Personal Automated Transportation:

Status and Potential of Personal Rapid Transit

Main Report

January 2003

by the Advanced Transit Association

Bob Dunning, committee chair
Ian Ford, report editor

Committee Members

Rob Bernstein
Catie Burke
Dennis Cannon
George Haikalis
Jerry Kieffer
Dennis Manning
David Maymudes
Jeral Poskey
Joe Shapiro
Markus Szillat
Göran Tegnér
Ron Thorstad
David Ward
Michael Weidler
William Wilde

NOTE: This report is published in a group of documents. Other documents in the group include an executive summary, a comparison of PRT systems, and other supporting reports.

The full set is detailed on the web site: www.advancedtransit.org/pub/2002/prt

Contents

History of ATRA's Study of PRT

In 1989, after a one-year study, an ATRA technical committee prepared the report: "Personal Rapid Transit (PRT)—Another Option for Urban Transit?" It was adopted by ATRA's Board and sent to ATRA members, many urban and transit planners, and others. Cutting through conflicting views (at the start) about PRT's nature, technical feasibility, and low costs, the committee in a surprisingly unanimous report (a) defined PRT; (b) examined and validated its technical feasibility; (c) noted microprocessor advances that permitted major reductions in the weight/size/cost of PRT command/-control equipment; and (d) gained the written opinion of two independent transit cost experts that very low cost estimates projected for PRT were developed in a straight-forward manner, based upon sound costing methods. Noting the urgent need for more service-effective, very low cost transit options, the committee urged that a full scale PRT system be tested and then demonstrated in revenue use, with a view to convincing policymakers and developers that PRT could be an effective option for transit planners.

Dissemination of the report helped enliven discussion during the 1990's of new transit modes for meeting the stubborn challenge of growing traffic congestion in the world's metropolitan areas. Interest and membership in ATRA increased. Also, after ATRA's chairman, the late Thomas Floyd, provided the report to staff of the Chicago area Regional Transportation Authority (RTA) and a presentation of a PRT concept to the RTA Board by ATRA Board member J. Edward Anderson, the RTA conducted a world-wide competition to select a contractor to build/test a prototype system, with the possibility of then building a working demonstration in the village of Rosemont, Illinois.

Using PRT concepts developed from an initial study by the Taxi2000 Corporation and Stone and Webster, the Raytheon Company won the competition and announced that it would build a system at the cost of $13 million a mile. However, once the project was underway, Raytheon and the RTA undertook a complete redesign of the PRT technology and departed from many critical design criteria established in the initial Taxi-2000 and Stone and Webster study. The resulting effort produced a much larger, heavier vehicle and guideway, which, at last information, produced a system projected to cost over $ 40 million a mile. While this system was successfully tested in 1998, it attracted no buyers. Raytheon management terminated the project in October 1999.

Why is a fresh assessment of the status of PRT development needed at this time?

Over the past decade, the world's metropolitan areas continued to spread out. Conventional transit modes, though still strongly advocated by many planners and commercial developers, haven't been and cannot be widely diffused, because of their service limitations and/or high costs. Consequently, this fact still leaves vast areas of metropolitan settlement without effective transit services. Hence, auto use has mushroomed worldwide, and road traffic congestion and poor air quality have become major challenges to the economic and social viability of metropolitan areas. Moreover, Europe, the U.S., and Japan have large and rapidly increasing older populations. Increasing numbers of these people don't drive or prefer not to. Without effective public transportation, they are often needlessly marooned and isolated, without convenient access to many services and amenities needed by older people.

Since 1989, these critical unmet needs and problems have gotten much worse. Therefore, despite the Raytheon/RTA experience, other PRT developers have continued their efforts to promote marketable PRT concepts. Considering PRT's potential, ATRA should do what it can to help encourage better understanding of PRT for meeting the needs of communities and developers for lower cost and better and more widely diffused transit service.

Study Goals

The ATRA Technical Committee on Personal Rapid Transit developed this report to analyze why exiting mass transit options can not make a dent in the problems of traffic congestion, air quality, accessibility, and transportation safety, and the ongoing dominance of the automobile. The committee also set out to demonstrate the need for advanced transportation alternatives. We intend to show how and why PRT can have a substantial and beneficial impact, and what are the characteristics of PRT that give it a better shot of handling these problems than existing mass transit options. Finally, we want to assess the current developmental status of PRT systems.

We hope that this report will provide information that will:

- help all interested parties in understanding what PRT is and is not, and address common concerns about PRT,
- help all interested parties understand why the automobile is dominant, and why mass transit cannot solve the problems stated above,
- make PRT known to a larger portion of the public and the media,
- help planners and decision makers understand when, where, and how PRT could be used for the public good,
- help planners understand how to evaluate PRT systems, and how to include PRT in an alternatives analysis,
- help investors understand the financial aspects of PRT, in order to attract capital for further development,
- and help PRT developers to improve their systems.

