksonville	1989	1km downtown line	30	Matra
London, Eng	1989	2km Docklands ext	145	GEC/Mowlem
Dallas, Tex	1989	2km new town center	33	Westinghouse
*Las Vegas	1990	2km downtown line	50	AEG/MTA
Dortmund, Germ	1989	2km H-Bahn ext	30	Siemens
Jakarta, Indo	1989	3km loop	10	Sur Coester
Yokohama, Jap	1991	1km shuttle	6	Soule
Milan, Italy	1990	4km arena line	122	UTDC/Ansaldo
People Movers of Metropolitan Scale				
Komaki, Jap	1991	8km line	149	Mitsui-Nippon
Vancouver, BC	1989	7km ext	170	UTDC
Kobe, Jap	1989	5km Rokko Isl line	200	Kawasaki
Lille, Fr	1989	18km second line	475	Matra
Tama, Jap	1992	5km distributor	100	n.a.
*Taipei. Taiw	1992	12km line	330	Matra
*Toulouse, Fr	1993	10km line	524	Matra
*Strasbourg	1992	10km line	450	Matra
Lyon, Fr	1990	11km metro	750	Alsthom/Matra

* Contract signed, construction imminent

Figure 2.5: APH Construction, Fall 1987

It remains to be seen whether non-PRT APMs adopting improvements in technology such as better automation, propulsion systems and other advancements, will have a broader application to general urban transit, outside specialized complexes. If the non-PRT APMs continue to rely on mass transit vehicle sizes and operating modes, they probably will not be able to achieve the significantly lower costs and higher quality of service that are essential to permit their widespread deployment in the underserved medium and lower density locations. This point is well summarized, with respect to APMs for downtown circulation, in a 1980 study which concluded: "…the findings point to the need for light, single-beam systems that would be less costly to build, obstruct less view, and not require any snow melting. When developed, such systems could have wide potential use, not limited to downtown circulation."[12] This quotation leads quite naturally into consideration of PRT, which is usually based on single beam guideways.

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[12] Pushkarev and Zupan, Op.cit., p. xxvi.

When living standards and auto ownership rise among the general population, mass transit nearly always begins to suffer. Observing this trend in the United States as well as elsewhere, some innovators as early as the 1950s began to suggest ideas for “individualizing” transit so that it might match better the attractions of the automobile. These ideas led to what today is called "Personal Rapid Transit”, which sought to change transit in the following way:[13]

1. to offer considerably more convenient service than bus or rail mass transit - “more convenient” being improvements such as stations within reasonable walking distance, on-demand service, and availability around-the-clock;

2. to offer passengers a direct no-transfer ride between their desired origin and destination stations without having to stop at intervening stations (“nonstop” riding);

3. to offer the same privacy as an automobile, allowing one to ride alone or with persons of one’s own choice; and

4. to accomplish these ambitious performance goals at the same or lower cost than current mass transit.

The question of whether transit based on small vehicles and “individualized” service could be built and operated less expensively than mass transit became a major challenge for these early innovators. In particular, they had to challenge one of the fundamental underpinnings of mass transit, which is that large vehicles are essential to hold down costs and carry the required volumes of passengers. They contended that although large vehicles may have been essential earlier, advanced automation (and other modern technologies) had made feasible the creation of a transit system of small vehicles — more cost-effective to build and operate, offering higher quality service.

Large vehicles, in spite of some obvious advantages, have disadvantages that are sometimes overlooked in evaluations. For example, for rail transit (and sometimes even for bus transit) large stations or terminals are needed. These are expensive, and especially so when aboveground or underground. The high concentrations of weight that large vehicles impose on tracks result in heavy and expensive aboveground structures with considerable visual intrusiveness. Large vehicles rely on massing of passengers along densely-travelled routes, which for costly rail systems, particularly, means that lines must usually be spaced far apart, producing lengthy access trips to reach stations. Stations, too, tend to be far apart on rail lines, for operational and efficiency

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[13] The “personalizing” of transit took it in the direction of a kind of automated taxi, we note, which not surprisingly led to PRT concepts being given names used in the taxi industry; for example, Cabintaxi, Cabtrack, TAXI 2000.

reasons. Finally, for economic reasons relating to the nature of mass transit, riders must often stand in large vehicles during peak travel periods; sometimes a safety hazard, nearly always a discomfort. These are some of the disadvantages of large vehicles.

2.4.1 Elements of PRT

Serious thought about PRT started as early as the 1950s. A noteworthy pioneer was Donn Fichter. He conducted private research for several years and published at his own expense a seminal book in 1964, entitled Individualized Automatic Transit and the City. Many other individuals and organizations have contributed PRT concepts. Since then, working models of PRT components, and some test systems of limited size and complexity, have been built. All of these PRT ideas offered vehicles and guideways smaller than those used for non-PRT APMs, and much smaller than conventional mass transit (heavy or light rail).

Equipment and operational characteristics vary considerably among the different PRT concepts. Some systems called “PRT” by their developers are not true PRT, as PRT is defined in Chapter 1. They do not provide, for example, for individualized service or for vehicles running between origin and destination stations without having to stop at intervening stations. It is unfortunate that the misuse of the PRT name has sometimes led to public confusion about the nature of PRT.

In these various PRT concepts, the number of passengers per vehicle typically ranges from 1 to 6, although as mentioned, the Morgantown system with a 21-passenger vehicle can offer service in PRT mode. Car sizes vary from ones that look like tall and wide telephone booths to those the size of the small van-type buses used to pick up airport passengers. Guideways have ranged from 2 to 11 feet wide [0.6 to 3.4 m] and 2 to 6 feet deep [0.6 to 1.8 in]. Some support columns have the diameter of a telephone pole; others are as much as 4 feet thick [1.2 ml. Some guideways look like a sizable girder; others like small aboveground walkways.

In some PRT designs, the vehicles operate only singly. In others, they operate sometimes singly and sometimes in trains. Some PRT designs have vehicles suspended from the bottoms or sides of guideways; others have vehicles that are supported on the top of the guideway; and others have one vehicle lane supported on top and another lane suspended from beneath the guideway.

PRT schemes locate each station on an off line siding of the main track. A stopping vehicle leaves the main line, while at or near full speed, and enters the station. After loading a passenger, the vehicle accelerates off line and re-enters the main guideway at full or nearly full speed, automatically placed in one of the gaps between vehicles already running on the main line. Each vehicle is programmed to go by the most direct route to the station the passenger(s) desires. There are no stops at intermediate stations to load or unload other passengers.

When a vehicle delivers a passenger to a destination station, it waits for the next passenger unless the automatic controls send it to another station needing vehicles, or to a garage or workshop for storage or maintenance. Unlike mass transit vehicles, PRT vehicles in most PRT concepts do not continue to run without riders on a particular route and schedule, although they must necessarily run empty when being re-deployed to meet demand at other stations, or to be stored or go to workshops. In many of the PIT concepts, stations have berths - two or three in an average station, although there can be as few as one — for the vehicles waiting for passengers. Heavily-used stations, such as at stadiums that suddenly release large volumes of passengers, have additional berths. Some PRT concepts do not rely on vehicle berths but instead employ other loading arrangements.

These various characteristics are intended to enable PRT to maintain higher rates of seat utilization than mass transit, and minimize stop/go travel. On- demand use of vehicles is also intended to reduce unnecessary movement of equipment, although system design (and related costing) must consider that empty vehicles which cannot remain at an unloading station will have to be sent to other stations that have available spaces, or to nearby staging areas.

PRT designs vary in the size of their stations and platforms. Generally, PRT stations are much more numerous, but smaller, than rail transit stations, especially for heavy rail, although larger and more visible than most bus stops. Upon arriving at a station and paying for a ride, a passenger enters the first empty vehicle in line or the one that comes to the station soon after the passenger arrives. Only that individual and additional persons of his or her choice ride together. Passengers choose the persons with whom they wish to ride, or may ride alone, another similarity to taxi service. As each loaded vehicle moves of f, the loading process is repeated continuously, as at a taxi stand.

Fares that are charged may be per vehicle rather than per person, but a fare for each individual or group may be charged, as in mass transit, depending on the preference of the owner/operator.

PRT, with its offline stations and individually-controlled and flexibly-routed vehicles can, in addition to carrying passengers, carry light freight loads among points that have freight-handling stations. The wider the network, the more attractive PRT would be for this service. An example of a use of this service might he for a large store to have PRT freight stations at the loading docks of its retail store and its warehouse(s) for rapid movement of parcels and other PRT-size freight among these locations. In addition to helping reduce the store’s own transportation costs, such freight service could help reduce on-street truck movements that congest urban roadways increasingly. The individually-controlled vehicles make feasible the idea of intermixing freight and passenger services on the same guideway.

Many features of the various PRT concepts have cost, operational, service and environmental implications that can indeed change the way urban transit is provided and expanded. However, no system satisfying the definition of PRT given in Chapter 1 has yet been demonstrated under full working conditions anywhere in the world.

2.4.2 Cabintaxi

The most thoroughly developed and tested PRT system is Cabintaxi (called Cabinentaxi in German), developed as a joint venture by Mannesmann Demag and Messerschmidt-Bolkow-Blohm (MBB) of the Federal Republic of Germany (West Germany). Considerable funding for Cabintaxi development was supplied by the West German Government. Appendix A provides additional sources of information about Cabintaxi.

The test facility in West Germany included a 6-foot-wide guideway (1.8 mL and 14 vehicles using offline stations. Twelve of these vehicles were 3-passenger; two were 12-passenger. The test track had 3 off line stations and 1 online station, a 15 percent grade, and guideway configurations that demonstrated all main line operations and applications expected to be encountered in an urban application. In the mid-1970s, the companies began to focus increasingly on the 12-passenger design of Cabintaxi, capable of operating on the same size guideway in both PRT and non-PRT mode, because of the interest of the city of Hamburg in a system based on 12-passenger vehicles capable of operating in PRT mode.

The Hamburg prospect collapsed for financial reasons, virtually at the last minute before contract award, and no other opportunity developed to provide for a demonstration of Cabintaxi under urban operating conditions. Even so, many hours and miles of endurance testing occurred at the test track, and several thousand individuals rode the system there. The developmental testing of Cabintaxi equaled or exceeded tests of PRT systems (or perhaps any other transit system at a test facility) in the world. It culminated with the designation of Cabintaxi by the West German Government as suitable for urban transit applications at headway operations of 2.5 seconds.

There has been no serious study of the reasons for the stoppages of work on PRT in the various countries during the 1970s and early 1980s, but some of the main reasons appear to have been technical problems, lack of perceived demand, doubts about cost-benefit or cost-effectiveness, other research or transportation priorities, lack of government support, or concerns about possible adverse public reactions to (a) travel in driverless vehicles on aboveground guideways, (b) the appearance and siting of PRT guideways, or (c) safe operation at the short headways that would be necessary in some locations to provide needed capacity.

In West Germany itself , the Federal Government’s decision in 1980 to cut off further financial support for Cabintaxi development was the result of the Government considering the system to be developed and ready for urban deployment.[14] The City of Hamburg had made a decision to go ahead with an

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[14] A technical review by the Federal Government near the end of the development program identified a control-related problem that would have to be corrected before final certification of the Hamburg installation for passenger service. This was not considered, however, to be a major technical difficulty at that time or a reason to stop the go—ahead on Hamburg

initial deployment of Cabintaxi. Shortly before contracts were to have been let, the Federal Government, in a budget crunch at that time, reduced its financial support for municipal governments. This action led to a last minute decision by Hamburg not to go forward with its planned installation of Cabintaxi. No other customer emerged who was interested in buying Cabintaxi in the near term. The German partners then decided to disband the Cabintaxi development team, and they have not made further PRT investments.

In the United States, the Urban Mass Transportation Administration in the 1970s allowed Cabintaxi to compete in the Downtown People Mover Program, a decision that the system met safety and other standards at that time for passenger-carrying operations in U.S. urban conditions.

About 3 years ago, the U.S. company, Cabintaxi Corporation, Detroit, Michigan, began to market Cabintaxi in the United States with the approval of the German companies. The President of this company, Mr. Marsden H. Burger, in his oral presentation to the committee, stated that he regards Cabintaxi as more cost-effective than any non-PRT APH system in present use or being marketed. He also said that if serious buyers for Cabintaxi emerge, his company would establish a management and engineering team, and develop an updated vehicle control system for a short headway application. There have been no sales thus far.

2.4.3 TAXI 2000

The most sustained PRT work in the United States, through a succession of arrangements with various governmental agencies and businesses, has been done during the past 20 years by Dr. 3. Edward Anderson, now President, Chairman and CEO of TAXI 2000 Corporation, of Revere, Massachusetts. Several sources of information about TAXI 2000 are contained in Appendix B. Although no prototype of the TAXI 2000 system has been financed, produced, or tested, active solicitation of funds for these purposes is underway. TAXI 2000 furnished considerable oral and written material to the committee, based on recently-awarded patents and current analysis and design activities, which will be identified and discussed later.

During the past six years, Dr. Anderson said, the TAXI 2000 system particularly its switching, guideway, vehicle, power distribution, and control concepts has undergone several stages of design to lower costs and improve performance. The company arranged for the construction of a full scale 3 x 3 foot (91.4 cm x 91.4 cm) guideway section with support posts, to provide information on costs and design simplifications for manufacturing. A 100-foot (30.5 m) track and a vehicle and control system have been assembled to test the twin linear induction motor design and the vehicle control system. Five U.S. patents have been awarded for switching, guideway, and network control. Patent coverage, financed by the University of Minnesota where Dr. Anderson was a professor, is being extended to most industrialized countries.

Dr. Anderson said that during 1984-1986, the Chicago Technical Center of the Davy McKee Corporation developed specifications for all major components of TAXI 2000, submitted many to industrial companies for bids, and estimated the cost of the remaining ones. During the process, he advised, three preliminary system proposals were prepared, a number of design improvements were made, and Davy McKee became convinced that the technical concepts of TAXI 2000 were sound and well within the state of the art.

During the past two years, Dr. Anderson also stated, engineers and executives of the Raytheon Company and its engineering subsidiary have reviewed the designs and costs of the TAXI 2000 subsystems and participated with TAXI 2000 Corporation in two proposals. Units of Raytheon, he said, will be subcontrators to TAXI 2000 Corporation during the demonstration and deployment phases of the TAXI 2000 system.

The design review process found, Dr. Anderson asserted, that all the components of the TAXI 2000 system are well within the state of the art. Detailed design and testing to provide a proven set of system specifications are the required next steps, he added, and then the system must be demonstrated.

Dr. Anderson believes that the first proven TAXI 2000 system which would demonstrate the essential features of an eventual large-scale urban transit system can be operating in an initial small and relatively simple installation within 3 to 4 years after the start of serious development work, if further funding of development can be obtained. Details about the plans for this initial installation are given in a subsequent chapter of this report. Dr. Anderson claims that his 20 years of sustained effort, including the bid process and other work noted above, have produced the most innovative and thoroughly optimized PRT concept available.

The TAXI 2000 company is seeking, but does not yet have, the necessary venture capital to proceed with the next stage of development of TAXI 2000. Some work goes forward, nevertheless, through the loaned and contributed efforts and money of individuals and corporate friends.

Dr. Anderson reported that the company intends to license independent companies in the United States and elsewhere to build TAXI 2000 systems, once the technology is demonstrated. Licensees would be granted full access to the technology and could contract directly for the fabrication and installation of their particular systems; choosing their own suppliers for guideway, vehicles, installation and operation. The TAXI 2000 company itself plans to manufacture and sell vehicles and control systems, and also will maintain a research and development program on vehicles, control systems and guideways. In addition, he stated, the company will act “as a center of focus for legislative, planning and insurance issues and will ensure effective communication among all licensees.”

Thus far the company has not made any sales or entered into any licenses. It has participated in some planning studies and prepared several proposals.

2.4.4 Visualizing PRT in Urban Application

The Pushkarev and Zupan study in 1980, previously cited, implicitly identified the competitive edge of PRT (referred to as an advanced “automated peoplemover”) under various scenarios of urban growth and transit needs, commenting that:

“The role of automated peoplemovers [sic] in this scenario is much more difficult to foretell. Judging by the threshold criteria established here - which obviously are more tentative for a nascent technology than for a mature one — automated or semi-automated systems, if they adopt low-capital, single-beam guideways, and if they break out of the downtown-only environment, will be in direct competition with conventional light rail as well as with buses. If their automatic controls become reliable and routine, they can capture a significant market in middle-sized urban areas and an additional market in some major cities as feeders to rapid transit.”[15]

The following visualization of a PRT system in an urban setting may help us better understand why the scenario envisioned by Pushkarev and Zupan may unfold in the future if PRT proves its feasibility during further development and demonstration.

A hypothetical PRT system in an urban transit service, using the TAXI 2000 concept as an example, might consist of a grid-like network of one-way aboveground guideways spaced at about half-mile [0.8 km] intervals.[16] Guideway interchanges placed at the intersections of guideways would allow approaching vehicles to continue straight, or turn and go in another direction. Stations would be approximately half-way between intersections, also at half-mile spacings, and would be off line, so that a vehicle could proceed past all stations except its destination station, where it would turn in. An illustration of a similar hypothetical “complex network” is shown in Figure 2.6, together with examples of several other less complex networks that show how initial PRT systems might look.

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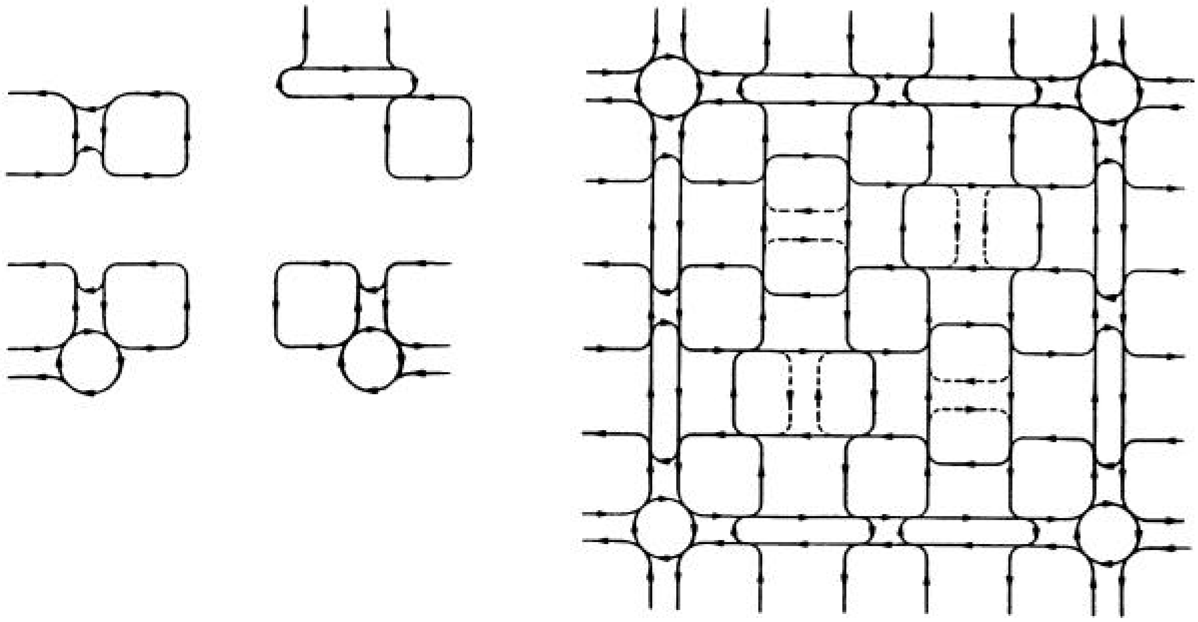
[15] Pushkarev, Op.cit., p.279

[16] Other PRT concepts, such as Cabintaxi, would give rise to similar but somewhat different configurations



Initial Systems…

Can Expand to Complex Networks

Figure 2.6: Hypothetical PRT Grids in Initial and Complex Networks

Half-mile station spacing would allow passengers to reach stations with a maximum walk of about one-fourth mile (1,320 feet - 402 meters]. The average walk for all passengers would be about one-sixth mile (880 feet - 268 meters]. In fact, however, passenger distribution within an area is rarely uniform, so the average walk distance could be shorter or longer, depending on a particular station. Considering these access distances, which are quite reasonable for most healthy persons, maximum walk time to a station would be about 5.5 to 6.0 minutes, and the average walk time would be about 3.5 to 4.0 minutes.

Guideways could be more closely spaced; for example, to quarter-mile intervals (1,320 feet - 402 meters]$_1$ which would cut maximum walk time approximately in half, to about 3.0 minutes, and average walk time to only about 2.0 minutes. Some PRT systems, especially in densely-developed locations, might be built with such close spacings, but cost rises as spacing decreases. If closer spacing generated higher revenues and/or other offsetting benefits, customers might want it. The most probable spacing is probably within the half-mile range; fluctuating as a function of the particularities of the site, the economic characteristics of the application, and the desires of a customer.

The guideways, 3 x 3 feet in size [91 x 91 cm] would be about 16 feet (4.8 m] above the ground, supported on slender columns similar to some types of light or telephone poles in their dimensions - about 24 inches diameter [60 cml at their base and about 12 inches (30 cm] at their top. Columns would occur about every 60 feet [18 ml, except where longer (or shorter) guideway spans are needed for special requirements. In off line and station areas, the main guideway, the off line guideway and the station platform would parallel each other, covering more surface area and requiring more columns for a given surface area under them. The station, however, having a length of about 36 feet (11 ml, would parallel only about one-tenth of the off line guideway, which would be about 350 feet long [107 ml in a PRT system having vehicles operating at about 30 mph (48 km/hI. Off line guideway length would be shorter for slower-speed vehicles, or if vehicles began to decelerate before they turned off the main line, or if the main line flow requirements were less.

A PRT vehicle in this hypothetical system would depart from the origin station on demand; that is, when a passenger was seated safely inside the vehicle. Passenger boarding would usually be shortly after the passenger’s arrival at the station. There would be no turnstiles to pass through, but immediately beside the vehicle’s door, the passenger would insert a trip destination card into a receptacle, which would cause the vehicle door to open and the vehicle to be programmed for non-stop service to the desired destination station. There would be no waiting delay to satisfy a pre-determined scheduled departure time (as in mass transit). The passenger would enter the waiting vehicle, travelling either alone or with other persons of the passenger’s own choosing.

In this hypothetical system, the vehicle operates at a nominal speed of about 30 mph, although a different speed could be specified, depending on the size of the area being served and the speed capability desired by the customer. The vehicle would travel by the shortest or quickest route from the origin station to the destination station. It would not stop at enroute stations. Passengers would not have to make transfers while on the PRT system, being able to go anywhere within the network simply by selecting a destination station.

Grids in a real system do not have to be perfect squares. PRT networks can assume many shapes, varying to fit land contours, existing structures, street layouts, traffic patterns and other conditions. This hypothetical system, for simplification, assumes that grids are neat squares. Each square mile served by this PRT network, therefore, would have 4 lane miles of mainline guideway, 4 interchanges, and 8 stations. If we imagine that the urban area included within the guideway network is about 40 square miles [104 km2], a PRT system based on the TAXI 2000 concept would have a total of about 344 stations, 170 miles [274 km] of mainline guideway, and an additional 25 miles [40 km] of of f line guideway (about 13 percent of the total guideway being of the offline type).

Some of the off line guideway would be at interchanges, and the balance at stations. Off line guideway at the TAXI 2000 types of interchanges would have radii and “spirals” to allow vehicles to change direction without slowing down. Each station, in addition, would have one off line siding to decelerate, unload, load, and accelerate vehicles.

The quality of service provided by such a PRT system would clearly be an extraordinary improvement over transit service offered today. If it motivated residents and others to use transit within the area for a much larger variety of their travel needs than they do today, it would impact daily life significantly, including the use of automobiles.

The first PRT applications will probably be in much smaller areas, probably in services that we would not normally call “urban transit” service. The most probable initial sites are specialized locations under unified ownership and management, such as within real estate or recreation developments, or in airports. PRT suppliers themselves probably will prefer these, to avoid the risk and uncertainties initially of complex applications and slow processes of political decision-making.

If PRT proves itself in these smaller undertakings, we imagine that the broader urban transit market would begin to open. Perhaps the first move into this broader market would arrive when a real estate development demonstrated a successful PRT operation and a demand arose for this small system to be expanded into the surrounding urban area, creating links between that development and the larger world. PRT would appear to be ideally scaled and conceived, like buses, for this kind of incremental growth, if its low cost and service goals can be demonstrated. Over time, such growth might evolve, as grids are added incrementally, into an area-wide network that resembles our hypothetical system and has a much higher cost-effectiveness than mass transit today.

If initial demonstrations prove to be successful, PRT would become one of the most promising lower-cost transit options for potential applications where policymakers have resisted or rejected high-cost guideway proposals that have been made in recent years.

Chapter 3

FEASIBILITY OF PRT

The question of PRT feasibility has been debated heatedly for at least three decades. “Feasibility” can mean a variety of things, depending on one’s perspective and anxieties. We focus on the following critical questions:

1. Will PRT work, carrying passengers safely and reliably in daily use?
2. Will PRT provide significantly better service than bus, rail or other non-PRT mass transit in low or medium density locations?
3. Will PRT have a combined capital and operating “life-cycle cost” significantly lower than other systems?
4. Will the public feel and be secure in driverless vehicles of PRT, using mostly unattended stations? And will the public accept PRT near residences and businesses, considering that eventually there may be thousands of small cars travelling on a relatively dense network of mostly aboveground guideways and stations?

Non-PRT APMs have overcome many of the hurdles that face PRT today. Just as there is skepticism today about PRT, there was great skepticism about these other APMs a decade or two ago. Much of it has been overcome even though these other APMs are continuing to seek market penetration in new and different applications.

Non-PRT APMs carry passengers safely and reliably today in spite of the anxieties earlier about driverless vehicles. Most of them, it is true, are in relatively benign environments (compared to true urban transit) such as airports or recreation facilities, but several recently-built ones provide mass transit service in urban corridors. Automated vehicle control has performed well thus far for these larger vehicles which have, nevertheless, relatively long headways.

From an economic point of view, non-PRT APMs in specialized applications such as airports are being built and operated generally within the costs claimed by their developers, but these costs are high. These installations, even so, appear to be affordable to their owners and operators.

The few non-PRT APMs built thus far for urban transit service have had capital costs similar to or higher than the costs of some kinds of rail mass transit, and in at least two instances, severe cost overruns.[17] It seems, on the other hand, that the operating costs of most of them — perhaps all — are proving to be lower than heavy or light rail operating costs, especially if the higher quality of service offered by the APM is taken into consideration.

Public acceptance of the non-PRT APMs in urban environments has been surprisingly favorable despite their aboveground structures. Even if their structures and vehicles are often relatively massive, compared to PRT, they are usually smaller than rail transit structures. This acceptance does not tell us what the public reaction might be to extensive and closely-spaced networks of aboveground but much smaller PRT guideways and stations, some of which like most non-PRT APMs) will be near buildings at second-story level.[18] As there are significant differences between the dimensions of the small PRT guideways and most of the non-PRT guideways it will be difficult to rely on the experience with non-PRT guideways to make predictions about public reactions to PRT guideways. This is also true for the relative sizes of PRT and non-PRT stations.

System safety and personal security on non-PRT APMs has been excellent thus far. There are, however, differences between PRT and non-PRT APMs. We will discuss them later.

3.1 Technical Feasibility of PRT

There are good reasons why PRT did not come to fruition in the 1960s and 1970s. Although some of the concepts were technically feasible, none achieved the right combination of desired performance, sufficiently low costs and public or environmental acceptability to convince their backers (governments as well as industry) that they offered a major advance in transit, or to convince potential customers that they should be bought.

3.1.1 Technical Weaknesses of Earlier PRT Concepts

There has been no comprehensive study, either by this committee or by others (in published form, at least), of the various PRT concepts of the 1960s and '70s why each was terminated and what we may learn from the technical and other choices that their developers made. Dr. Anderson of TAXI 2000, however, made available to the committee a document that he had prepared in Fall 1984,

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[17] Detroit (Michigan-USA) and Miami (Florida—USA).

[18] Both the Detroit and the Miami non-PRT APMs have many elevated portions that pass by second-story windows.

for the information and guidance that it might provide to his own PRT work.[1919] A summary of some of the material from that document provides insight into some of the trade-off decisions that the pioneers faced. The following are solely the data and opinions of Dr. Anderson, which the committee has not tried to validate, but are especially intriguing because Dr. Anderson is one of the few pioneers who continues to develop PRT:

> CVS, a Japanese system, was among the leaders. It had, however, a major problem of guideway size; 8 feet 10 inches wide by 7 feet 7 inches deep [269 x 231 cm]. PRT is not viable economically, and from a public acceptance point of view, with such a guideway. In addition, its vehicle switch was a relatively clumsy device, located in a trough below the running surface in a configuration susceptible to excessive interference by snow and ice. CVS had several other deficiencies, including central computer control of all the vehicles, so that a computer failure would stop all operations. The running surface for the vehicles was welded steel plate. Ensuring a smooth ride — recognized increasingly as very important to passengers - was nearly impossible with this kind of surface.
>
> Aramis, a French system, used rotary electric motor propulsion, with braking through the wheels. This design configuration inevitably led to a relatively wide and unsightly guideway having low vehicular capacity, especially in inclement weather (notably during snow and ice conditions). The Aramis control system was suitable mainly for a line-haul operation.
>
> Monocab, an American system, was one of the earliest PRT designs, invented in 1953 but not developed until well into the 1970s. One of its interesting features was its hanging suspension, with the vehicle suspended under the guideway. Hanging vehicles, a popular PRT idea then, were thought desirable because their running gear and switches were better protected from winter weather. Serious offsetting disadvantages eventually became apparent: (a) the support posts had to be longer and cantilevered, raising guideway costs considerably; (b) special provisions were needed for crossing the slot in the switch sections of the guideway, an extraordinarily difficult design problem; (c) at-grade or tunnel applications were virtually ruled out; and (d) visual impact was much greater because the guideways were higher in the air and the support posts must therefore be larger. Another interesting feature of Monocab, adopted in the 1970s, was its use of magnetic levitation (“maglev”). At that time, maglev technology needed years of additional expensive investments in research and development before PRT could be based on it.
>
> TTI-Otis, an American system, had another novel feature, a combination of air suspension and linear induction motor (LIM) propulsion for the vehicles. Unfortunately, a wide guideway was needed for air suspension, which increased cost and visual impact.

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[19] Anderson, 3. Edward, Research and Development Efforts That Contributed to the Advancement of Automated Guideway Transit, Fall 1984.

Early developers of PRT deserve praise, we feel, for their pioneering efforts. Research and development is built on the foundation of many errors and few successes, usually requiring several decades. The stronger technical position of PRT today flows from the imagination and trials of the inventors and innovators of the 1950s, ‘60s and ‘70s.

3.1.2 Possible Technical Deficiencies of PRT

The performance goals of PRT are ambitious, perhaps even daunting, when one considers mass transit today. Such splendid performance could probably not have been accomplished (at least at acceptable cost) a few years ago. For nearly a decade there has been no serious public evaluation of specific PRT concepts by technically-qualified individuals, even though some research and development of PRT has continued. It is therefore worthwhile identifying the most important earlier criticisms of PRT, to decide whether present PRT activity addresses those criticisms adequately.

One of the principal criticisms of the PRT concepts that appeared during the 1960s and 70s was that PRT attempted the impossible of combining small vehicles, ideal for low-density travel, with complicated and electronically controlled guideways that would prove to be economically feasible only on heavily-traveled routes. The argument in essence was that in suburban areas where small vehicles might be optimal the construction of guideways would be too expensive; and along major travel corridors and in center cities where the guideways might be economically justifiable, the small vehicles could not travel close enough to each other to provide the required passenger-carrying capacity.

Some of the early PRT guideways and stations were indeed complex and undoubtedly impracticable, at least economically, if not (in some cases) technically. As the earlier criticism justifiably emphasized, PRT guideways and stations must be simple and inexpensive if PRT is to have any chance of success. Otherwise, the large number of required guideways and stations will be prohibitively expensive. We will examine in a moment whether current guideway and station design concepts appear to have found a solution to this dilemma.

This earlier criticism also deservedly focused on the problem of providing adequate passenger-carrying capacity with many small vehicles, another major historical concern about PRT. The question being raised was whether PRT vehicles could operate with one-second, or even sub-second headways. A number of technically-qualified individuals felt that operation with distances between vehicles that were much shorter than the braking distance of the vehicles would not be acceptable, and that such vehicular flow might not be physically possible to attain under automatic controls.

The headway issue (i.e., the spacing of vehicles while running) is especially important for PRT because it has a major effect on how many passengers the system can carry; that is, the system’s “capacity”. The more closely that PRT vehicles follow each other, while maintaining required speed, the more passengers a lane of guideway can carry.

Spacing has always been one of the important methods of ensuring safety in all forms of transportation, including transit. Rules applicable to mass transit have been adopted historically by safety regulatory authorities, design engineers and others, specifying distances that must be maintained between vehicles to ensure an adequate margin of safety. Typically, such spacing rules provide for relatively large margins of safety, with wide spacings.

The fundamental principle respected in mass transit is that the headway between vehicles at authorized speed must be greater than the stopping distance, by a factor called “k”. This means that if the leading vehicle suddenly stops as though it had hit a brick wall, the trailing vehicle must be able to stop before it strikes the leading vehicle. The headway of all conventional mass transit vehicles on guideways is designed so that “k” is greater than the number 1. It is hoped, although never completely achieved in practice, that the observance of this principle in mass transit will prevent an accident from ever occurring due to a vehicle trailing another vehicle too closely (called “tailgating” when automobile drivers get too close to the leading car, a contributor to accidents on the highway).