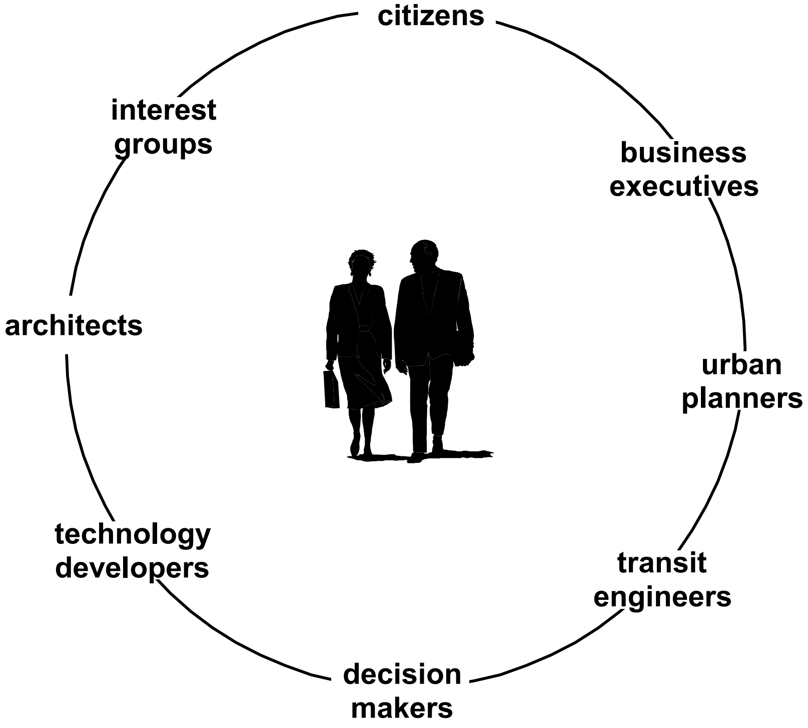
Based on knowledge of the technical and social issues, the report team unanimously feels that PRT is technically viable and will deliver on its promises once implemented. The main obstacles seem to be in the marketing, rather than technical realm. Therefore the report is intended, through the use of objective information, to help bridge the parties involved in advocating for, planning for, investing in, and developing PRT systems, so that they can work together towards the larger goal of making PRT a reality.

The team also has serious reservations about some of the systems presented. This report is not just a marketing effort to help “sell” PRT, but a critical look at the claims made by system vendors, and where they stand in their development process. The report is a non-profit activity and is not supported by any system vendors.

Rationale and Discussion

Our Purpose: Increasing Awareness of Advanced Transit Alternatives

This report aims to inform key groups of people about the potential for significantly improving the quality of life in our cities through the implementation of Personal Rapid Transit (PRT).



PRT embodies a series of basic *technology-independent* improvements to transit systems. These improvements are the logical culmination of trends that have existed in public transportation systems for the last 200 years. In the context of the developed urban landscape, PRT provides a travel option that is superior to the automobile for many potential users.

In the following sections we will:

- Describe PRT.
- Show why it is superior to existing forms of transportation in cities.
- Presents analyses of the PRT systems that are under development at this time.

By providing descriptions of the characteristics of the PRT systems in development and of their current state of development, we hope to hasten the day when such systems are available in all our cities.

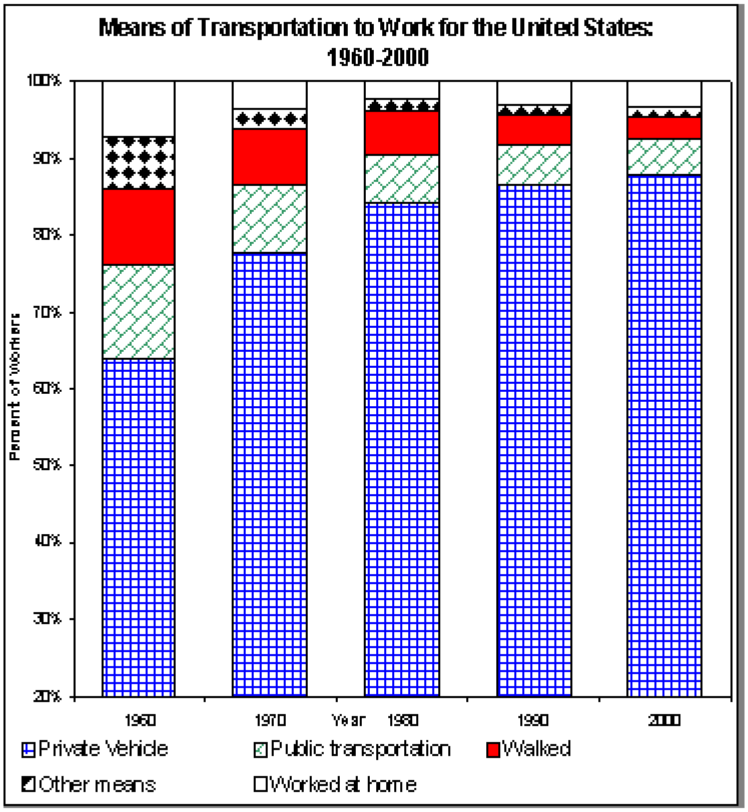
Our Principal Motivation: The Struggling Transit System

> *Not everyone can own or drive a car. An honorable society has to find ways to include the disadvantaged in the mainstream of urban life. Nevertheless, public transit is not delivering* ***a product that people want at a price that the people can afford****. We can do better.*

Public Transit

When we speak of transit, we usually think about the public transportation options that are built at great expense to provide an alternative to the automobile.

Public transit serves people effectively and is an important part of our transportation system, especially for those who do not drive. Transit serves a few percent of the total trips made, as shown in the following chart. Although transit ridership has gone up somewhat in the last decade, transit's share of the total has not increased. This is because total travel per capita has increased, and almost all of that increase has been auto travel. The share of trips made by transit has actually decreased steadily since 1960.[1]



Public transit has not seen a comeback***, despite ever-increasing public subsidies.*** If cost-effectiveness were an issue, public transit would have ceased operating long ago.

Automobile-based Transit

The other option for transit services within our cities is failing. The most popular transit mode – the private automobile – has severe deficiencies. It is costly to own and operate. It is the source of many

---

[1] U.S. DOT, Census Transportation Planning Package (CTPP), http://www.fhwa.dot.gov/ctpp/

accidents, injuries and deaths; it is the leading cause of death in children under the age of 12. These deficiencies, in turn, lead to high court costs and other public expenditures to regulate and control traffic.

From the view of **sustainability**, automobile-based transit uses great quantities of carbon energy and pollutes our air and water. It has made us highly dependent upon foreign energy sources. It consumes enormous space in cities for roads and parking, adding to the costs of its use.

Setting aside other significant deficiencies in automobile-based transit (like the death of people and the destruction of the environment), the greatest price that we pay for automobile-based transit lies in the time and effort wasted in **traffic congestion**. Harshly, our society pays a huge penalty for the loss in timeliness and the unpredictability of traffic:

- We each pay personally with our precious time, our energy, and in aggravation.
- Our business communities pay in lost productivity and promptness, with a consequent loss of business and profitability.
- Our local governments pay in lost tax bases and in unfavorable business climates.

We have now arrived at the point that long established businesses are considering their options as aging production facilities need replacement and as expansion requires new production facilities. Traffic congestion is a key component in the cost of living and in our prospects for the future.

On the positive side, when everything goes well and traffic is light, the automobile is the paragon of the transit service that riders most desire. It leaves when people want to leave. It starts from where people are located. It goes where people want to go, often without interruptions, transfers, or significant delays. The automobile can be extremely convenient for those who are able to own and drive a car. For many it is the only way to get to their work, recreation, professional services, shopping, and cultural venues. Any public transit system that can not provide a level of service comparable to that provided by the automobile will not succeed by any reasonable measure.

Reasonable measures for public transit systems would include things like **profitability**, an indication of appreciation by the public in proportion with the expense of the public transit system. Another measure of public appreciation for a transit system would include the **modal-split**, the proportion of all transit consumers using that system. This contrasts with measuring and publishing the large absolute numbers (but small proportional numbers) of transit users, trips, and boardings that public transit professionals often use. It would take a significant percentage of total commuters using mass transit to justify huge subsidies where profits do not exist.

Mobility and Disenfranchisement

Over time, the physical streets, parking lots, and buildings of our cities have been designed to support auto access rather than pedestrian access. We do not approve of this, but it has become a fact of life. For those without easy access to the automobile, the roads and parking lots devoted to the auto become barriers to their participation our society.

Although it is often believed that most people have access to a car, in fact many people do not:

- Those who are poor.
- Those who are physically or mentally disabled.
- The elderly.
- The young who do not yet have licenses.
- People in one-car households where one takes the car to work.
- People convicted of drunken driving.

All these people are denied the benefits of the auto.

Increasingly those benefits are critical to material well being. Buildings, parking lots, freeways, and busy streets all fragment our cities and neighborhoods into islands that challenge the pedestrian (and even the bicyclist). In many cities, it is no longer only an option to own a car. It is a necessity. Only a car can provide the necessary access to such fundamentals as jobs, supermarkets, and schools.

As time passes, infrastructure increasingly adapts to the reality of the automobile. Schools are built larger and larger, drawing upon wider and wider regions for their students. Similar trends are seen in hospitals, police stations, firehouses, retail outlets, and entertainment facilities. At the same time, the mobility of the automobile allows the existence of small specialty facilities that can only build a large enough clientele to be profitable by drawing upon wide regions and large populations.

We can no longer deny all the completely apparent benefits of mobility within our society. Likewise, we must not deny those benefits to the disadvantaged. Disadvantage, however, takes many less apparent forms. Merely having to drive and deal with traffic is a major disadvantage to one who really only wants to get somewhere. Yes, driving is a burden and that burden is not spread equitably.

The burden of helping people get to their destinations falls disproportionately on women. Children must be taken to school, soccer leagues, Camp Fire Girls, doctors, music lessons, etc. The elderly must go shopping, visit doctors, and get to recreation and entertainment facilities. The disabled need to do all these things as well. Those without a family member or friend to help may be forced to use one of the most expensive forms of transportation, the taxi, because it is the only option available to them.

As our population ages, more and more people will be denied the right to drive either by insurance companies who will not sell to the elderly or by failing eyesight, slowed reflexes, or physical disability. Barring some attention to this problem, this will become an untenable situation within the decade as the baby boomers age and the proportion of elderly rises.

While many of the problems of the auto can be ameliorated through better engine technologies, the fundamental waste of natural resources, road capacity, land use, and the safety problems will remain. Despite certain promising technologies, the skill required to operate road-based autos will likely be a constant for our lifetimes. We learn this in the results from recent investigations into *Intelligent Transportation Systems* (ITS), or fully automated automobiles.

A Brief History of Trends in Public Transit

Buses

The first bus service was introduced in London in 1905.[2]

Because buses operate on roads that are already paid for by the public, their capital costs are significantly lower than the cost of trains. They can also travel anywhere a road is available making them more flexible as cities evolve. Operating costs are high because each bus must have a driver. Also, the required vehicle capacity during peak hours becomes a waste of both buses and operators during off-peak hours.

Other problems include:

- The long wait between buses during off peak hours.
- The difficulty in making connections when buses are widely spaced.
- The dangers of waiting at bus stops at night and in remote locations.