Even though the headway issue is one of the most important challenges facing a PRT developer, we feel that excessive attention has been concentrated during past discussion of PRT on high capacity operations based on one-second or even half-second headways. Many useful applications, enough to justify further development of PRT, will not require high capacity systems.[20] Attention to high capacities should not be neglected during development, but there is no reason to judge PRT impractical for all applications if these extremely high capacities cannot be achieved during later development. There also is a question whether the traditional headway principle for mass transit needs to be respected for PRT, a question we will discuss later when we take up TAXI 2000’s headway claims and the safety features that have been incorporated into its PRT design since the quoted comments were made in 1980.

There was another technical concern about the PRT concepts of the 1960s and 70s. Some authorities felt that those concepts had the same severe limitations that auto use has had in urban areas; that is, a requirement for extremely large amounts of land for stations, guideway interchanges, and vehicle storage areas.

Some of the early PRT concepts did, indeed, require too much space for off line guideway, interchanges and stations even though the cross-sections of the structures and their “shadows” were usually smaller than those of mass transit. Station size and the length of the required off line sidings have particularly been disputed in the past. Early PRT developers asserted that

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[20] In this connection, nevertheless, it is worth noting that Cabintaxi, in West Germany about 10 years ago demonstrated safe operation of its 3-passenger vehicles with 2.5-second headways at its test track under those guideway and merging conditions.

average PRT stations would need waiting berths for only a few vehicles and little waiting space for passengers. Others contended that more berths and passenger waiting space had to be be provided to serve peak period pressures. There were also disputes about how long the off line sidings must be for acceleration and deceleration.

The station size argument is an economic issue to a degree, but the fundamental challenge is technical, concerned with the ability of PRT developers to create PRT that provides smooth and rapid availability, boarding and deboarding of vehicles, as well as relatively trouble-free "automated management" of arriving and departing passengers. If PRT stations become larger or sidings become longer than predicted, the negative impact on PRT cost and visual attractiveness might be considerable. Thus, this too is an important issue for further consideration.

Other questions raised about PRT, which were sometimes phrased as technical issues, seem to be principally issues of economics or public acceptance, and therefore are presented later in this report. An example is the criticism that PRT will not be safe because passengers cannot be evacuated quickly from disabled vehicles stopped on the guideway. This criticism derived from a decision of some PRT developers not to incorporate a guideway walkway onto which a passenger could step from a disabled vehicle to go to the nearest station. There was no technical barrier to walkways in most PRT concepts; their lack usually flowed from a conscious judgment, right or wrong, that choices that were safer, less-visually intrusive and less costly had been adopted.

These then were the most noted technical challenges to PRT historically. We will soon see how well they have been addressed in the past decade of additional research and development.

3.1.3 Recent Technology Advances of Significance for PRT

Advances have occurred generally in technology and theory during the past decade that are significant for the feasibility of PRT. Examples are:

- Linear induction motors (LIMs) were still largely experimental in the 1960s and early 1970s. Quite good LIMs can be purchased today at moderate prices for PRT designs based on linear motor propulsion. Moreover, the theory of LIMs is now well worked out, allowing precise calculation in three dimensions, which removes most guesswork from design.

- Solid state controller technology for induction motors has advanced rapidly, to the point where a large number of companies in the United States and elsewhere can supply state-of-the-art units that are perfectly satisfactory for PRT.

- Microprocessors have had an almost explosive advance in the state-of-the-art. A decade or more ago, placing significant control functions onboard PRT vehicles would have been expensive and even questionable; today it is simple and relatively inexpensive. Low cost, in addition, allows much more use of redundancy for safety, reliability and improved performance.

- Automated fare collection and passenger handling systems, now in service on mass transit for about two decades, are used more and more in new and updated mass transit systems.

- Theories of control of automated transit systems have moved from a primitive to an advanced state, due to the continued work of a growing number of experts as well as to the operational experience with non-PRT APMs. In addition, the considerable financing of such work during the 1970s by governments and companies worldwide has advanced the state- of-the-art.

- Significant advances in computer-based computational techniques and theories have changed the theory of reliability and service dependability from very little to a straightforward and comprehensive procedure for system and component design. Similar advances have allowed an enormous simplification in the calculation of the effects of operational data on the performance and cost of PRT systems. In addition, better materials, coupled to computer-based calculation and design, are contributing to significant reductions in cost as well as to improved cost estimates, and they also contribute to better safety, for many of these materials are highly fire-resistant.

3.1.4 TAXI 2000 Technical Feasibility

TAXI 2000 Corporation (through its predecessor company) began, according to testimony to this committee, “extensive analysis and preliminary design” of the TAXI 2000 system in 1981.[21] The company says that today it has quantitative design information on the control system, the linear induction motor, station operations, vehicle dynamics, switch operation, vehicle design, station design, maintenance facility design, and guideway structures. It arranged for the construction of a 30-foot section of the guideway by Peerless Welders, Inc. of St. Paul, Minnesota, to prove the manufacturability of its design, and arranged with Unico, Inc. of Racine, Wisconsin, for the construction and test of a full-scale model of its linear induction motor configuration. This test was on a 100-foot track at the Unico facility.

The company asserts that preliminary design of the critical elements of TAXI 2000 has been completed (as well as considerable work toward final design and procurement), and it is ready to commit to final design and construction of a “breadboard” TAXI 2000 system, including several types of guideway, stations, vehicles, and fare collection equipment, at a test and demonstration facility.

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[21] Appendix B references several sources of information about TAXI 2000.

The committee received a description (including detailed budget) of a 16-month “Phase I, Design and Breadboard Testing” program. The committee also received a number of technical documents from the company, and references to many others. Some of the more important subjects that these covered were:

- Capacity (maximum flow on lines, maximum flow through stations, maximum f low in networks, maximum throughput of a multiple-berth station, minimum headway, recycling of empty vehicles),
- Command, Control and Communication (block diagram for system control, block diagram for vehicle control, congestion management and control, empty vehicle management and control, failed vehicle control and pushing, failure management and control, inter-vehicle spacing control, merge synchronization control, speed profile control, switch logic control),
- Failure management (minimization of the probabilities of failure, procedures in case of failure)
- Guideway and stations (calculation of the coordinates and orientation of the guideway through off line stations, curves, hills and straight sections; also, the operation of a station of arbitrary size in the presence of randomly distributed flow rates of vehicles and passengers)
- Linear induction motor (design theory, design complexity and maintainability and reliability, all-weather operation, effects on system capacity, energy use, noise, safety and liability, tradeoff between linear and rotary propulsion, visual impact)
- Personal security (no strangers in vehicles, station platform surveillance, TV monitors, two-way voice communication, vehicle stop button)
- Power supply (power requirements and means of meeting them, wayside transmission line system)
- System safety (automated pushing, crash survivability, emergency procedures, failure control, fire prevention)
- Vandalism (deployment and use of attendants, identification of vandals, psychological counter-efforts, surveillance)

Vehicle (simulation of the yaw, roll and sidewise motion of a vehicle passing through a guideway switch section under varying conditions of vehicle weight, tire spring constants, physical dimensions, lateral wind, passenger weight and passenger offset; also, simulation of the motion of the vehicle on-board switch arm)

What TAXI 2000 claims, in essence, is the eventual ability to build and operate a safe and reliable transit system that in its fullest application will consist of thousands of small cars without drivers, offering individualized service while running on a narrow, lightweight track, mostly aboveground. The driverless car will pick up passengers at an off line station, which will be largely automated for selling tickets and informing passengers. Some stations may have attendants to advise and help passengers, but most will probably not. The car will carry its passengers direct to their destination station, bypassing intervening stations (each of which would be off line)

If PRT is used in some heavy-use urban transit applications, it will need capacity to carry as many as several thousand passengers per hour on a particular guideway lane during peak travel periods. To achieve such high passenger capacities for applications that require them (many do not), the many small PRT vehicles will have to run with average spacing (i.e., “headway”) of only one second or less between the leading and trailing car -sometimes with average spacing of even less than one second where extremely high capacities are needed. TAXI 2000 claims a design capable of average headways of one-half second with a theoretical capacity of over 7,200 vehicles per hour per lane.

We do not know whether TAXI 2000 can achieve its high capacity goals; this has to be demonstrated at test and demonstration facilities. The company’s analytical work seems to be of high professional quality that has considered the main technical problems which one will encounter in designing and building a PRT system with this capacity. State-of-the-art technology should be sufficient for the construction of a “breadboard” system, as TAXI 2000 proposes, to test and demonstrate capacity, considering the rapid advances in technology of the past decade.

Of special importance for high-capacity PRT, when needed, has been the advancement in design and construction of solid-state power technology, without which close-headways for vehicles, especially those using electric linear motors, may not be feasible.

Most applications, however, will not require high capacities. Most needs may be satisfied with average headways of three seconds or more. The first commercial PRT systems built will probably be at sites allowing longer average headways, to decrease risks of problems or possible failure.

The Committee saw engineering drawings of the TAXI 2000 guideway and also a scale model. It is an interesting design that appears to minimize possible snow and ice interference with vehicle operation. It probably also eliminates any need for guideway heating and its associated high maintenance costs for ice and snow removal. Of built-up truss construction, the guideway would appear to be a relatively simple structure to manufacture and erect, as well as to maintain during operations. It allows the running surfaces, which are protected from the elements, to be adjusted easily (if necessary) to improve ride quality. One important feature is the absence of switches in the guideway. All switching is accomplished by a switching device located on the vehicle.

Communications and power supply cabling is enclosed within the guideway structure, also protected from the elements. The guideway has exterior cover panels that can be easily removed for internal access to maintain the cabling and the running surfaces for the vehicle. Most maintenance and repair is feasible without disturbance of vehicle operations. All guideway elements appear to be state-of-the-art of relatively simple design.

TAXI 2000 says that all components of its vehicle are state-of-the-art and many are available off-the-shelf. We have no reason to doubt this assertion, based on our professional knowledge and the information received thus far about the vehicle. The Committee saw a detailed design of the chassis of the vehicle. The company states that it has found one or more suppliers for each of its components. It has, in addition, prepared a specification and cost analysis of the vehicle body but has not yet initiated a detailed design because the conversion of this specification into a detailed design poses no unusual problems, the company asserts, that would justify the expense of final design before the next stage of development has begun. The Committee saw an engineering drawing of the switch, which is an on-board patented device. There appears to be no unusual component technology in it.

We agree with TAXI 2000’s assertion that significant advances have occurred in the knowledge of electric linear motors and motor controllers. The proposed application of these on a TAXI 2000 vehicle is well within the state-of-the-art. Both the types of motors and the types of controllers that the company proposes to use are fully tested devices whose properties are well known today. Other elements of the vehicle, as well as we can determine at this point, are commercially available.

3.1.5 Conclusions As To The Technical Feasibility Of PRT

1. Research and development work on PRT during nearly four decades has created the foundation for current development of PRT systems that can rely on state-of-the-art and mostly off-the-shelf components. This past R&D has provided theories and other “tools” to enable PRT developers today to design and build systems that have a high probability of working as claimed.

2. Much of the rapid advancement in several fields of technology during the past decade or more is directly applicable to PRT. Important advancements have occurred, and are still occurring in: (a) automated control, (b) lightweight structures and fire-resistent materials for vehicles, guideways, and stations, (c) fare collection and passenger information, (d) vehicle suspension, propulsion and braking, (e) computer-aided design and manufacturing techniques, and (f) assurance of reliability and service dependability.

3. The committee thinks that a PRT system is technically feasible; that is, that a PRT system can be brought to the urban market within a reasonable time (depending upon the resources committed to further development), using state-of-the-art technology for each required component of the system -- technology that does not require further research and the components of which can be procured mostly of f-the-shelf.

4. A market-ready PRT system does not exist at this moment. TAXI 2000 is prepared technically to move forward immediately with the development of PRT at a test site (subject to the availability of funds). Cabintaxi was a market-ready PRT system in 1980, based on development completed at that time in West Germany. Cabintaxi Corporation says that it could bring that PRT system to the market within a relatively short time after updating its control system. The necessary technical and financial resources would have to be assembled by the company before this market readiness could be achieved.

5. Further development of either TAXI 2000 or Cabintaxi is necessary, even though the components used in these PRT systems are thought to be state-of-the-art. The updating of Cabintaxi and, for both Cabintaxi and TAXI 2000, the successful integration of current technology into a sale, cost-effective and smoothly-functioning PRT system can be proven satisfactorily to the various interested parties only through development and demonstration.

6. PRT can probably be developed with a variety of designs; those that we have identified as being active today are only a few that might be undertaken. During our investigations we discovered several interesting technology concepts in the history of PRT. Some of these ideas focus on the critical need to reduce the size and cost of guideways and stations. Others attempt to achieve extremely small turning radii. Such ideas should be resurrected and examined during further study of PRT.

3.2 Economic Feasibility of PRT

There is more to the economic prospect of PRT than simply how much a PRT system would cost to build and operate, especially if compared to conventional mass transit systems. We concentrate on direct costs in this report but a future evaluation of PRT should give high priority to estimating revenues, as well as indirect costs and benefits, that PRT systems might generate. This kind of analysis would allow one to arrive at an overall cost-benefit comparison of PRT with other kinds of transit systems.

There is an important reason for this suggestion. PRT service should be much more attractive to potential passengers than most conventional mass transit service today; consequently it should generate more revenue than conventional transit services for equivalent capital and operating costs. The service improvements that PRT is supposed to offer are described in Chapter 2. If significantly higher revenues and the claimed low costs of PRT should both prove to be valid forecasts, the economics of PRT services could become much better than most conventional mass transit.

3.2.1 Methods for Comparing PRT with Alternative Transit Systems

A comparison of costs and benefits, of all kinds and for all parties, is ultimately the most important measure of the value of a transportation system. “Cost-benefit” methodology attempts to compare the total costs and benefits of transit alternatives that are being considered for a particular application. It is sometimes an exceedingly valuable tool even though not the sole measure of the relative merits of alternatives. One of its weaknesses is the difficulty, often considerable, of identifying and estimating all the relevant costs and benefits in ways acceptable to everyone. This is the case, for example, in trying to measure the benefits of convenience or service accessibility, or of trying to measure the environmental impact costs of aboveground guideways. Other methods of comparing alternatives, therefore, are often more readily adopted. One of these methods is “cost-effectiveness.”

Cost-effectiveness methodology is frequently used in comparing transit alternatives. Perhaps the most satisfying cost-effectiveness ratio technically is the life-cycle cost per passenger-mile of the alternatives under consideration that provide the same or closely comparable services. Using this ratio, one tries to select the transit system that has the lowest life-cycle cost per passenger-mile, if the system satisfies the stipulated requirements for performance and service, safety, dependability and environmental impacts.[22]

A cost-effectiveness ratio that is less satisfying technically but more widely used presently is the life-cycle cost per added rider, which is a measure of marginal cost-effectiveness. It fails to consider trip length (i.e., miles) adequately, a deficiency, but has the merit of simplicity and being more understandable to many persons outside the community of transit planners. Either index is vastly better than other ways of evaluating alternatives, such as comparing total costs of the alternative systems or their costs per mile of guideway. And yet, comparing total costs or per-

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[22] A passenger-mile is one passenger carried one mile. If, for example, the annualized cost of a transit system is X dollars, and it carries Y passenger-miles in a year, its cost per passenger mile is X divided by Y. The number of passenger-miles is usually estimated, at least in the United States, by relying on data collected through statistical sampling methods prescribed by the Urban Mass Transportation Administration as a condition for receiving Federal financial assistance.

mile guideway costs can be useful as a starting point to put a transit decision problem in perspective. It helps to screen out obvious misfits.

The Urban Mass Transportation Administration (UNTA) in recent years has stressed the marginal cost-effectiveness ratio of “life-cyle cost per added rider” as the most significant basis for alternatives analysis. UNTA adds the estimated annualized capital dollars to build the complete system and the estimated annual operating and maintenance dollars to run the system.[23] This total is then reduced by the farebox revenue and by the estimated dollar value of annual travel time savings to existing riders. The remainder is divided by the number of new riders that the proposed new transit system or upgraded transit system is forecast to carry.

A recent example of this type of calculation generated a ratio of between $6.90 and $7.25 per new rider for a proposed mass transit system being studied for Phoenix, Arizona.[24] The choices ranged from busways (i.e., buses operating mostly on dedicated roadways) to light rail transit to non-PRT APMs. Heavy rail was not studied because it was considered to be excessively costly for Phoenix. PRT was not studied because a commercial PRT system is not available. Local or arterial bus options (i.e., on ordinary roadways in mixed traffic) were also not included in the comparison, which was an evaluation only of guideway alternatives.

Interestingly, as these figures reveal, there was not a wide variance between these alternatives even though traditional ways of discussing costs would have led one to think that there would be important differences. For example, the capital cost for an at-grade busway was estimated to be a low of about $5 million per mile compared to the high figure of about $50 million per mile for a fully grade-separated light rail or APM transit system. Yet when these per-mile costs were incorporated into a total comparison, the real cost differences among the choices were relatively small.

These findings are important because the ratio for PRT, relying on some of the general parametric cost data provided to the committee by TAXI 2000 (cited later), would be significantly lower than the ratios of the mass transit alternatives studied for Phoenix. These data indicate that PRT cost might be as little as one-quarter of the cost per added rider of the most economic guideway alternative evaluated in the study. Even if it were only one-half of the cost, the gain offered by PRT would still be notable.