---

[2] *This was the last modern innovation in public transit. The monorail in Wuppertal predates this development. Streamlining and elaborating old technologies may provide some improvement, but the fundamental service characteristics remain unchanged.*

Security issues make the bus less than satisfactory for many people such as night workers, the elderly, the physically disabled, women, children, and the bus drivers themselves.

Trains – Light Rail and Heavy Rail

At one time there was a real difference between heavy rail and the small trolleys that people used to get around town. Trolleys were a logical development from the need for **more frequent service in a larger number of places**. The smaller vehicles could be deployed in more places at less cost and thus cover a larger service area for the same price.

Trolleys had their time and were mostly forced out of the transit market in the days before irrational public subsidies to mass transit. Nostalgia aside, trolleys could not compete with the service provided by automobiles. Automobiles leave when you are ready to go. Scheduled trip offerings can not compete with that kind of service.

In recent times the distinction between light and heavy rail has become somewhat problematic. Commonly, subways and elevated trains are referred to as heavy rail, while rail systems on the street are referred to as light rail. There is no distinction in size between heavy rail and light rail. This change seems to result from a warping of the common understanding of the needs of mass transit by comparison with the theories of mass production. Certainly the service and cost characteristics of the trolleys of old has been completely lost.

Rail systems are very costly to build in most urban areas – roughly $300 million per mile for systems built recently. Due to their size and expense they can not be distributed in a nonlinear pattern to match the two dimensional distribution of the population. The older systems are proving costly to operate, and some cities such as Chicago have had to shut down parts of their system due to high maintenance and operating costs.

It is common wisdom that it takes a big vehicle or a train to move a lot of people. But a large vehicle creates a lot of problems. It can not stop in time at lights so traffic lights must be timed. It can not stop for pedestrians so pedestrians must be kept off the tracks. It can not be deployed widely, so certain places must have populations dense enough to provide that big load of passengers for each vehicle.

Light rail, which can operate on surface streets, must contend with pedestrians and auto traffic, and this is a safety problem with light rail. But we have built a modern mythology to justify the use of light rail transit (and the associated subsidies.)

Although trains can provide adequate stress-free service for some people, trains cannot serve the vast majority of people in modern urban areas. Modern metropolitan areas have many commercial, industrial and residential centers**. With a few exceptions, the central city is no longer the dominant travel destination** as there was in the late 19th century when the first urban rail systems were built. Even in a city such as New York, where Manhattan is the major destination, roughly 73% of the people arrive in the metro area via autos and busses, and only 10% by rail transportation.[3]

Only the island cities of Hong Kong and Singapore are not spreading into a vast urban metropolis. The pattern of a spread urban network holds true worldwide, and this pattern prevents any rail system from serving the vast majority of people and their varying trips. Service from the central city to outlying industrial and commercial areas is poor and suburb-to-suburb (beltway) travel by train is virtually non-existent.

Summary

None of the existing transportation technologies for cities can significantly increase transit's share of total trips. Extreme policy incentives – such as free transit passes – could increase the share somewhat,

---

[3] The Public Purpose, published at http://www.publicpurpose.com/ut-nycommuter$.htm

but the basic fact remains that the existing transit technology does not easily take people from where they are to where they want to go at the time they want to go.

What is needed is a mode of transportation that is an improvement on the automobile – a mode which will attract people and provide better service than is currently available. We cannot return to the cities of the late 19th and early 20th centuries. We must prepare for the cities of the 21st and 22nd centuries.

Personal Rapid Transit – The Better Option

PRT Defined

Various inventors and designers have provided similar but not identical definitions of PRT. The Advanced Transit Association took note of these variations and developed a definition in 1989 which is widely agreed upon today. Personal Rapid Transit has *all* of the following characteristics:

- Direct origin-to-destination service with no need to transfer or stop at intermediate stations.
- Small vehicles available for the exclusive use of an individual or small group traveling together by choice.
- Service available on demand by the user rather than on fixed schedules.
- Fully automated vehicles (no human drivers) which can be available for use 24 hours a day, 7 days a week.
- Vehicles captive to a guideway that is reserved for their exclusive use.
- Small (narrow and light) guideways, usually elevated but also can be at or near ground level or underground.
- Vehicles able to use all guideways and stations on a fully connected PRT network.

Note that these bullets define characteristics of service and safety only. PRT is technology-independent, and manufacturers are free to use any technology they choose. For instance, propulsion can be through linear induction motors, linear synchronous motors or rotary motors. Vehicles can sit atop a single beam (a monorail), sit atop multiple beams, or be suspended below a beam. They can use wheels or magnetic levitation. Thus, the terms "PRT," "maglev" and "monorail" are not mutually exclusive. "Maglev" refers to one of several different methods of propulsion and levitation, "monorail" refers to the positioning of the vehicle, and "PRT" refers to the way the vehicles are operated.

Although not required in the definition, the best PRT designs can also be adapted to carry light freight – for example postal distribution, special deliveries to office complexes or shopping malls. A shopping mall might have several PRT stops to serve customers as well as one or more facilities for receiving freight. The same chassis could be used for a vehicle to transport people and for a palletized vehicle to carry freight.

This report provides information on various forms of PRT that are being proposed by their developers. You will see how they appear and their service characteristics. There will also be an assessment of their readiness for deployment in an urban area. We do not advocate any particular approach. Our purpose is to provide information on potential systems and their characteristics.