Comparing costs per added rider can be a useful methodology when there is little transit service in an area and the goal is to increase service. It is less useful, however, in an area that already has considerable transit, such as a well-developed bus network. The methodologies of cost-benefit analysis or of a cost-effectiveness comparison of life-cycle cost per passenger mile are more

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[23] Capital dollars are typically annualized over the estimated life of the system; for example, 10 or 20 years for equipment, and 40 or 50 years for facilities.

[24] Phoenix Transit Systems Planning Study, for the Regional Public Transportation Authority, Phoenix, Arizona, by CUS Sirrine, Inc., draft of Task 7 Report, December 1987.

appropriate analysis tools. PRT will have to be justified either by having a more favorable cost-benefit ratio or by having a lower life-cycle cost per passenger mile.

Even if PRT costs prove to be higher than presently estimated, their exceedingly low range argue strongly that PRT deserves serious consideration. PRT in urban applications may cost three to four times less than current guideway mass transit per added rider served. If such low cost goals are achieved by PRT developers, PRT may even compete economically in some applications with existing bus mass transit, especially if one takes into consideration the much higher service quality of PRT, and PRT can even offer the prospect of profitable operations. In the following sections we consider whether PRT costs have been under-estimated by as much as two, three or four times, or whether PRT, in fact, offers the potential for major improvements in cost-benefit and cost-effectiveness.

3.2.2 Evaluation of Cost Claims Made for Taxi 2000

What are the cost claims made for TAXI 2000, how do they compare to the costs of mass transit (buses, rail, non-PRT APMs), and are these cost estimates plausible at this stage of TAXI 2000’s research and development?

Cabintaxi Corporation has not provided cost data to the committee for any planning studies that it may have performed. TAXI 2000 Corporation told the committee that its own limited financial base has not allowed the company to undertake major planning studies of specific sites where its PRT system might be suitable for urban transit service. As a consequence, the company does not have cost estimates for such urban applications, based on detailed knowledge of local conditions and requirements. However, the company was able to furnish several kinds of useful cost data to the committee.

Three kinds of cost data were furnished. One set of cost data is for a 1-mile demonstration system for the Loon Mountain Recreation Corporation, Lincoln, New Hampshire. These data are in Appendix C. The second set of data consists of two tables of performance and economic parameters for TAXI 2000 systems for various networks of one-way lines. These data are in Appendix D. The third set, which is in Appendix E comprise a computer program and examples of the output of this program. The company employs this program, a printout of which is included in the appendix, to generate performance and economic data for preliminary plans and cost estimates for a specific site.

The Loon Mountain data, which are for a ski resort, are for one lane mile of guideway (including a long span across a river), 3 offline stations, 35 vehicles, and 2 sets of automatic fare collection equipment per station, and a maintenance facility. All guideway is aboveground. Nominal vehicle speeds are 25 mph. Except for its small size and lack of interchanges in the stage 1 layout, the Loon Mountain configuration has many of the system elements that a larger PRT system might have. Moreover, it is conceived for a possible stage 2 addition that would increase network complexity. An architectural rendering of the TAXI 2000 system passing beside the Loon Mountain Conference Center and Country Club is shown in Figure 3.1.

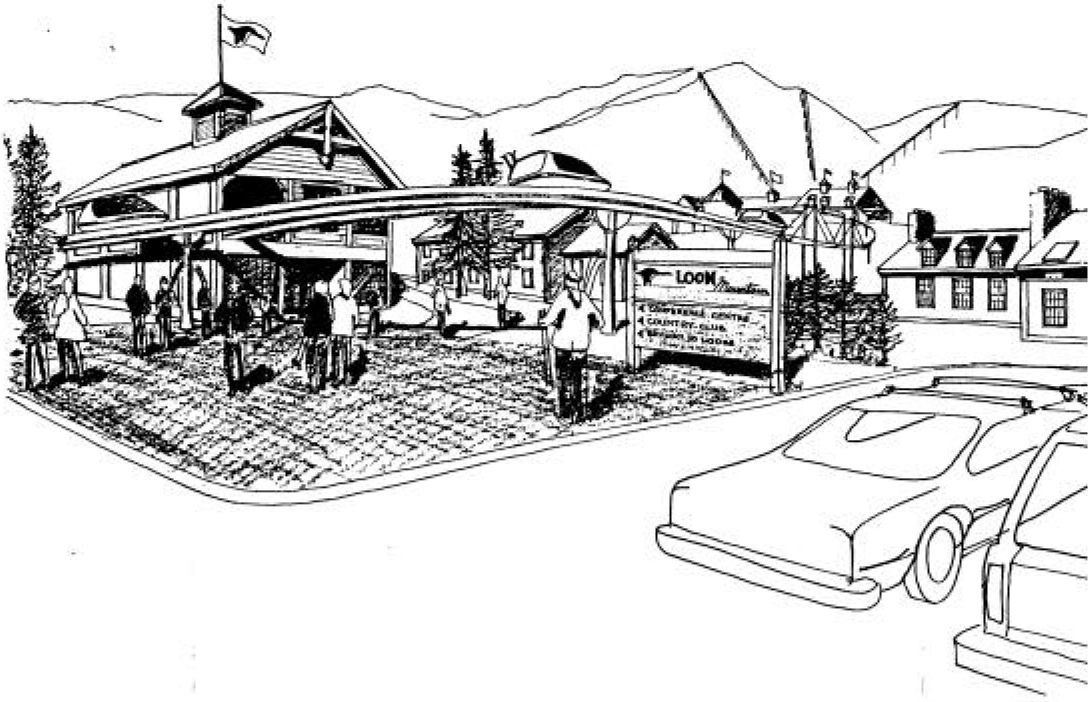

Figure 3.1: TAXI 2000 Loon Mountain Rendering

The estimated unit costs for Loon Mountain are both higher and lower than for an urban transit PRT system with complex networks. The estimated total capital cost for the 1 mile installation is $8,062,000, including overhead and profit margin. The estimated $61,000 per vehicle does not, the company claims, reflect what vehicles would be priced at in a larger system requiring hundreds and even thousands of vehicles. On the other hand, costs often encountered on urban projects, such as the cost for relocation of utilities, are not being incurred to any significant degree at Loon Mountain. Nor is any cost for land (right-of-way) included.

It should be noted, nevertheless, that the proposed installation at Loon Mountain includes a portion within a shopping center that has underground utilities. One reason that TAXI 2000 has incurred no significant cost for the relocation of utilities is that avoiding utilities, and thus their relocation costs, has been relatively easy for the TAXI 2000 system because of the small size of its guideway columns and footings. This suggests that TAXI 2000 may have an easier time than the large-scale structures of mass transit in coping with utilities and other features of urban streetscapes in major urban activity centers.

Operation and maintenance costs for the Loon Mountain system are estimated to be about $180,000 a year, assuming a 12-month operating period.[25] When these are added to the annualized cost of all capital expenditures, the estimated annual cost of Loon Mountain to the new owner is expected to be about $968,000.[26]

There are a number of reasons why PRT's costs may achieve this low level, but there also are a number of uncertainties in these cost forecasts. The following passages summarize the reasons, and give our comments on them:

3.2.2.1 Guideway Cost

The lower cost for PRT guideways per lane mile results from spreading the weight of passengers and equipment over many small vehicles rather than concentrating weight in a few large vehicles with high steel wheel loadings at a few small points on the guideway. A large proportion of the total capital cost of a transit system that uses a guideway is the guideway cost itself, and therefore this cost reduction can be of great significance.

The design for TAXI 2000's guideway, <u>if it can be proven during further R&D</u>. reveals an enormous reduction in weight when compared to guideways for conventional rail transit and first generation non-PRT APM systems. The weight for TAXI 2000's <u>fully-equipped</u> guideway (single lane) is estimated by the TAXI 2000 Corporation to be about 140 pounds per foot [210 kg per meter), compared to about 600 to 2,000 pounds per foot [900 to 3000 kg per meter] for a first generation non-PRT APH guideway, and an even greater weight for rail mass transit. Cabintaxi Corporation tells us that its over-and-under guideway, which carries two lanes on the same beam, would weigh in at about 400 pounds per foot [182 kg), and if this guideway were modified to carry only one lane, its weight per lane would be in the range of 150 to 200 pounds per foot [68 to 91 kg).

The TAXI 2000 guideway is only 36 x 36 inches [91 x 91 cm). All cables, running services and other accessories are enclosed within this structure. The structure is bolted to a tapered structural steel bracket which in turn is welded to an octangle tapered steel column 16 feet tall [4.8 m] from their footings. For a standard guideway span, these columns would be about 12 inches diameter [30 cm] at their top and about 24 inches diameter [60 cm] at their bottom. Somewhat sturdier columns would be required for non-standard longer guideway spans.

Weight and size reduction usually translates into cost reduction, even though not necessarily linearly, and therefore is of considerable importance. On the other hand, some regulatory authorities responsible for safety, concerned about the possible risks of lightweight structures in

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[25] The resort will function year-round for various recreation purposes, including skiing in the winter.

[26] Capital costs are annualized over 30 years for everything except the vehicles, which are annualized over 10 years, all at an assumed 7 percent interest rate

urban settings, may impose design standards that drive up weight and costs.[27] One or more of the following reasons might cause cost trouble for PRT.

- Guideways, in the web of real cities, tend to become more complex and heavier than predicted. Practical issues drive up costs, such as having to build long and non-standard spans to clear street intersections, driveways, building entrances, and obstructions, or having to place support columns in difficult (i.e., expensive) locations to avoid underground obstacles. TAXI 2000, the committee was told, has considered these issues and already prepared specifications and preliminary designs for several non-standard lengths.

- The construction of guideways and stations in real-world conditions must include costs for the relocation of underground and aboveground utilities. Placing footings along a street, for example, may require relocation of as many as a dozen utilities; e.g., residential power, telephone, TV, water, gas, sewage, street lights, traffic signals, signs and landscaping. As mentioned earlier with regard to the Loon Mountain project, a PRT system with small and light columns and footings and stations should have fewer relocation problems to solve.

- TAXI 2000 may not be allowed to use the most slender and light support columns and horizontal members of their present designs. Imposition of traditional construction and safety codes, applicable today to transit, may force an increase in the quantity of materials and associated costs. For this and other reasons, however, TAXI 2000 has designed a guideway that they say will continue to be safe (while being repaired after an accident) for the passage of vehicles even if a column is accidentally struck, damaged and unable to continue to provide support. Guideway deflection would increase only a few inches, the company says, with one column totally damaged and out of service. The design of the column provides for clean breakaway in the event of a strong impact.

- The design and construction of transit systems for urban environments inevitably becomes involved in political and other complexities that cause delays, generate project changes that are not always fully compensated, and thereby drive up overhead costs. These costs are usually anticipated by competent suppliers and consultants but sometimes underestimated (and sometimes even overestimated).

3.2.2.2 Station Cost

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[27] There are, it should be noted, other lightweight guideways in commercial use today, in the same weight range as the TAXI 2000 guideway; for example, the systems built by Universal

TAXI 2000 forecasts that use of many automated cars will reduce the cost of individual stations, compared to rail mass transit stations, because passengers will be able to board cars quickly of f line after arriving in the stations. This would diminish the need for the spacious “holding areas”, typical of conventional transit, for passengers waiting 5, 10, 15 or even more minutes. The stations would be smaller per passenger served than the stations of conventional rail transit or first generation non-PRT APMs. Some of the issues that inevitably arise are:

- TAXI 2000 stations should often be relatively small, but it is not clear whether this translates into lower costs per passenger served than the cost of non-PRT stations. Some non-PRT APH stations are quite small, being merely part of a building to which they provide transportation service. Some of these “stations” can hardly be called stations. The vehicle simply pauses on its track, opens its doors, and passengers leave or enter an adjoining pedestrian concourse, as with elevators.

  Under usual circumstances, nevertheless, (in comparison to rail mass transit), PRT stations should be small because they would not have to have large holding areas for many waiting passengers. Assuming that further development proves the technical feasibility of the passenger handling and vehicle loading principles of PRT, passengers would often be able to board a vehicle immediately upon arriving in a station but rarely with a wait of over 1 to 2 minutes. In addition, nonstop PRT service between origin and destination stations would eliminate the transfer delays that occur in other forms of transit except transfers between PRT and other transportation systems.

- An issue yet to be resolved is the number of vehicle berths that must be present in PRT stations to serve passenger demands of various volumes. If many berths are required, the savings in passenger handling space might be more than offset by a requirement for considerable space for small vehicle queuing and handling.

  Studies and simulations by TAXI 2000 predict that the number of vehicle berths required will be relatively small because of the rapid movement of vehicles in and out of the station — about 3 berths in the average station. These simulations appear to be of professional quality and are therefore convincing, but only further development, including realistic test track trials with average passengers, will enable the community of transit professionals to become convinced of these analytical forecasts by TAXI 2000.

- A typical TAXI 2000 station, with 3 berths for vehicles, fare collection and passenger information signs and equipment, an elevator rising from the street level to the platform, steps between the street and the platform, and a fully-enclosed passenger area to provide protection from the weather, would have the following approximate dimensions:

- from the groundlevel to the floor of the passenger platform:
  about 19 feet [5.8 m].
- from the floor of the passenger platform to the station top:
  about 10 feet [3 m].
- station area (in plan view): about 7 feet wide [2.1 m] by about 36 feet long [11 m]; with stations with less than three vehicle berths (or more) being shorter or longer.
- total width of the station, off line siding and nearby mainline guideway: about 19 feet [5.8 m]. (Actual width of each guideway would be 3 [91 cm] feet, with open space between the off line and mainline guideways, and between the off line guideway and the station platform. Guideway depth would also be 3 feet).

- Some stations might function adequately with only 1 or 2 berths and a few stations might need more than 3 berths, according to TAXI 2000.
- Costs are related to station size even though other factors are also important. One of the other factors is the high degree of automation that would characterize PRT stations (according to the description of TAXI 2000). This might produce labor savings within the station, but automation is not cheap, and it can incur considerable maintenance cost (including labor cost) related to the station. Even so, automation of fare collection and other passenger processing systems within stations is increasing in conventional transit and non-PRT APH services. This experience helps generate more reliable cost estimates for PRT.
- The aboveground (and underground) stations of PRT will require elevators or escalators — both types in some stations. The large number of PRT stations, compared to the much smaller number of aboveground or underground mass transit stations, would make this a significant capital and maintenance cost item for PRT. Escalators and elevators are notoriously demanding of maintenance, in spite of their general dependability. Earlier mass transit systems did not install either escalators or elevators, but all transit systems built today in countries having high standards for accessibility for the elderly or the handicapped must be “barrier-free”.

3.2.2.3 Vehicle Cost

The passenger cab of the 3-passenger vehicles of the TAXI 2000 concept is about 64 inches wide [163 cm] and 54 inches high [137 cm].

Figure 3.2 shows the concept TAXI 2000 vehicle. Figure 3.3 compares, in representational manner and plan view, some dimensional differences between PRT and other transit vehicles.