Detailed Service Characteristics of PRT

Source of this section: Modified by J. Schneider, in 1996, from an article by Remi Kaiser, published in PRT II, 1974, pp 48-49. Last modified: January 26, 1998

The following criteria and features are proposed for use in defining the attributes of an ideal Personal Rapid Transit technology. It is expected that they will evolve over time as additional viewpoints and objectives are set forth. Persons interested in encouraging the developers working in this field are invited to provide their suggestions for improvement in the definitions provided here.

Type of Operation

- Automated vehicles, ticketing and control; 24-hour service, demand-responsive, fully-developed vehicle prepositioning capability (i.e. placing empty vehicles that are ready for use in locations where demand is expected to materialize).

Network Characteristics

- One-way loops, some adjacent for two-way travel in particular corridors, adapted closely to site requirements
- All stations are off-line
- One or more storage/maintenance depots, located to minimize the movement of empty vehicles around the network.
- Distance between Stations: Around 500 meters or less
- Line Capacity: From 1,500 to 8,000 passengers per hour each way; on certain lines with higher capacity to be achieved later
- Station Dimensions: The smallest possible footprint/structure
- Elevation of structure variable, depending on each particular case
- Station capacity: At least 300 passengers per hour per berth
- Station Locations: Sited so that around 85% of potential patrons can walk to/from in 5 minutes or less

Geometric Characteristics

- Minimum radius of curvature: 30-50 meters
- Possible grade: up to 10% possible

Quality of service

- Minimum required characteristics:
  Length of trip, ride time, average speed
  -- 2 km, 6 minutes, 20 km/hr
  -- 4 km, 9.6 minutes, 25 km/hr
  -- 6 km, 20 minutes, 30 km/hr
  -- 8 km, 20 minutes, 40 km/hr

Fares

- Possibility of recovering O&M costs or even covering capital costs and making a profit

Vehicle Comfort and Convenience

- All passengers seated
- Space provided for parcels
- Easy access for elderly people and children
- Special vehicles for disabled persons on call
- Climate controlled

Urban Installation

- Structures should be able to be installed on streets less than 20 meters wide
- Construction should not require substantial disruption to adjacent areas

Visual appearance

- As unobtrusive as possible; structural flexibility designed to be as attractive as possible; customized to satisfy local tastes.
- Stations custom-designed to satisfy local desires Storage/maintenance facilities sited to minimize local impact

Noise pollution

- Much less than that of a heavily traveled arterial street (standards need to be defined)

Cost considerations

- Capital costs: Should, in general, come to between \$10 and \$20 million (1996) dollars per system lane-kilometer (includes stations, vehicles and all other necessary facilities)

Adaptability

- Possibility of increasing the initial capacity later on
- Possibility of improving the initial network as well as extending it into other nearby areas. Possibility of adapting the initial system to new technologies as they become available

Cargo carrying capabilities

- Vehicles capable of carrying containerized and non-containerized goods, automated loading/unloading possible

Manufacturing flexibility

- Maximize use of widely available components having multiple, well established suppliers in most parts of the world
- Modular design capable of being built by a variety of licensed manufacturers

Technology Details

Chapter Introduction

We believe that PRT systems could be constructed using “off-the-shelf” components. Our assessment of PRT state-of-development is that underlying technologies are generally available and could form a base for PRT. Varying degrees of further refinement will be required. As with all engineering endeavors, there will be many trade-offs. In this section we will look at many different aspects of PRT technology, how these are interrelated, and how systems at various stages of development have tackled design challenges.

This chapter divides PRT system attributes into three major categories with a high level of interconnectedness: the **physical system**, the **control system**, and the **end-user environment**. The physical system comprises the guideways, vehicles, propulsion system, and physical guidance system. The control system comprises route planning, communications, embedded control systems for safe motion and the means for emergency control and passenger communications. The end-user environment includes the station and vehicle interiors and various interfaces as well as any accommodation for freight transport. Finally, an additional section covers the special case of dual-mode systems and how these compare to strict PRT.

Much existing work on PRT has focused on the physical system, hence the description of guideway sizes or vehicle passenger capacity is based on vendor documentation and earlier prototype systems. A much more detailed analysis of the approaches used by the surveyed systems is given in the System Evaluations (a separate document in this report). Certain aspects of PRT design, such as control methodologies and user interface issues, are less accessible and often only partially designed in proposed PRT products. There is some literature available and in many cases, guidelines will come from existing standards for other forms of transport. *Care will need to be taken to ensure that the standards used for PRT are appropriate.* Some concepts such as signage guidelines or ride comfort standards may transfer well, while basing control methodology, fire safety, or crashworthiness on standards for large vehicles (such as APM's or rail-cars) may have an adverse impact on PRT system viability.

Other features of PRT, such as fare collection and vehicle amenities, are likely to develop in parallel with PRT systems themselves. Pilot systems will necessarily be limited in their capabilities, but over time will hopefully develop into mature transport systems and usher in new levels of user service, comfort, and safety as well as having a significant positive impact on society. We will cover the attributes expected of initial systems as well as how capabilities might develop.

Physical Facilities

Here we examine what are the most obvious features of a PRT system – its physical aspects: the guideway, the vehicles, the propulsion system, and the lateral guidance system. While PRT may not usher in a revolution in any one of these technologies, it is unique in that it is not constrained to evolve within the constraints of a pre-existing infrastructure. PRT will operate on a widely distributed network of dedicated guideways. Designers can start with a clean slate and creatively combine different technologies to optimize the end product. This also implies a large set of design choices requiring a careful decision-making and system integration process. Below we describe the basic requirements and choices for the guideway, the vehicles, propulsion, and steering. Along the way we also show some of the decisions made for different designs.