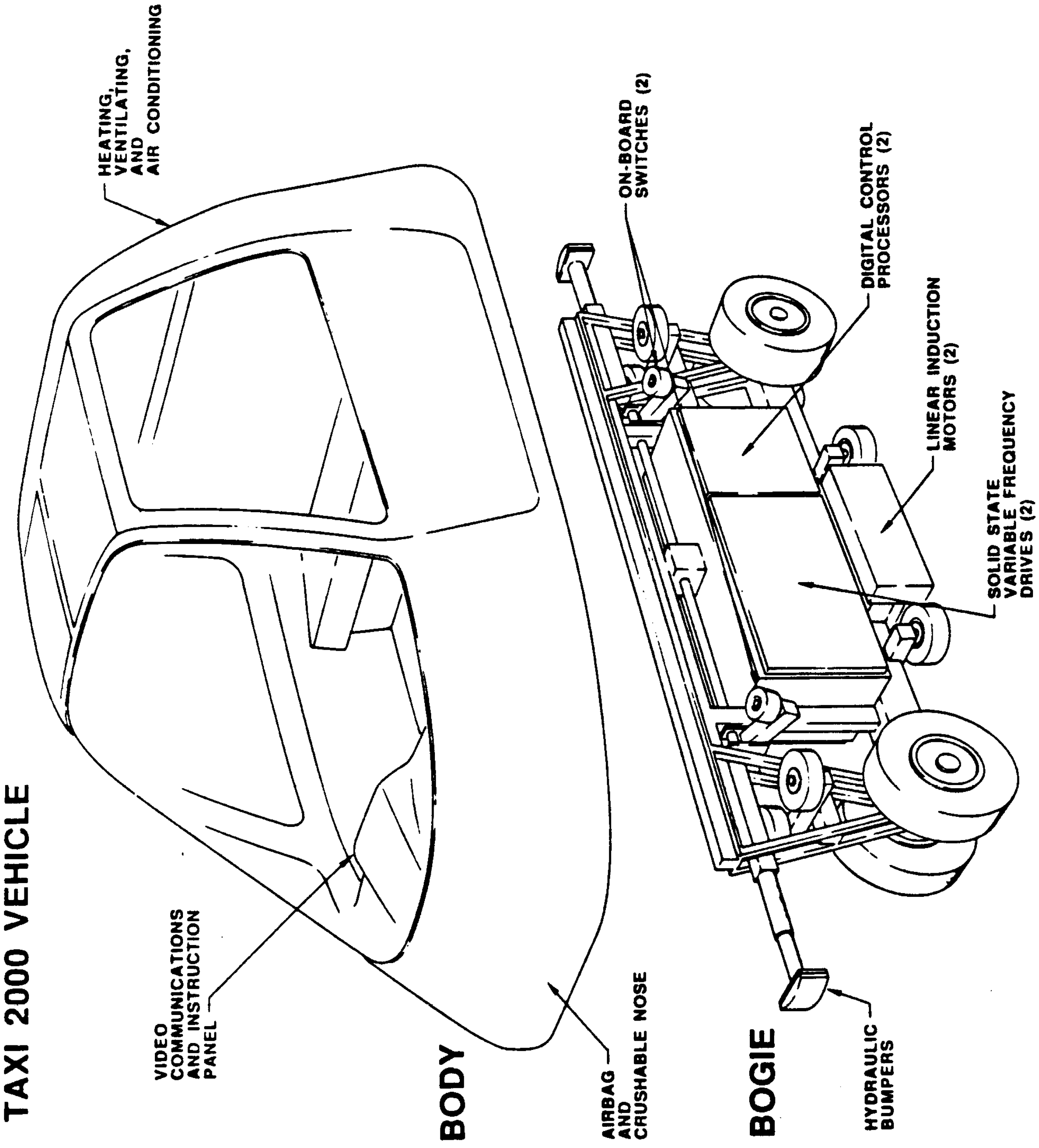
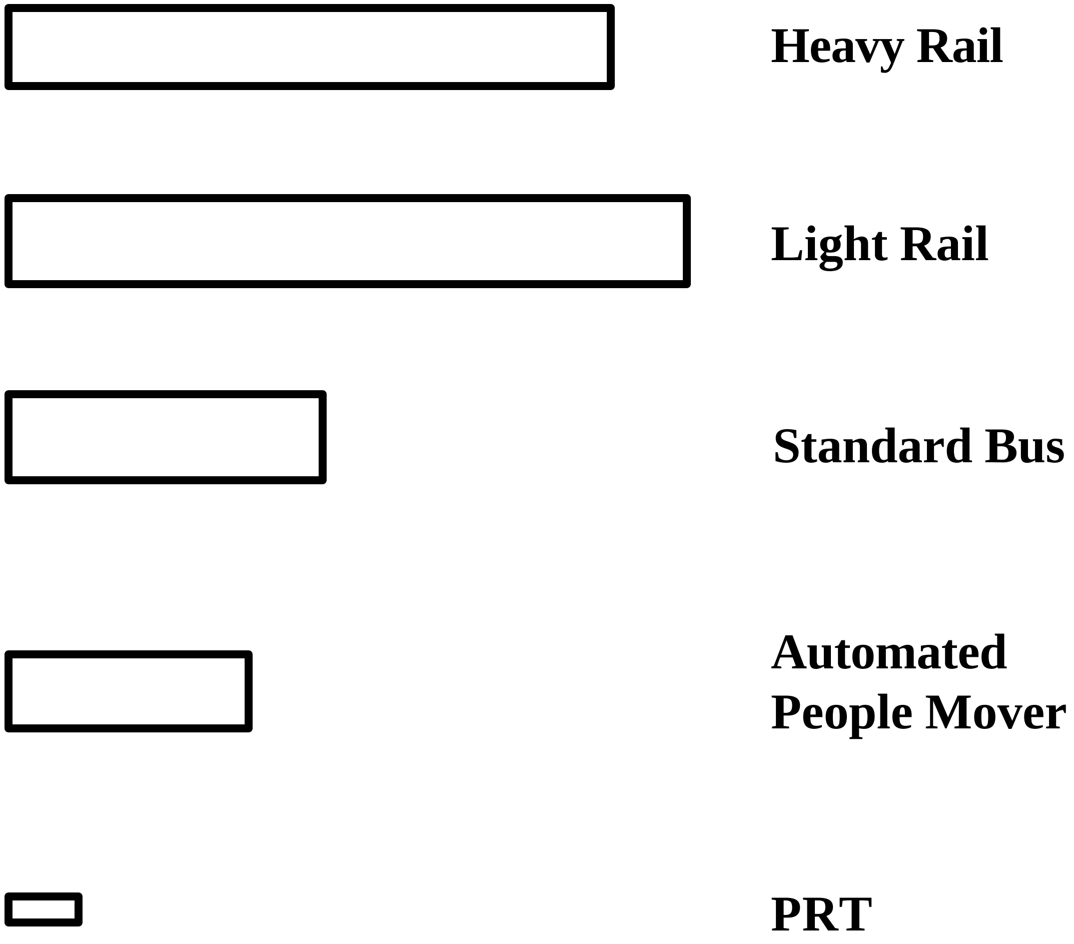


Figure 3.2: TAXI 2000 Vehicle

Comparison of Selected Transit Vehicles Cross Sections



Note: Vehicles are shown in block diagram, without aesthetic features or "streamlining" to avoid identification with a particular vehicle concept. Dimensions are average and do not represent either the smallest or the largest in their types.

`Figure 3.3: Representative Sizes of Transit Vehicles`

TAXI 2000 estimates that its vehicle costs, in Production quantities, will be approximately the same per pound or per passenger space provided as the costs of the larger (and heavier) vehicles of conventional rail transit and first generation non-PRT APM vehicles. This translates (not precisely) to something as low as $30,000 per PRT vehicle bought in large production quantities, compared to about $750,000 to $1,000,000 for the typical first generation non-PRT APMs, or about $1,000,000 to $1,500,000 for the conventional transit self-powered rail vehicle. The cost data in the appendices, which relate to the early years of PRT deployment with networks based on larger and larger vehicle quantities, show an average vehicle cost of $43,700 each.

For the first PRT systems sold, vehicle cost should be higher because of the small initial quantity of vehicles being purchased, as well as the “learning curve phenomenon” — which can mean that these early vehicles might cost as much as $75,000 or more per vehicle, although the Loon Mountain vehicles are estimated at $61,000 each. Initial small quantities of vehicles built would be more expensive than the cost of vehicles in production quantities. A PRT supplier would be faced with deciding whether to try to recover these initial high costs on the first PRT system installed, or to amortize a portion of those costs over subsequent (hopefully larger) contracts.

The committee has not seen either a detailed design of the TAXI 2000 vehicle or a prototype (which does not exist), although as noted earlier, the company says that it has produced a detailed design of the vehicle chassis (the crucial element), and a complete specification for the vehicle body. The conceptual design of the vehicle is impressively simple, giving rise to optimism that its cost can be held down. Yet those who assert that a 3-passenger PRT vehicle will cost several times as much as the eventual $25,000 to $30,000 predicted by TAXI 2000 Corporation are raising, obviously, a fundamental challenge to the cost forecasts for PRT, taking into consideration the large number of cars that a PRT system will need.

TAXI 2000’s estimated cost for vehicles will ultimately have to be demonstrated. Some of the arguments that have been presented historically for why small PRT vehicles may cost more are:

- small vehicles may require as complex subsystems of propulsion, braking, control and air conditioning as large vehicles. Even though these subsystems will be smaller in a small vehicle, this argument runs, costs may not drop as rapidly as the decrease in vehicle size or passenger capacity because experience with first generation non-PRT APM cars demonstrates that reducing vehicular costs in direct proportion to reductions in vehicle weight and passenger capacity is a challenge.

- small transit vehicles, although approximately the same size as automobiles, may tend to have higher costs than even expensive automobiles. Automobiles are mass-produced with many standardized components and for design lives of only a few years, but small transit vehicles will have to be produced in relatively limited quantities (at least in the beginning years) with a mixture of standardized and purpose-built components, and perhaps for longer design lives. Mass transit vehicles are typically designed for 30 years[1] but often run many years longer. This fact does not necessarily require PRT vehicles to have such long design lives, but buyers of PRT vehicles may insist on longer lives than PRT manufacturers prefer to offer. We note in this connection, however, that the Loon Mountain cost estimate is based on a 10-year amortization for vehicles.

- the reliability and safety of a transit vehicle is expected to be significantly higher than the reliability and safety of an automobile. This, too, tends to drive up the cost of any vehicle used for transit service.

The Committee notes that even though it is conceivable that vehicle cost per passenger space provided may increase as transit vehicles become smaller, this has not been the case thus far with mass transit vehicles. Generally speaking, guideway transit vehicles that are in common use today have approximately the same cost per unit of capacity provided, regardless of size. Cost is also about the same for equivalent vehicle weight.

The Committee also notes that the TAXI 2000 vehicle has considerably fewer parts than automobiles. Moreover, the TAXI 2000 estimates, in the absence of cost criticisms based on up-to-date knowledge and analysis of the present vehicle concept, Should be taken seriously. TAXI 2000 has built up its costs from design detail. This methodology deserves respect, especially when the company has been willing, in addition, to expose a considerable amount of this detail to the professional community of transportation specialists.

A PRT vehicle will work in a closely-controlled environment, compared to an automobile - no potholes, no rubber-burning starts, no heavy braking. Its environment should be more benign than the operating environment of mass transit vehicles. In addition, unlike large mass transit vehicles, PRT vehicles can be quickly pulled from service for a few moments of minor and corrective maintenance.

There is no inherent reason why PRT vehicles should have to be designed for at least 30 years. Studies using cost-effectiveness and value engineering methods may show that a shorter design life is reasonable. Design life should also, of course, be influenced by the prevailing financial discount rates and the pace of technological obsolescence. We should not too quickly apply current rail mass transit standards to personal transit technology. Buses, for example, are not designed for 30-year lives.

Professionals who have expressed skepticism about past estimates of PRT vehicular costs, perhaps with justification in some instances, may not have updated themselves on the most recent designs and cost estimates of TAXI 2000. We urge them to examine this latest design and estimate its costs. They should be careful not to exaggerate the costs that must be built into PRT vehicles, even while insisting they must be safe, comfortable, durable, reliable and attractive.

The large number of vehicles used in a PRT system makes it especially important to resolve vehicle cost uncertainty as early as possible. The next stage of development should give particular attention to the validation of vehicle cost.

3.2.2.4 Right-of-way, Utility Relocation and Other Costs

It appears that the costs for acquiring land and relocating underground and aboveground utilities will be minimized by reliance on small stations, light guideways with narrow clearance requirements, and slim and tapered support posts whose footings occupy little ground and subsurface.

Even so, TAXI 2000's current cost estimates do not fully include the sometimes high and unpredictable costs for relocation of utilities (e.g., water mains, electric and communications lines). There was little reason to be concerned about them for the Loon Mountain project. The more general parametric data, by its nature, lacks site specificity. For this reason alone, the ultimate cost of PRT may be higher than portrayed by the cost estimates referenced in this report.

It is also conceivable that TAXI 2000, in spite of trying, has not fully accounted for the different costs that may result from variations in lengths of guideway spans that may be required along urban roadways and at intersections and driveways.

The maintenance process for a PRT system may be less costly than for mass transit, per passenger mile served, because of the mass-produced quickly-replaceable components of which PRT will be constructed, and also because of the smaller scale of the repair facilities for vehicles and other equipment. It is difficult to predict maintenance cost now, nevertheless, until the final configuration of TAXI 2000 emerges from development, test and demonstration.

All these costs, admittedly, (right-of-way, utilities relocation, maintenance) are among the more difficult to forecast, and it is prudent at this stage of PRT development to overestimate rather than to underestimate them. TAXI 2000 corporate management is aware of these cost factors and the necessity of including them in site-specific studies.

3.2.3 Conclusions As To The Economic Feasibility Of PRT

Our conclusions, based on the information submitted by TAXI 2000 and our knowledge of the costs of conventional mass transit systems and non-PRT APMs, are:

1. The TAXI 2000 Corporation has given cost reduction a high priority and has made a serious attempt, considering the stage of development of its PRT system, to identify the major sources of its costs and to attribute these costs to their sources. The company's cost estimation methodology, based on a detailed cost build-up from equipment design, is a preferred methodology at this stage of R&D. It inspires greater confidence than a cost

extrapolation methodology based merely on analogs, which is a methodology better applicable to an earlier stage of R&D.

2. Correspondence received from two reputable individuals, Richard R. Radnor and M.W. Loeff 1, both involved with organizations that have recently completed technical reviews and costing of major components of the TAXI 2000 concept is encouraging. See Appendix F for copies of such correspondence. One says that "specifications on [many of] the major components of the TAXI 2000 systems [were] submitted... to industrial firms for bids and estimated.. .through [our] cost estimating department".[28]

3. TAXI 2000's engineering designers and cost estimators appear to have profited from the past two decades of experience with the design, installation and operation of first generation non-PRT APMs. There have been noteworthy examples of serious cost overuns for such APMs during these decades due to failures to anticipate potential problems, especially for those non-PRT APMs built to provide regular urban transit service.

4. The cost data presented by TAXI 2000 indicate that if their development program is successful, a significant advance will have occurred in the cost-effectiveness of guideway transit, measured in life-cycle cost per passenger mile or by other measures common to the transit industry. It will be feasible to build and operate a guideway transit system that offers a quality of service significantly better than is usually provided by guideway transit, and accomplish this at a significantly lower annualized cost.

   In total, cost reductions that may be achieved with TAXI 2000 will mean that a lane of fully-equipped PRT (including vehicles) can be furnished, depending upon design, for between $5 and $10 million per mile [1.6 kin] instead of the $7.5 to $20 million per mile (or even higher) for light rail mass transit, or $15 to $25 million per mile for first generation non-PRT APMs or $25 to $50 million per mile (or even higher) for heavy rail mass transit. Cost-effectiveness comparisons of life-cycle cost per passenger-mile or per additional rider should be equally favorable.

5. A final point that deserves mention, which is as true for mass transit as for personalized transit, is that the individual locality (or other buyer of a transit system) can have a substantial effect on the magnitude and characteristics of costs incurred by a new transit system. Customers should avoid decisions and actions that unnecessarily impose added costs on PRT.

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[28] Letter from M.W. Loeff 1, Vice President—Projects, Davy McKee Corporation, Chicago, Illinois, to Dr. J.A. Kieffer, Secretary of ATRA, September 23, 1988)

> The new heavy rail system in the Washington D.C. metropolitan area has been unusually expensive because of decisions to make it architecturally beautiful, minimally intrusive, and extremely comfortable and convenient (e.g., spacious and magnificent underground stations; total station and car air-conditioning; extremely quiet; considerable trackage underground).
>
> In contrast, the new light rail system in San Diego, California, was unusually inexpensive because of a strong commitment to low-cost solutions (as well as because of some cost-reducing factors that were particular to that city)
>
> Future buyers of PRT systems should take care not to impose higher costs on PRT that result from standards or practices used in mass transit which are not relevant to PRT. In its basic configuration, PRT will be a significant advance if it succeeds during further development. It should not be encumbered with unnecessary requirements, especially now, that boost costs.

3.3 Public Acceptance Feasibility

One set of public acceptance issues of PRT relate to its potential environmental impact; another set to its potential safety and security for passengers. The main environmental concern is probably the visibility of aboveground structures of PRT, but anxiety about possible noise may be a problem, especially for guideways near residences.

If noise becomes a major issue, it will occur only because PRT developers have failed to do what they can do — to reduce noise levels sufficiently and to convince the public that noise will be negligible. PRT will be far quieter, for example, than diesel buses whose powerful engines (with many moving parts) and air brake systems, which are required to propel and stop a large vehicle, are frequent contributors to urban noise.

Public worries about safety and security, already an issue in today’s mass transit, may be intensified by highly automated PRT, with its driverless cars (sometimes running closely-spaced) and stations that may not be attended except at a few heavily-used locations.

3.3.1 Environmental Impacts

PRT guideways, like other transit track, can be built underground, at or near groundlevel, or aboveground. All three locations may be used to satisfy travel and community needs and preferences.

Underground construction of PRT systems, when required by circumstances, will be less disruptive to communities than subway construction for mass transit. The technique of “cut-and-cover" construction under main streets for conventional mass transit stations, and even for the guideways, has sometimes seriously inconvenienced community life and imposed heavy financial burdens on local businesses during the lengthy construction period. In contrast, tunneling (and only occasional cut-and-cover work) for the guideways and stations of PRT, because of their small scale, will not disturb the surface significantly or for long times when PRT needs to be placed underground.

Groundlevel guideways for PRT may be used rarely; only when rights-of-way can be obtained at low cost and fencing will not create unacceptable barriers within an urban area. With many automatic cars in operation, PRT guideways would have to be fenced well to exclude accidental or intentional intruders, arguing against most groundlevel installations, at least for the guideways.