1. The Guideway

The guideway is the most visible portion of the PRT system. It is also a major cost, especially in initial systems with small fleets. Guideway design is one of the key enablers of PRT – providing low-cost, inconspicuous infrastructure. Some aspects of a good guideway design include:

- static / dynamic issues: the guideway must provide sufficient structural (and comfort) support and rigidity in all cases (i.e. up to worst case scenario + safety factor)
- it must provide appropriate vehicle interfaces: for propulsion, guidance, and control/communications
- it should minimize cost, visual intrusion and related "barrier" effects
- it should consider future expansion

These goals immediately introduce several trade-offs. Once an actual alignment is proposed, further trade-offs begin which, in turn, affect the choice of guideway. For example, construction at-grade (ground-level) is likely to be cheapest but it also requires significant protection to prevent accidental or deliberate obstruction. It also introduces barriers to other traffic. In many urban areas, suitable rights-of-way are unlikely to exist, although there may be some "natural" alignments such as existing highways, train lines, or rivers. This leaves elevated and underground implementation.

Of the two, elevated is generally less costly than underground, although tunneling may be necessary to penetrate sensitive areas. If much of the guideway is elevated or underground, a more "unconventional" vehicle interface, such as a suspended design, may become attractive. The vehicle/guideway interface is one of the most critical design elements. It constrains both guideway and vehicle design and will have a major influence on the future development of the system.

Guideways can be grouped according to the relative position of guideway to vehicle:

- **Supported** – this is the most common form in transport – the vehicle rides upon the guideway. With PRT, most supported systems involve a type of U channel so that vehicles can choose independent paths with no moving parts on the guideway. Other possibilities include the use of rails, or a dual-mode method where vehicles ride a monorail and switch to a road-type interface at junctions (e.g. RUF). Benefits include a relatively simple interface (e.g. Ultra is based on a road / tire interface), relative ease to install at-grade, and lower overall height. Drawbacks include increased weather exposure and the complexity of banking curved segments.

- **Suspended** – in a number of PRT designs the vehicles hang beneath the guideway. While not common in other transport forms, it is used in niche markets such as factory material handling systems, chair-lifts, and even a metro-system (the famous Wuppertal "Schwebebahn"). Advantages include the ability for the vehicle to automatically bank in curves and better weather protection of running surfaces. Drawbacks include a generally more complex interface, particularly at junctions; and a higher, cantilevered support structure (although there is uncertainty about the extent of cost differentials arising from this). If a system is to include an emergency egress path at all points, this would place a greater burden on a suspended system.

- **Other** – while all surveyed systems fit in the above categories, at least one proposed transit system operates vehicles along both sides of a single beam with path selection made via a vertical switch (Futrex, System21). Another (Cabintaxi) operates vehicles on both the top and bottom of a single beam.

In addition to this break-down of guideway types, there are many additional guideway aspects which drive the design of other system components such as the propulsion method, the maximum vehicle weight, the maximum vehicle speed, and the path selection (lateral guidance) method.

2 Vehicles

While the guideway may be the most expensive and visible part of a transport system, users are likely to identify the system by its vehicles. PRT vehicles are to be personal, to carry individuals or self-determined groups without the drawbacks of mass transit such as intermediate stops or transfers. This implies that vehicles should be small – approximately automobile size. Such size reduction brings many other advantages such as significant reductions in vehicle weight and guideway dimensions. In turn, this results in significant reductions in cost and energy consumption.

While the dictates of the vehicle/guideway interface and propulsion system force a significant portion of vehicle design, many PRT designers agree on the need for small, light vehicles. In the survey group, vehicle sizes range from 2 passenger (e.g. Higherway Dove) to 32 passenger (Swedetrack). Vehicles at the larger end are expected to operate in Group Rapid Transit (GRT) fashion, similar to the Morgantown "PRT" system. Suppliers emphasizing PRT are targeting car-like sizes between 3 and 6 passengers, although some propose a mix of vehicles.

Beyond the basic agreement of approximately car-like dimensions for PRT, there is much variation in vehicle design:

Some systems have designed vehicles reminiscent of public transit: generally with a large sliding door and an open central area with seats on the periphery. The central area is to facilitate wheelchair passengers. While not participating in this survey, PRT2000 is a good example of such a design, since its vehicles are essentially developed to the deployment stage. It is a large, heavy vehicle in which the cabin is separate and rests upon a large bogie (based on a transport van chassis) which rides in a deep, U-shaped track.

Ultra and Frog share similar public-transit-like designs, but they are also more car-like in that the bogie is not separate from the passenger compartment. They both use a simple road interface and hence the overall vehicle (and guideway) height is much less. However, the guideway is still broader than the vehicle, leaving some visual intrusion issues.

Frog goes even further by dispensing with a conventional U-shaped guideway and relying on an internal map and sequence of beacons to traverse a virtual guideway (e.g. a particular path across a paved surface which may be a street or a parking lot). While Frog can operate without mechanical guidance, we would still recommend means to segregate the guideway. A dedicated right-of-way, free of interference and conflicts with other transport modes, is paramount in providing safe and efficient PRT service.

Pathfinder is a suspended design with a similar vehicle cabin. Weight is still expected to be minimal via the use of monocoque fabrication techniques for the cab design and a very modest bogie that runs short distances at low speeds under battery power.