There are several differences between PRT guideways and non-PRT APH guideways that would affect how the public might react to aboveground PRT guideways. Figure 3.4 depicts, in representational manner, the dimensional differences between the cross-sections of PRT guideways and the guideways of non-PRT APMS and of rail.

Figure 3.4: PRT Guideway Compared to Non-PRT and Rail Transit Guideways

The critical differences between PRT and non-PRT guideways and stations, with respect to their environmental impacts, are:

- First generation APMs use relatively large cars and require large guideways and stations, accumulating relatively large crowds of waiting passengers, similar to conventional rapid transit. In contrast, PRT guideways can be narrow (TAXI 2000 is three feet wide and three feet deep [914mm x 914mm]; some PRT concepts are even smaller), and may be perceived as relatively unobtrusive. Stations are similarly small.

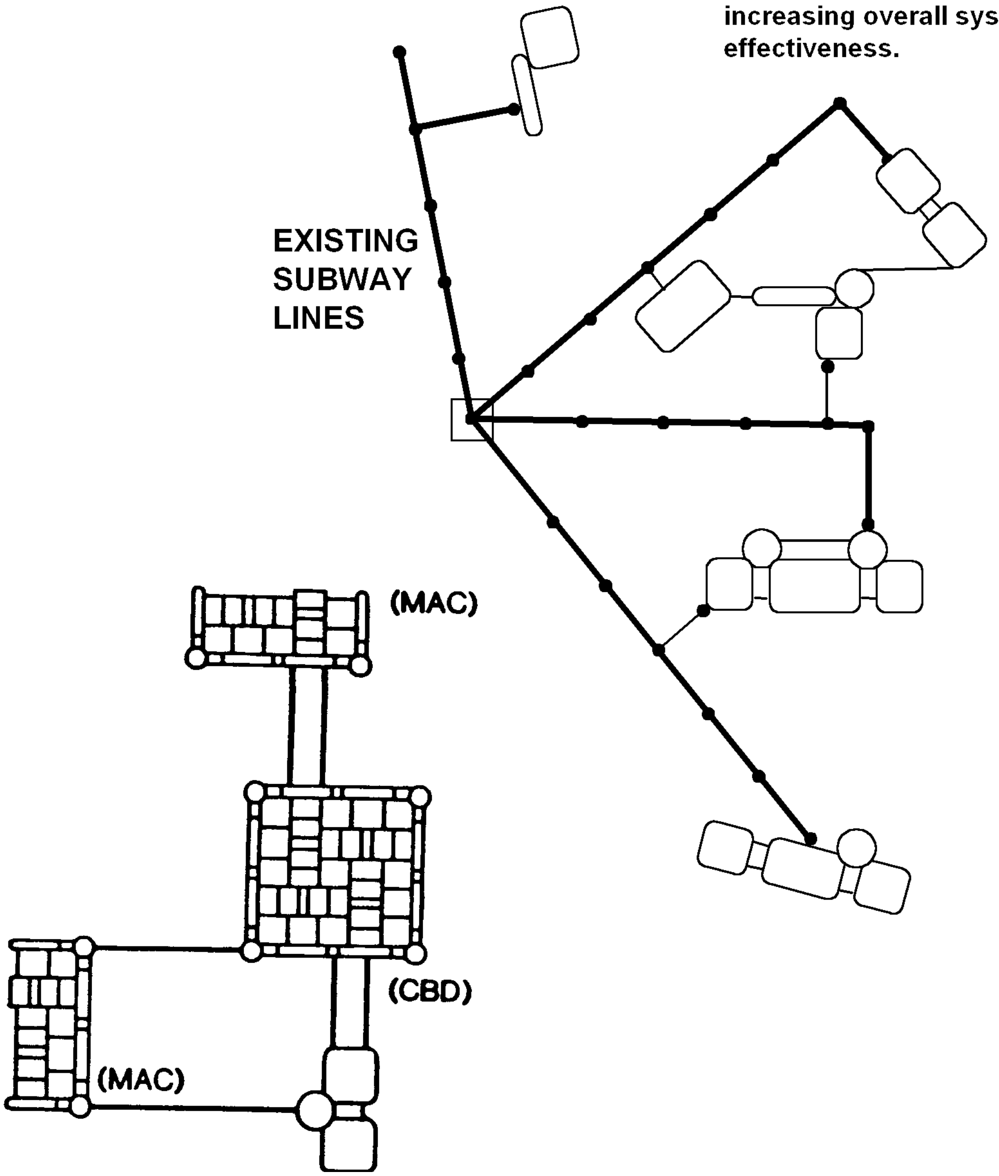
- On the other hand, the guideways and stations of non-PRT APMs are spaced relatively far apart, like rail transit track. Spacing them near each other imposes a heavy financial burden because their capital costs are high, and close station spacing reduces the average speed of their vehicles. In addition, the location of mass transit guideways has tended to be in corridors already impacted by other kinds of structures, or even underground. Non-PRT guideways, consequently, have not always created the strong negative public reactions that one might think they would. PRT structures, even though much smaller, would be closely spaced and often erected where guideways have not previously been in view. They would , in addition, penetrate residential areas more than non-PRT APMs or rail transit have done, although probably no more than local bus services.

Most bus stop shelters on routes are considerably smaller than PRT stations would be. At major transfer points, however, bus stops sometimes occupy considerable land; for example, at terminals or at park-and-ride or kiss-and-ride transfer points with rail mass transit.

The roadway occupied by buses, which is usually at grade, is several times as wide as the most narrow PRT guideways but is normally shared with other vehicles, both publically-owned and privately-owned, under increasingly-congested conditions. Intensively-used roadways during peak periods are sometimes dedicated to buses, and special busways are even occasionally built, but buses eventually re-enter the traffic mix on regular roadways. On balance, nevertheless, most bus routes and shelters are not as obstrusive visually as PRT would be. Buses have, however, other environmental disadvantages; for example, relatively high noise, exhaust emissions, and unpleasant odors.

Assuming that PRT guideways would usually be aboveground, a key question is whether the public would allow them to be built. The TAXI 2000 guideways, if seen from above, would roughly resemble grids of one-way lanes. Interchanges at the intersections would allow approaching vehicles to continue straight ahead or turn and go of f in another direction. Stations are between (not at) intersections, off the main lines.

In a hypothetical pure grid, which would rarely exist in practice, guideways would be spaced equidistance from each other, and so would stations. Probably an ideal spacing, from the point of view solely of service quality, would be approximately a quarter mile between guideways as well as stations, which would require a maximum walk of one-eighth mile to reach a station. For economic reasons, spacing might more typically be about one-half mile, requiring a maximum quarter-mile walk to reach stations. In actual communities, of course, spacing would be uneven, as guideways adapted to land contours, existing roadways and traffic routes, prevailing development and many other site-specific features. Figure 3.5 displays, in line diagram, several kinds of hypothetical networks of TAXI 2000 to serve areas of different sizes for various kinds of travel demands. It also shows has a PRT network might be connected to existing rail mass transit stations to increase the overall service furnished by transit.



For cities with existing rail transit, PRT provides access to stations thus increasing overall system effectiveness.

For citieis without transit, initially limited but useful systems in the Central Business District (CBD) can be expanded and interconnected with small systems in Major Activity Centers (MAC). Gradual expansion of both provides fill-in and area-wide transit.

Figure 3.5: Hypothetical PRT Networks for Primary or Supplemental Services

Guideway spacing for a specific site will result from studies that compare alternative spacings of lines and stations, taking into consideration costs, patronage, benefits, environmental impacts and other considerations. If quarter-mile spacing, for example, is forecast to generate increased revenue that would offset (or more than offset) the increased cost of the PRT system, closer spacing might be adopted, all other effects being equal (which they rarely are). The spacing issue can only be decided in a specific context.

If guideways and stations are spaced at about half—mile intervals, giving passengers a maximum walk of about one-quarter of a mile to reach a station [roughly 1320 feet or 400 meters], this would be no more than about 5 minutes for an average healthy person. The average walking distance for most passengers would be less. Buses running on streets and highways that are "arterials" or "main streets," with frequent "stops", are within this walk range to their potential riders. It may be reasonable to assume that PRT, if it proves itself, could replace many on—street bus routes, with its guideways aboveground over the same streets or sidewalks.

Some of these guideways might run near office and apartment windows at second-story level. Would the public oppose them, or the insertion of aboveground guideways and stations into or near low-rise residential areas? Aboveground PRT structures would be smaller than mass transit structures. Would such designs and smaller sizes be acceptable to a public that desires to obtain high quality transit service, even if it preferred not to have aboveground structures?

Our opinion, based on public attitudes toward conventional mass transit structures recently built, is that potential public opposition to aboveground structures may be the most difficult hurdle for PRT to overcome, even though PRT structures are quite small. PRT builders must be astute in coping with this potential problem.

Well-conceived PRT designs, taking advantage of PRT's small scale, may help avoid public opposition, but excellent public relations programs will be needed before public positions harden. These programs will have to include visits for a representative cross—section of government officials and the public to see real PRT guideways and vehicles at demonstration sites. Accurate architectural sketches will also have to be prepared, depicting PRT structures along actual streets. PRT's service and environmental advantages will have to be held constantly before the public during the debate on aboveground structures.

One important advantage that PRT guideways would have for gaining public support for PRT would be the speed and relative ease with which (we think) they could be erected. This would minimize disruption of the community and businesses. Whether rapid installation would always be practical in actual communities remains to be proven, but perhaps it would be at **many** sites, especially outside densely—developed locations.

Even if the public has not always been pleased with the much larger and more obtrusive guideways of non-PRT mass transit, or the even larger overpasses and ramps used for roads, it often has accepted them over time. PRT, offering improved transit service and less obtrusive guideways, may arouse less public opposition. As PRT develops, public reactions to aboveground Btructures should be monitored closely. PRT designs should be modified as much as possible to accommodate to public concerns.

Public attitudes, it should be noted, are not static. The worsening congestion and lengthening trip times of auto travel may well lead the public to consider alternatives that they earlier have rejected. The public accepts relatively unattractive urban freeways and wide arterial streets, large parking lots, parking garages, and cars parked on both sides of urban streets, largely because of the essential function that automobiles perform. By reducing auto needs and freeing up urban land, and by performing an important urban transportation function, PRT guideways and stations may prove more acceptable than now imagined by some persons. Moreover, PRT guideways, like other transit structures, can be designed to be assets to the urban landscape.

3.3.2 System Safety and Passenger Security

Several groups and organizations have stakes in system safety and passenger security, in addition to passengers. Non-riders are concerned, as are workers on the system. Especially concerned are the insurance companies, investors, consulting firms, and construction companies that have substantial stakes in transit planning, design, construction and operation. If PRT developers fail to satisfy the concerns of these important groups about both system safety and passenger security, PRT will not come alive.

TAXI 2000 Corporation has placed a high priority on assuring system safety and passenger security. Earlier PRT developers such as Cabintaxi also devoted serious attention to system safety and passenger security.

3.3.2.1 Evaluation of TAXI 2000 Passenger Security

There may or may not be a rising rate in the types of vandalism and crime that affect the security of passengers using transit, but there has been a worsening problem with vandalism of transit vehicles and stations, and occasional shocking incidents of crime. The committee is aware of rising anxiety in at least some communities about transit—related vandalism and crime. Passenger security must be regarded, therefore, as a crucial issue in the development of a new transit technology.

A new transit technology based on the idea of passengers riding in vehicles without drivers and using unattended stations accentuates the vandalism and crime issues, in spite of the fact that current crime is often committed on **mass** transit in the most crowded places (on platforms and escalator, and inside vehicles) where the violator can attack and then disappear quickly in the resulting confusion.

Several security features are inherent in PRT, or are being designed into TAXI 2000, to attempt to ensure a high standard of personal security. Some examples are:

- small and simple station platforms, well-lighted, with clear lines of sight and no places to hide, allow the area to be monitored by closed-circuit TV from central control rooms;

- a right to ride alone or with persons of one's choice, plus a stop button in a vehicle that permits a passenger to order the vehicle to turn-in and stop at the next station (usually only a minute or two away);

- negligible required wait time in stations (allowing passengers to board vehicles and depart almost immediately, and calling attention to loiterers who remain too long in stations);

- two-way emergency communication with panic buttons for passenger use in stations and vehicles (when pressed on a vehicle, a panic button causes a locked vehicle to proceed directly to the nearest station where the police have been alerted and are waiting to unlock the vehicle and assist the passenger);

- vehicles that can be locked by central control and routed direct to a secure site under police control if an intruder has forced entry into a vehicle as it is leaving a station, and is detected (even if a passenger has not pressed a panic button);

- at a customer's option, station doors that can be closed and locked by central control until police can arrive to deal with a problem.

Some possible weaknesses in the personal security arrangements for PRT, which must be carefully evaluated as PRT development proceeds, are:

- unreliable TV monitoring due to boredom and fatigue that gradually diminishes the alertness of persons watching the equipment. Moreover, with so many stations and hundreds of cameras being used, a viewing rotation procedure would presumably become necessary to reduce excessive labor cost. An incident might occur while a particular station is not being viewed, but yet, a violator does not usually know whether a camera is in service. Some cameras might be out—of—service for maintenance. What percentage is tolerable and what redundancy is required to ensure adequate surveillance? This and similar questions have been studied and will continue to require examination.

- Panic buttons may not always be accessible to threatened persons. Row serious is the risk that the small PRT vehicles will offer excellent environments for dangerous persons who force entry just before the vehicle leaves a station, and then overpower weaker or frail passengers enroute? Within relatively isolated stations during late evening or night hours, will lonely passengers be highly susceptible to mugging or attack? Will incidents occur so swiftly that the attacker will have long disappeared, even though detected immediately by closed-circuit TV, before the police arrive, or will the situation be better than in crowded mass transit stations where violators easily disappear into the crowd?

<u>Ensuring passenger security will be a challenge, in our opinion, to PRT developers</u>. One reason is that criteria for measuring security are, in comparison to safety criteria, more emotionally based, less definable, and therefore less easy to specify in engineering terms. Another reason is that there will always be a degree of non—controllable and random security deficiencies in transit that will give the public some sound cause for alarm.

TAXI 2000 and Cabintaxi have taken this subject seriously. Even so, the unique features of PRT and the deficiencies of current closed—circuit TV, two-way communicators with panic buttons for passengers, and the many relatively isolated stations that will be used by large-scale PRT networks during late evening or night hours, call for continued serious attention to passenger security.

Security risks that individuals tolerate with their automobiles — seeking their car in lonely or poorly-lighted parking lots, for example - are not accepted, at least in principle, in public transportation. In fact, however, waiting for mass transit vehicles in some stations and at some stops today is not as secure as most passengers would prefer, and some of today’s refusal to use transit service is undoubtedly the result of this fact. If passengers become convinced that the future PRT stations are not secure enough, they will also decline to use PRT if they have a choice.

The record of conventional mass transit in providing personal security for passengers (on-vehicle and waiting) has been good, nevertheless, compared to the security available to automobile users, but security levels vary greatly among urban areas. Personal security appears to have worsened in recent years, which has increasingly alarmed passengers, perhaps even more than the facts justify. Regardless, security is justifiably a major concern of the owners and operators of conventional mass transit, and will have to be a major concern of PRT developers. The standard to be sought is probably the personal security that a passenger obtains with an automobile taxi ride.

Advances in automated passenger security technology may be necessary to allow large-scale and complex PRT networks to come into existence. One kind of desirable advance might enable automated equipment to detect possible threats to passengers and then immediately alert human controllers before the threat has come to the controllers’ attention through TV monitors or panic buttons. Infrared detectors might be used in stations during lightly—used periods to alert controllers to the arrival of an individual in the station, so that continuous TV monitoring of that station would not be necessary.

Present technology, nevertheless, should be adequate for PRT for the initial demonstration installations in small and relatively simple applications.

Driverless vehicles are an essential ingredient of PRT but unattended stations are not. Some stations, even smaller ones, may need to be attended some of the time (which will affect cost estimates). A PRT station may be either attended or unattended, depending on the preference and the economic capabilities of the owner of the system. Different rules can be adopted for different hours of the day. The question is an economic one but the degree of the economic burden can be significantly affected by technology.

3.3.2.2 Evaluation of TAXI 2000 Safety

In contrast to “Passenger Security”, which is concerned with the protection of passengers against other persons, “System safety” is concerned with the protection of passengers, employees and other persons, and their property, from injuries, death or damage caused by failures of the PRT system itself. Conventional mass transit systems have, in general, an enviable record of safety. Serious injuries are rare, especially when compared to the safety record of the automobile.

Rail mass transit has an excellent record; rarely injuring persons on-board the vehicles, but safety is poorer in stations. When rail collisions do occur, they are sometimes major disasters that attract worldwide attention.

Buses have relatively good safety records for in—vehicle passengers, but are considerably less safe for waiting passengers, pedestrians and other motorists. The safety record of non-PRT APMs thus far has been similar to rail mass transit, a better record than some early skeptics about automated guideway transit expected.

The critical question is whether PRT can maintain (and improve upon) this enviable safety record. The primary concerns about PRT system safety revolve around the use of small driverless vehicles and the means for evacuating passengers from stalled, damaged or dangerous vehicles on the main guideway.

One concern is whether close-headway operation will be safe enough. Will a closely—trailing vehicle inevitably crash into a stalled vehicle, especially if the stalled vehicle has made a sudden or near—sudden stop? If so, to what degree will passengers be protected from injury? Even if headways are larger than a vehicle’s safe braking distance, will crashes still occur because of failures or even sabotage of control systems managing hundreds or thousands of small vehicles? Will points where vehicles merge and demerge to leave or enter offline stations be especially risky, particularly at peak periods when vehicles may need to be closely-spaced on the main line?

The special concern expressed historically about close—headway operations has been beneficial. It has concentrated the attention of PRT developers, including TAXI 2000, on both the justification for close headways and the means of assuring safe operation when close headways are required. It has also, unfortunately and unnecessarily, side-tracked serious attention to PRT. Many applications of PRT, as noted earlier, would not require close headways. PRT should be allowed to prove itself and its safety on grounds other than whether it can achieve fractional-second headways.

In conventional mass transit, as in aviation, considerable spacing between vehicles has been one of the most important methods for trying to ensure adequate safety. Such lengthy spacing may not be as important for the small vehicles of PRT. They can provide more protection for passengers during crashes, if designed properly. In addition, however, safety features can be incorporated in PRT that sharply reduce the probability of crashes in spite of close—headway operations.

Safety has been sufficiently considered in the TAXI 2000 concept analysis to allow work to proceed immediately on the next step of its development. TAXI 2000 seems to have adopted, in fact, an even more progressive position regarding safety than traditional mass transit has been able to incorporate in its safety provisions. The company's goal is to design a PRT system that not only prevents crashes but also, if a crash ever does occur, protects passengers against serious injury. The small vehicles and certain other characteristics of PRT seem to make this goal attainable, whereas it is virtually impossible in the large vehicles of mass transit to protect passengers adequately against injury when crashes occasionally occur.

TAXI 2000 Corporation claims that crashes will rarely occur even with close— headway operations. The design of TAXI 2000 stresses redundancy of critical subsystems and components, to provide for high safety and reliability, and the engineering studies of TAXI 2000 have given a great deal of attention to safety. Several safety features are being designed into TAXI 2000 vehicles; for example, all-seated passengers (compared to the many standees of mass transit), energy-absorbing bumpers, padded interiors without sharp projections, air bags, and fire-resistent materials. Vehicles will have, in addition, ultrasonic sensors (a pair at each location) looking ahead, to the rear and to the side. Anomalies that they detect will immediately trigger defensive reactions by the vehicle itself and by the system controlling other vehicles on the same lane of guideway.

TAXI 2000 says that its vehicles, as presently costed, are designed to be virtually fire—proof. It seems to be the case that the linear motor propulsion system of TAXI 2000, without drive train with rotary motor moving parts and gears, can be made highly fire resistent. All combustible components of the propulsion and control elements of the vehicle can be placed under the floor of the vehicle and completely shielded from the passenger compartment by a solid metal plate. Vehicle interiors, especially in such a small vehicle, can be built of materials that are either fire-proof or have a high resistance to fire. If, in spite of all these design features and precautions, fire were to spread within a vehicle, it would threaten only the one to three passengers of that vehicle and not ordinarily spread to other vehicles or threaten other passengers, as is common on large mass transit vehicles, especially those coupled into trains.

With regard to vehicles stalled, damaged or in danger (e.g., on fire) while on the guideway, should passengers be able to leave the vehicle and walk in safety to the nearest station? Not all PRT concepts have provided for walkways or allowed passengers to exit onto the guideway. On-vehicle fire is of particular concern because emergency help may not arrive in time to help passengers who are not allowed to leave the vehicle.

For PRT concepts that do not include walkways, such walkways can usually be added at an additional cost if the public or safety authorities insist on them. In Germany, Cabintaxi was considered to be safe without walkways even though vehicles are suspended under, as well as supported by, the Cabintaxi over-and-under guideway. TAXI 2000 opposes walkways, arguing that they are not needed for adequate safety, and they are of limited or no benefit for persons unable to walk to the nearest station. Even conventional mass transit, they point out, nearly always discourages or prevents passengers from leaving a disabled vehicle because there often is more danger outside the vehicle than within. Evacuation has been necessary, however, where conventional vehicles were not designed satisfactorily against on-board fire or were trapped in tunnels.

Assuming passengers can remain safely in a disabled PRT vehicle until help arrives, the usual assistance will be in the form of (a) a repair person, or (b) a trailing vehicle that gently engages and then pushes the disabled vehicle to the next station, or (c) a “cherry picker” emergency rescue vehicle that parks beside the guideway and lifts the passengers or perhaps the vehicle from the guideway. We suggest that extremely careful study be made of the need for a walkway before a decision is made by consulting engineers, insurers, buyers or others to insist on one.

In this connection, an advantage of PRT over line-haul mass transit is that a stalled PRT vehicle will almost never block or seriously delay transit service. Other PRT vehicles can be switched around the stalled vehicle, using other available guideways. A bypass procedure can also be employed on line-haul mass transit but it is often not feasible because extra track and bypass switches may not be readily accessible.[29]

The small vehicle offers safety advantages on a guideway in a controlled environment, because of its size, if it is designed and built properly. Standees on large vehicles are always at risk during crashes. Passengers on TAXI 2000 vehicles will be seated. In general, PRT vehicles will not be in tunnels, in which fire hazards are greater. If they ever are, it is worth noting that their undercarriage, including propulsion and control equipment, is enclosed within a guideway structure that should help prevent fire as well as reduce its tendency to spread.

Having said all the above about safety, it is worth noting that anxiety about automated vehicles cannot be, and should not be, dealt with theoretically. Equipment must prove itself safe. This was true of automated elevators, it has been true with automation of non-PRT transit, and it will be true of PRT. Cabintaxi demonstrated safe operation at its test facility. When TAXI 2000

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[29] The New York City Transit rail system, large and complex, has many “crossovers” that are used as operational and emergency bypasses, but it does not approach the relative number of bypasses that would be inherent in a PRT system.

does the same, and when PRT systems continue to prove adequate safety in small—scale demonstrations, the public, liability insurors, consulting engineers and others will be satisfied. We are satisfied that safety, thus far, has been given the serious attention it deserves.

3.3.2.3 Conclusions As To The Public Acceptance of PRT

Our conclusions, based on an examination of the TAXI 2000 concept, Cabintaxi and other PRT concepts historically, as well as recent installations of nonPRT APMs and new rail mass transit systems, are:

1. The most difficult hurdle that PRT may face could be public objection to its numerous aboveground guideways and stations. PRT guideways and stations, in spite of their extremely small size compared to most rail and APM mass transit facilities, will undoubtedly be vigorously questioned at times by the public, at least for the earliest installations of urban transit PRT systems. Aboveground, PRT guideways will sometimes pass close to second story windows of offices and apartments. They may also pass near or through the neighborhoods of single family homes. A fine-grained grid of guideways will bring the aboveground structures of PRT into the line of sight daily of a high proportion of the residents and workers of an area.

2. Public opposition (for environmental reasons) can probably be overcome, or perhaps even avoided in some instances, but the PRT developer and local advocates of PRT will need to pay special attention to public concerns from an early stage. There are many ways to do so, and in addition PRT will have several off—setting advantages, such as:

   - the high quality transportation service it will bring to the area;
   - the speed and ease with which its guideways and stations probably can be erected;
   - its lack of other adverse environmental impacts (for example, noise or emissions);
   - certain significant environmental advantages, such as extremely moderate land use;
   - its appealing economics, especially as compared to the guideway—based mass transit alternatives;
   - its eventual displacement of most large buses (noisy, smelly, etc.) within much of the territory that it serves; and
   - the reduction in the intensity of automobile land use and infrastructure within the PRT-served area.

3. The sate operation of high capacity, close-headway flows of vehicles on a single-lane guideway will have to be proven at a test track, but the success of PRT does not depend solely on being able to provide fractional-second headways. Many applications can be satisfied with longer headways. In any case, the safety design philosophy of TAXI 2000 deserves praise. It places as high a priority on prevention of injury to passengers as it does on preventing accidents that can cause such injuries. In view of this, we question whether the historical rule of lengthy headway spacing applied to mass transit should be imposed on PRT. Clearly, a decision on this crucial question should not be made in advance of further development at a test facility.

4. Walkways may be needed on PRT guideways for evacuation of passengers from stalled or hazardous vehicles, but this is not a clear—cut issue. It deserves evaluation during development before the added costs of walkways are automatically imposed on PRT developers and customers. Good reasons have been advanced by several PRT developers historically and today for not adding walkways, including the protective safety that can be built into PRT vehicles and the safety benefits of passengers remaining with a vehicle until it is pushed to the nearest station or the passengers can be removed by system employees.

5. Passenger security against threatening individuals may be better on PRT than on conventional mass transit, but PRT has unique characteristics. These require the addition of special features to the system to ensure that passenger security is indeed assured. Moreover, there is an important psychological factor to be considered; a risk that public perceptions of the degree of security provided by PRT is lower than the actual security that passengers receive.

   PRT developers need to give passenger security the highest attention. The small vehicle of PRT, providing rapid minimum—wait loading and private service without strangers having to ride together, possesses inherent security advantages if adequate measures are taken at the stations and within the vehicle to capitalize on these potential benefits. Two-way TV surveillance, two-way voice communications, panic and stop buttons, and psychological preparation of riders for the differences inherent in PRT — these are some of the measures that require careful design and test before a PRT system is ready for the true urban market.

Chapter 4

RECOMMENDATIONS

An unfortunate deficiency in leadership and institutional arrangements (including financing) for transit research and development (R&D) are, we feel, the main reasons why there is a shortage today of new transit technology options that can provide good transportation service at affordable costs within the under-served parts of urban areas.

The enthusiasm and optimism of the 1960s about “new systems” of urban transportation collapsed in the ‘70s and ‘80s. Several examples of design failures, cost overruns, and (perhaps) too much hype, led to growing pessimism about advancing transit technology. A revised public agenda is needed that focuses better on transit research and development (R&D).

In the present circumstances, most companies still making transit equipment feel little incentive to undertake R&D aimed at large improvements in the cost—effectiveness of transit. Local and state (or provincial) leaders —including the consultants who advise them — believing that new technology offers no hope, rarely try to induce these companies to commit capital to search for “a better mousetrap”. Venture capitalists, for the same reasons, see little financial incentive to commit their funds to new ideas in transit. National governments, for the most part, have simply abandoned the field, and local authorities have not pressed for new technological approaches to meeting under-served transit needs.

Non-PRT APM technology has moved ahead but, with its large vehicles, has been focused on specialized loop and shuttle applications in major activity centers, or on providing traditional mass transit services in urban corridors, where markets have emerged for this kind of technology.

A continuation of the present indifference to the development of more cost-effective technology for urban transit points to a no-win future. If urban transportation persists on the present path, tomorrow will be a dreary replay of yesterday and today, with communities seeking solace in:

- more roads that are increasingly expensive;
- more stringent “road management” and “pricing” schemes; and
- traditional mass transit technology, which is not capable of giving quality service at acceptable cost within most of the urban area; only within the major activity centers and heavily travelled (mostly radial) corridors.

The underserved and unmet travel needs of the smaller cities and the contemporary metropolitan “spread city” of many “centers” and **many** “neighborhoods” in medium and low-density locations, where most people live and work today, will not be satisfied.

We offer the following recommendations for advancing transit:

1. 1.Personal Rapid Transit, after about four decades of study and some development, including over a decade of relative neglect, should be moved back onto the public agenda for consideration as one of the promising options for improving urban transit.

   PRT in its urban transit applications should be seen initially as a supplement to, and strengthening of, conventional mass transit. Its first applications, assuming a successful development program, will probably be for services that guideway mass transit systems cannot provide economically. Its lower cost and its several high—quality service features, if proven during tests, can make it attractive for these applications. Like all better products and services, PRT will offer new capabilities and create new opportunities that open new kinds of markets for transit systems.

   Some initial applications for PRT include connections with present mass transit stations, which can help mass transit serve a larger territory better (and probably secure a more favorable revenue/cost ratio). PRT will not displace present guideway mass transit systems, at least in its early years, but rather strengthen their services in various ways.

   Like all guideway-based transit systems, PRT will have to compete with on-street bus transit during a community’s evaluation of alternative transit systems. The communities that select PRT should gain a significantly higher quality of service, even if the capital costs of PRT prove to be above those of bus transit. However, no guideway system now designed or imagined can offer service as inexpensively or flexibly as buses under some conditions; for example, where low capital cost is important, or desired service quality is modest. These economic and service considerations will continue to be important in alternatives analysis.

2. Stronger institutional arrangements for financing advanced transit development are needed, and governments may have to help bring them into existence.

   No satisfactory financing mechanism is working today to bring PRT (or other promising advanced transit) through a development cycle. Private investors and industry, even interested ones, do not see large and fast-enough returns on an investment in advanced transit to justify making it.

Private companies are rarely stimulated in the transit market, if left alone, to make significant investments in new technology. Returns on investment are too chancy and too slow to arrive, compared to similar investments made in other products or services.

Serious financing of transit R&D will probably occur only with governmental involvement, but this does not necessarily mean that governments themselves have to budget large sums of money for such R&D or that they should become directly involved in specifying or designing PRT. Governmental involvement can take many useful forms:

- help and encouragement for localities (and states/provinces) interested in PRT to form joint test and evaluation capabilities, and to adopt other measures that stimulate suppliers to become more interested in PRT;
- changes in laws or policies that inhibit excessively the use of government-supplied capital and operating subsidies for testing and evaluating PRT technology;
- provision of small quantities of “seed money” to encourage development, test and evaluation of PRT;
- encouragement to professional organizations and universities, especially those receiving large government grants for transportation research, to undertake PRT projects;
- stimulation to non-profit organizations and foundations to focus their attention and resources on PRT

Governments, without spending large sums, can affect beneficially the general climate of opinion about the desirability of developing and testing PRT and other advanced transit technology. They can help bring joint ventures into existence - merging public and private interests -or they can ignore their value. They can help private investors see opportunities in transit R&D, or they can discourage them. There is a great need for a new kind of governmental leadership in this field.

3. <u>A leadership gap must be closed if PRT is to be given an opportunity soon to test itself in the next stage of development. Leadership must be reoriented and strengthened in a variety of ways that encourage the advancement not only of PRT but also of transit technology in general</u>.

Many different groups and organizations can help advance PRT if studies and tests convince them of its potential value. Persons in urban development, real estate development, environmental action, programs for the elderly, and many similar organizations, have as much potential interest in advanced transit as members of the established transportation industry. Some of the various interested groups, and some of the contributions that they can make, are:

* <u>Local government officials</u>, faced with insufficient choices and rising costs among existing transit technologies, have a need to encourage the development of new transit options that serve better the travelling populations within their jurisdictions. They can urge industry and investors, as well as national (and state or provincial) governments, to respond to this need for advanced transit options having higher cost—effectiveness. Their regional and national associations should help promote this attempt to stimulate more interest in PRT development and demonstration.

* <u>Local citizen</u> concerned about public transportation. should begin to request consideration of PRT in local transportation studies. This needs to be done even though a market-ready PRT system is not available at this moment. Some may say it is impractical to study PRT if there is no system to buy. This reveals a misunderstanding of how the urban marketplace can work to motivate investors (public and private).

  "Demand" (that is, a felt need), in the political marketplace, often precedes supply. The inclusion of available PRT concepts in such studies is healthy and essential even though everyone knows they cannot yet be bought. It will demonstrate to industry and investors, including governments, that citizens want better transit and are trying to keep in touch with the latest developments. Supply will eventually emerge, if the political and public demand is sensible and development of the new product proves to be feasible. "Necessity is the mother of invention" -a cliche that is still often true.

  The inclusion of PRT concepts in planning studies will also enable initial comparisons to be made between the services and costs that PRT may be able to offer and those that conventional mass transit can offer today. No prudent business person, investor or government official will support a major PRT development program without confidence that demand will emerge for PRT when it is ready to be delivered; that is, that local citizens and governments really want something like PRT.

  Interested citizen groups include organizations concerned about the environment, mobility for senior citizens and the handicapped, desirable land use planning and urban development, and labor availability to business, as well as organizations interested particularly in transportation itself.

* <u>Architectural, engineering and planning consulting firms</u> in transportation are in unique positions to take a fresh look at PRT. Although their present transit business derives largely from mass transit, no one is asking them to leave this industry. Indeed, PRT and mass transit will often strengthen each other.

Professionals have a social responsibility to examine new ideas thoughtfully. The best professionals and firms have been leaders historically in promoting new technologies that provided greater benefits relative to costs, and which functioned more cost—effectively. Such technologies benefitted their clients, and ultimately themselves as well. Successful PRT could open up a large new market in transit planning, engineering, construction and operation.

* <u>Owners and operators of present mass transit systems</u> need to get more serious about research and development for transit, especially PRT. Individually and through their associations —the American Public Transit Association (North America). and the International Union of Transport (world-wide) — they have mostly concentrated on seeking capital and operating funds to sustain conventional mass transit systems.