Higherway is a suspended vehicle design with strong emphasis on minimal size and weight. Vehicles resemble glider cockpits (1 or 2 passengers sitting front-to-back) more than public transit vehicles. Vehicle and system performance will be enhanced via relatively high-g maneuvers and emergency deceleration rates. To attain these, passenger restraints are part of the design. Accessibility provisions and transport of bulkier items are foreseen by means of larger, specialty vehicles. Vehicles bank in curves via a hinge between the vehicle and the bogie in the overhead guideway.

Taxi2000 provided inspiration to PRT2000 but maintains a smaller vehicle size. It features 3-passenger cabs with all-forward facing seats. This size is considered optimal for the vast majority of trips while preventing solo passengers in larger multi-vehicle groups. The cab also has a sliding door and sufficient space for a wheelchair facing the side of the vehicle. Like PRT2000 and the suspended vehicles, the bogie is separate from the passenger compartment, but overall vehicle weight is intended to be kept to an absolute minimum via a smaller cab and a simple propulsion and path selection mechanism.

This is merely an overview of vehicle designs, much more detail is available in the System Evaluations (a separate document as part of this report).

In addition to the critical functional design aspects of the vehicle, there are many passenger amenity aspects of significance. These will be covered in a separate section.

3 Propulsion

The requirements for the design of the guideway, the vehicle, and their interface heavily rely on the choice of propulsion system. Many different propulsion systems have been designed and even more proposed. Most of those which advanced to prototype stages are based on the standard rotary motor to pneumatic tire to road surface set of interfaces. These include PRT2000, Ultra, RUF (while off the monorail), Frog, and such older efforts as Morgantown PRT, Aramis, and CVS.

Through-the-wheel propulsion has the major advantage of extensive experience and high-volume production from the automotive sector (or the rail sector for some proposed designs). The entire propulsion system can use off-the-shelf components – even the road surface might be factory produced (and even if poured on sight, production will still borrow technology and equipment from the road construction industry). The major disadvantage is the limited and weather-dependent, variable traction achieved via gravity based friction. For example, the Morgantown system consumes inordinate amounts of energy to heat the guideway in inclement weather in order to ensure sufficient traction. Other disadvantages include somewhat lower efficiency due to the relatively high friction losses in pneumatic tires and the possibly higher noise levels with friction-based traction.

Other systems use wheels for vehicle support but linear induction motors (LIM) for propulsion. Systems that have progressed to a (near) finished product include Cabintaxi and Taxi2000. This technology is already in use in passenger-carrying equipment such as the Vancouver Skytrain. In the survey, LIM's are only proposed on Taxi2000 and Urbanaut.

With LIMs, the issue of sufficient traction does not arise. Disadvantages include a somewhat more complex guideway that may require tighter tolerances. Also, efficiency is somewhat lower (a significantly greater loss than that due to pneumatic tire friction). This is inherent in induction designs. Moving to linear synchronous motors (as proposed by the Aerospace Corp. in the early 70's) greatly improves efficiency but adds significant cost due to permanent magnets (or alternatively, due to large numbers of coils).[4] [i]

A different method to overcoming the limitations of gravity based friction is to run wheels on different guideway surfaces. With a suitably angled surface, wheels experience a force much higher than gravity. Austrans makes use of this concept on a rail-based system. Even higher forces are attainable by clamping the drive wheels (or emergency brakes) to the guideway. RUF makes use of these concepts on its monorail sections (but uses through-the-wheel propulsion during switching or dual-mode operation).

Finally, some systems not included in the survey (notably Skytran) have proposed a maglev system for propulsion (and also vehicle suspension). With the advent of passive maglev, this may prove a very interesting solution. While at least one passenger-carrying maglev system has gone into operation (and since ceased again)[ii], the technology is still considered advanced and not without risk. The systems may also lead to a relatively expensive guideway and/or vehicle due to the large number of copper coils or magnets in the guideway or due to significant cooling requirements (if superconduction were used as with the maglev train designs).

4 Physical Guidance

The physical guidance system comprises the components that physically provide lateral guidance, allowing the vehicle to perform path selection at diverge points. This system is closely coupled with the propulsion system, but again, many different implementations are possible. A common requirement is for the turning mechanism to provide independent path possibilities to many successive vehicles over a short

---

[4] Fundamentals of Personal Rapid Transit, by Jack Irving, Aerospace Corporation, published by Lexington Books, 1978.

period of time. Some systems foresee vehicle flow rates well above 1 per second. Turning mechanisms which are mechanical and guideway-based are unlikely to achieve such rapid switching at acceptable reliability levels. Alternatives include non-mechanical switching, vehicle-based switching, or using smaller numbers of larger vehicles at wider intervals. Rail-based vehicles such as Austrans and Cybertran have opted for the last solution. This moves away from the individual trips of PRT to requiring some level of ride-sharing as with GRT.

Complementing a through-the-wheel propulsion system would be through-the-wheel steering. Frog and Ultra have opted for this (although Ultra may also include curbs and additional, redundant, horizontal guidance wheels). Another possibility is the use of horizontal wheels which can move up and down into channels within the guideway to provide path selection. The method is proposed / implemented on systems such as PRT2000, Taxi2000, and Higherway (which proposes a dual system of steering and horizontal guidance wheels).

Certain systems (although none surveyed in this document) such as Skytran and the Aerospace Corp. system utilize infrastructure based, magnetic path selection in which vehicles are guided to the appropriate path via magnetic force.