The limited R&D that transit owners and operators have encouraged has focussed on present transit equipment, operations and planning. During the recent difficult decades for transit. this orientation has been understandable, but it is not sufficient for the future. Most owners and operators are public authorities supported by taxpayers. They can, if they commit themselves to helping advance transit technology, earn the public’s gratitude for bringing better transit service. And they can achieve greater cost—effectiveness in their operations. Their mass transit systems could gain from PRT, which could be a means, if PRT proves itself, of enhancing the service areas and ridership of these systems.

* <u>The Advanced Transit Association</u> (ATRA) has had only minimum impact on transit R&D, and a minimal program of activity. It should strengthen its membership promotion and fund-raising efforts. It should in addition seek foundation support for (a) a follow-up study with deeper professional quality (using paid staff) into the costs and benefits of PRT, and (b) a program of public education about the status, prospects and benefits of advanced transit research and development.

ATRA should aim to acquaint as large an audience as possible with the information that PRT is not a barren concept. Rather, it offers one of the more promising hopes for transit within the present spectrum of new transit options. In doing so, it should seek cooperation with all other interested organizations, such as it has already done in becoming a co-sponsor with the American Society of Civil Engineers (ASCE) and others for the March 1989 Automated People Mover Conference in Miami, Florida.

4. One or more national governments — in the United States this would probably be through the U.S. Department of Transportation, in cooperation with other agencies such as the Department of Housing and Urban Development - should begin a study for the establishment of an advanced transit technology assessment capability.

   A transit technology assessment capability should evaluate all forms of advanced transit technologies, including promising PRT ideas. Evaluation activities should lead to assurances that can be provided to communities, and others, that technology will work as claimed for approximately the cost claimed.

   The functions of this assessment capability should be, among others, to: (a) design and undertake systematic tests and evaluations of guideway technology that promises large reductions in cost and significant improvements in service; (b) select and help organize and staff the places where tests and evaluations can best be performed; and (c) disseminate publicly the findings on actual performance and costs.

   The persons responsible for this assessment capability should not engage in design, or specify the design of, PRT and other advanced transit concepts. One of the mistakes of the 1970s was the excessive involvement of governmental agencies in technology conceptualization, detailed design and project management to try to advance transit. Most of this work should remain the responsibility of private companies and other independent entities, responding to market demand and their creative drives.

   Finally, this assessment capability should not be located at a single “test site”. “Capability” should be established, in some instances, near or at a manufacturer’s test facility, to provide confirmation of claimed results. Other “capability” should be established in a locality to identify and report results of an initial urban demonstration of a new technology. Some “capability”, nevertheless, will probably need to be at a conventional “test site” that is well equipped with permanent and specialized test equipment.

Other steps may eventually have to be adopted to ensure that better transit technology reaches urban areas, but these are the minimum needed. They should be tried first and quickly, with strong emphasis on encouraging private entrepreneurs, at least two of whom are waiting for more encouragement, to respond to the unmet travel needs of a rapidly-changing urban travel market. It is time to stimulate and unleash the creative energies of both Drivate enterprise and governments in the pursuit of better options for urban transit.

Appendix A

SOURCES OF INFORMATION ABOUT CABINTAXI

Cabinentaxi. C-Bahn, Cabinenleft '79, Munich, West Germany, 1979, a publication in German by Demag+MBB, available from Cabintaxi Corporation, 8114, St. Paul, Detroit, MI, USA 48214.

Development/Deployment Investigation of Cabintaxi/Cabinlift System, a study by Transportation Systems Center and Studiengeselschaft Nahverkehr mdH, December 1977, prepared for the Urban Mass Transportation Administration, U.S. Department of Transportation, and the Ministry of Research and Development, Federal Republic of Germany. UMTA Report MA-06-0067-77-02.

Appendix B

SOURCES OF INFORMATION ABOUT TAXI 2000

TAXI 2000: A New Generation Personal Transit System, a promotional brochure issued by Taxi 2000 Corporation, 474 Revere Beach Boulevard, Suite 802, Revere, MA 02150, 1987.

Anderson, 3. Edward, “The TAXI 2000 Personal Rapid Transit System,” *Journal of Advanced Transportation*, Vol. 22, Spring 1988, Institute for Transportation, P.O. Box 4670 Duke Station, Durham, North Carolina 27706, USA. This article is a summary of descriptive information furnished to the Technical Committee on PRT of the Advanced Transit Association.

Anderson, J. Edward, “A Note on Fare Policy in Personal Rapid Transit,” *Journal of Advanced Transportation*, Vol. 21, No. 1, Spring 1987.

Anderson, 3. Edward, “Automated Transit Vehicle Size Considerations,” *Journal of Advanced Transportation*, Vol. 20, No. 2, Summer 1986.

Anderson, 3. Edward, “Optimization of Transit-System Characteristics, *Journal of Advanced Transportation*, Vol. 18, No. 1, Spring 1984.

Appendix C

LOON MOUNTAIN COSTS: TAXI 2000

TAXI 2000 COST ESTIMATES – JANUARY 1989
Loon Mountain Recreation Corporation Site
Lincoln, New Hampshire
Source: TAXI 2000 Corporation, Revere, MA, USA

COST CATEGORY	UNIT	QNTY	DOLLARS PER UNIT	TOTAL DOLLARS	P'CNT	LIFE
1. CONSTRUCTION						
G'way, columns, fndatn	Mile	1.04	$2,582,692	$2,686,000	33.3	30
Stations w/o guideway	Total	3	$304,800	$914,400	11.3	30
Survey, landscaping	Total	1	$64,200	$64,200	0.8	30
SUBTOTAL				$3,664,600	45.5	
2. SYSTEM-WIDE ELEMENTS						
Electrification	Total	1	$371,000	$371,000	4.6	30
Wayside C—3	Total	1	$66,300	$66,300	0.8	30
Maintenance facility	Total	1	$364,300	$364,300	4.5	30
Fare collection	Each	6	$50,000	$300,000	3.7	30
SUBTOTAL				$1,101,600	13.7	
3. VEHICLES & SPARE PARTS						
Vehicles	Each	35	$61,000	$2,135,000	26.5	10
Spare parts (5%)	Each	35	$3,050	$106,750	1.3	10
SUBTOTAL				$2,241,750	27.8	
TOTAL				$7,007,950	86.9	
4. PROJ & CONSTRCTN MGMT	Total		$1,054,000	$1,054,000	13.1	30
GRAND TOTAL				$8,061,950	100.0	

ANNUALIZED COST OF LOON MOUNTAIN RECREATION PROJECT

COST CATEGORY	YEARS	FACTOR	TOTAL COST	ANNUAL COST
Cost items 1, 2 & 4	30	0.08059	$5,820,200	$469,050
Cost item 3	10	0.14238	$2,241,750	$319,180
SUBTOTAL			$8,061,950	$788,230
Operation & Maintenance	N/A	N/A	N/A	$179,970
GRAND TOTAL				$968,200

Note: Operations are year—round.

Appendix D

PERFORMANCE & COST PARAMETERS: TAXI 2000

PERFORMANCE AND ECONOMIC PARAMETERS FOR TAXI 2000
Source: TAXI 2000 Corporation, Revere, MA, January 1989.

This appendix includes two tables that are intended to show, in parametric fashion, some of the critical performance and economic characteristics of the TAXI 2000 system for systems having specified features.

Table 1 provides for the expression of assumptions relating to such planning factors as assumed average vehicle occupancy in persons, average line speed of vehicles, and forecast cost per vehicle. Factors can be varied for planning purposes.

Table 2 hypothesizes such site-specific system characteristics as alternative guideway line spacings of quarter-mile (0.4 kin] and half-mile (0.8 kin), alternative system lengths in miles, or alternative sizes of service areas in square miles.

A variety of parametric data emerge from the interaction of these various factors; such data as the number of stations required, average trip lengths, or number of vehicles needed to serve demand. Capital and O&M costs are estimated as a function of the requirements.

TABLE 1 Performance and Economic Parameters

Average vehicle occupancy persons	1.00
Average dwell time sec	9.50
Line speed, mph	25.00
Service acceleration g	0.25
Maximum jerk, g/sec	0.23
Excess time to stop at a station, sec	15.14
Spacing between main and station tracks, ft	10.00
Number of station berths	3
Length of station berth, ft	10.00
Length of off-line-station guideway ft	316.87
Ratio of peakhour to weekday trips	0.087
Ratio of yearly to weekday trips	310
Maintenance float, %	2%
Guideway cost per mile, third year	$1,890,000
Station cost without off-line guideway	250,000
Vehicle cost third year	43,700
Storage & maintenance-facility cost per vehicle	7,000
A&E + Construction, % of above costs	27%
Energy cost per vehicle-mile	0.007
Interest rate on borrowed money %	8.0
Lifetim of vehicles, years	10
Lifetime of fixed facilities, years	25

Source: TAXI 2000 Corporation, Revere MA, January 24, 1989

Table 2, Part A Parameters Related to Operation of TAXI 2000 in a Network of One-Way Lines

Line Spacing mi	System Length mi	Service Area sq mi	Number of Stations	Average trip Length mi	Average trip Time mm	Average Speed mph	Trips per Day per sq mi	Total Trips per Day	lumber of Vehicles
0.25	1.0	0.125	4	0.50	1.45	20.7	10,000	1,250	4
0.25	2.5	0.313	10	1.00	2.65	22.6	10,000	3,125	17
0.25	6.0	0.750	24	1.08	2.84	22.8	10,000	7,500	42
0.25	15.0	1.875	60	1.51	3.87	23.4	10.000	18,750	137
0.50	2.0	0.500	4	1.00	2.65	22.6	10,000	5,000	21
0.50	5.0	1.250	10	2.00	5.05	23.8	10,000	12,500	97
0.50	12.0	3.000	24	2.16	5.44	23.8	10,000	30,000	252
0.50	30.0	7.500	60	3.01	7.49	24.2	10.000	75,000	860
0.25	1.0	0.125	4	0.50	1.45	20.7	20,000	2,500	7
0.25	2.5	0.313	10	1.00	2.65	22.6	20.000	6,250	29
0.25	6.0	0.750	24	1.08	2.84	22.8	20,000	15,000	74
0.25	15.0	1.875	60	1.51	3.87	23.4	20,000	37,500	244
0.50	2.0	0.500	4	1.00	2.65	22.6	20,000	10,000	40
0.50	5.0	1.250	10	2.00	5.05	23.8	20,000	25,000	191
0.50	12.0	3.000	24	2.16	5.44	23.8	20,000	60,000	493
0.50	30.0	7.500	60	3.01	7.49	24.2	20,000	150,000	1690
0.25	1.0	0.125	4	0.50	1.45	20.7	40,000	5,000	12
0.25	2.5	0.313	10	1.00	2.65	22.6	40,000	12,500	53
0.25	6.0	0.750	24	1.08	2.84	22.8	40,000	30,000	137
0.25	15.0	1.875	60	1.51	3.87	23.4	40,000	75,000	458
0.50	2.0	0.500	4	1.00	2.65	22.6	40,000	20,000	79
0.50	5.0	1.250	10	2.00	5.05	23.8	40,000	50,000	378
0.50	12.0	3.000	24	2.16	5.44	23.8	40,000	120,000	975
0.50	30.0	7.500	60	3.01	7.49	24.2	40,000	300,000	3351
0.25	1.0	0.125	4	0.50	1.45	20.1	80,000	10,000	23
0.25	2.5	0.313	10	1.00	2.65	22.6	80,000	25,000	102
0.25	6.0	0.750	24	1.08	2.84	22.8	80,000	60,000	263
0.25	15.0	1.875	60	1.51	3.87	23.4	80,000	150,000	887
0.50	2.0	0.500	4	1.00	2.65	22.6	80,000	40,000	158
0.50	5.0	1.250	10	2.00	5.05	23.8	10,000	100,000	751
0.50	12.0	3.000	24	2.16	5.44	23.8	80,000	240,000	1940
0.50	30.0	7.500	60	3.01	7.49	24.2	80,000	600,000	6673

Notes: The four networks used in this Table are shown in Figure 3.
The service area includes the area inside the network plus 1/4-tb the cell area times the number of edge stations.

Source: TAXI 2000 Corporation, Revere MA, January 24, 1989

Table 2, Part I Performance and Economics of TAXI 2000 in a Network of One-Way Lines

Trips per Peak Dour per Station	Average Headway sec	Average Line Flow people/hr	Pass-miles per Year	Pass-miles per Year per Lane-mi	Total System Cost	Cap. Cost per Pass-mi	O&M Cost per Pass-mi	Total Cost per Pass-mi	Total Cost per Year
27	72.0	50	193,750	193,750	$4,504,049	$2.25	$0.507	$2.76	$534,431
27	38.0	95	968,750	387,500	11,710,847	1.19	0.280	1.48	1,429,164
27	37.9	95	2,510,419	418,403	28,113,299	1.11	0.262	1.37	3,446,918
27	27.0	133	8,760,891	584,059	72,518,695	0.83	0.201	1.03	9,045,391
109	17.8	202	1,550,000	775,000	7,998,962	0.53	0.122	0.65	1,013,136
109	9.2	390	7,750,000	1,550,000	22,862,717	0.32	0.083	0.40	3,132,124
109	8.6	420	20,083,350	1,673,613	56,106,789	0.31	0.081	0.39	7,773,883
109	6.1	586	70,087,125	2,336,238	155,076,442	0.25	0.070	0.32	22,530,719
54	36.0	100	387,500	387,500	4,697,216	1.20	0.282	1.48	574,194
54	19.7	182	1,937,500	775,000	12,483,515	0.66	0.164	0.82	1,590,048
54	19.0	190	5,020,838	836,806	30,243,747	0.62	0.155	0.77	3,875,255
54	13.6	265	17,521,781	1,168,119	79,408,318	0.47	0.124	0.60	10,481,106
217	9.1	394	3,100,000	1,550,000	9,222,353	0.32	0.084	0.41	1,268,023
218	4.6	780	15,500,000	3,100,000	28,915,283	0.22	0.065	0.28	4,393,913
218	4.3	839	40,166,700	3,347,225	71,624,538	0.21	0.063	0.27	11,010,913
218	3.1	1171	140,174,250	4,672,475	208,519,312	0.18	0.058	0.24	33,687,695
109	19.6	183	775,000	775,000	5,019,161	0.66	0.165	0.83	641,077
109	10.1	358	3,875,000	1,550,000	14,028,851	0.39	0.105	0.49	1,911,818
109	9.5	380	10,041,675	1,673,613	34,300,254	0.37	0.101	0.47	4,719,284
109	6.8	529	35,043,563	2,336,238	93,187,564	0.30	0.085	0.38	13,352,537
435	4.6	778	6,200,000	3,100,000	11,733,524	0.22	0.066	0.29	1,790,440
435	2.3	1557	31,000,000	6,200,000	40,956,026	0.17	0.056	0.22	6,904,845
435	2.1	1678	80,333,400	6,694,450	102,660,036	0.16	0.055	0.22	17,484,974
435	1.5	2342	280,348,500	9,344,950	315,469,441	0.15	0.052	0.20	56,014,291
217	9.8	366	1,550,000	1,550,000	5,727,440	0.40	0.109	0.51	787,487
218	5.1	708	7,750,000	3,100,000	17,183,912	0.25	0.077	0.33	2,568,000
218	4.7	759	20,083,350	3,347,225	42,413,268	0.24	0.075	0.32	6,407,342
218	3.4	1058	70,087,125	4,672,475	120,810,445	0.21	0.066	0.27	19,108,044
870	2.3	1555	12,400,000	6,200,000	16,820,255	0.17	0.057	0.23	2,847,918
870	1.2	3109	62,000,000	12,400,000	64,973,123	0.14	0.051	0.19	11,914,067
870	1.1	3356	160,666,800	13,388,900	164,795,421	0.14	0.050	0.19	30,445,738
870	0.8	4683	560,697,000	18,689,900	529,369,699	0.13	0.049	0.18	100,667,483

Note: Average headway below about 2 seconds exceeds system capacity.

Appendix E

PERFORMANCE & ECONOMICS: TAXI 2000 NETWORK

TAXI 2000 Corporation made available to the committee the computer program, written in Quick Basic 4.5, that it uses to calculate performance and economic indicators for TAXI 2000 networks that are “square grid”. The data are calculated for the purposes of preliminary planning, based on engineering cost estimates made in advance of, and near the time of, the operation of the program.

The basic assumption underlying the program is a square grid of a given area and given population, uniformly distributed. Detailed studies, site-Bpecific, would of course be required to arrive at greater precision based on the real layout and other characteristics of a PRT system that might be built for that site.

The program allows a large number of variables to be input by the planner. For example, one can quickly vary the assumed cost of vehicles to determine the economic consequence of increases or decreases in the estimated cost of PRT vehicles. Similarly, alternative assumptions as to the assumed capital cost of guideways or stations, or the interest rate of money borrowed, can be readily examined.

The computer program requires the operator to input a modal split.

This appendix displays several examples of some of the output data from this program, showing technical and economic performance of the system.