The Control System[5]

As described in the ATRA definition, PRT systems are to be fully automated. At present, there are no operational systems which can be compared with what is required of PRT. However, automated mass transit has been operating with a very good safety record for many years. Systems such as San Francisco's BART, Morgantown's PRT, London's DLR, and many APMs and automated Metros around the world show that fully automated transport is technologically viable. PRT control can be thought of as a major evolution in automated control with many of the research foundations already laid by engineers working on PRT, APMs, Automated Highway System projects, and mass transit automation.[iii]

Still, there are different approaches to automation and the expectations of PRT will in many ways push the envelope of present designs. Automated system control can be divided into various levels with different tasks and levels of responsibility for safety and reliability. In general, higher levels of control are more complex and less directly responsible for safety.

Control also relies on vehicle and guideway attributes. The control system will need to incorporate a model of vehicle motion and operate based on how reliably vehicles can comply with planned motion. Components of the control system include:

- Vehicle scheduling
- Vehicle path selection
- Emergency communication systems
- Non-automated operator override provisions
- Operator and passenger inputs to the control system

Another consideration in control systems is the distribution of control mechanisms – these may be incorporated into the vehicle, distributed across the system infrastructure, or managed through a central or distributed control facility. Most likely, some combination of these different levels will be used.

While a detailed analysis of control methodology exceeds the scope of this document, this section is meant to provide an overview of how a PRT control system might be constructed.

---

[5] Control system information adapted from: Markus Szillat, "A Low-Level PRT Microsimulation", PhD Thesis, University of Bristol, UK, 2001.

1 Control levels

In a typical automated transit system, control is divided into levels. These generally trade-off flexibility and safety. The more complex and flexible the algorithm, and hence difficult to verify, the less it should be directly responsible for safety. One possible control concept for PRT is described below. It is divided into 3 levels, which in many ways parallels the control of trains. There, the levels are scheduling, automated train operation (ATO), and automated train protection (ATP).

At the highest level, control algorithms will be responsible for routing and scheduling tasks. This level is mostly concerned with optimizing system throughput and vehicle utilization. Routing deals with moving vehicles from A to B using the most efficient path, where efficiency is measured according to a cost function which is likely to include both user aspects (e.g. minimizing wait times and trip duration) and system aspects (e.g. minimizing congestion and total vehicle km). Scheduling uses similar approaches to distribute empty vehicles to places of known and/or expected demand and to select vehicles for particular trips. These tasks become more important as a system grows in size.

Such optimization tasks are well known in many large systems. For routing, reasonably efficient shortest path algorithms exist. If segment costs are variable and partially based on congestion, this can help to balance loads, although some care must be used to prevent oscillation.

Scheduling is in many respects a more difficult problem. While system optimal algorithms exist for scheduling vehicles given a known, static, origin/destination matrix (a type of linear programming problem which is common in many large systems) – this is not particularly useful in PRT networks. Real systems are not static and place a large emphasis on limiting costs to users (e.g. maximum wait time/trip duration). In many cases, PRT systems will need to use various heuristic methods to respond to immediate travel requests such as maintaining a target number of empty vehicles in stations. If an underlying, static, passenger trip demand (origin / destination or O/D) matrix is known or measured, it can be used to improve performance.[iv]

At this high level of control, safety is a secondary concern and if it were to fail in any manner, the system should ideally suffer only moderate reductions in capacity. At the very least, failure should have no impact on safety. This level is not considered safety critical.

There will likely be some higher level algorithms to assist with platoon formation (if desired), station operation, and merge/diverge operation. It is unlikely that this level will be capable of issuing commands which would cause vehicles to deploy emergency brakes (which would have safety implications).

This level of control interfaces with users who issue trip demands, and also with operators who may wish to tune the routing and scheduling algorithms based on additional knowledge (e.g. sporting events). It provides direction for lower levels of vehicle control by suggesting vehicle paths.

The Automated Operations level is concerned with direct vehicle control. This level issues commands to the motor controller and is concerned with all aspects of normal vehicle operation. This will also include such functions as door operation and operation at points (or switches - here some of the control may be off the vehicle). This level receives recommendations from the higher level which influence its operation. The control strategy is a trade-off between safety considerations and many other system level concerns. Regardless of the criteria, a safe operating space will be defined and the control algorithm is then responsible for producing desirable vehicle operation while remaining in this space and taking appropriate measures if the present state is in violation. This may include deploying emergency brakes. This level of control is safety critical.

Automated Operations would include such user interfaces as door control buttons. Emergency passenger interfaces would also be incorporated at this level (or possibly the higher level where vehicle re-routing and police assistance are required). There are various scenarios in which a passenger would require emergency assistance: a severe operating fault (e.g. obstacle on guideway, vehicle on fire, etc.) which is likely to require an immediate vehicle stop. There is also the possibility of criminal passenger activity where a victim passenger requests emergency aid. The operator may also interface with this level of control to override user requests once the situation has been evaluated.

The lowest and least complex level of control (in terms of decision structure) is the safety watchdog. This monitors the vehicle controller and also receives information from the environment such as radar or ultrasound data. It may also receive independent information of vehicle state (such as additional speedometers). It has a well-defined safe operating space (which must be larger and encompass the safety space of the vehicle controller) and a method of determining the present state. It controls the emergency brakes. These may be simple on/off devices, but in many cases it would be better if there were additional control to regulate their usage based on the level of detected danger.

Automated Protection is likely to have no user input, although a local operator override may be required to allow a vehicle with a failed sensor to be moved to a repair facility. This would be a special event, requiring coordination with other aspects of the control system to clear the relevant guideway sections. Post-emergency behavior will also depend on the nature of the vehicle and guideway designs – for example, whether it is possible to push or tow a failed vehicle through a switch.

2 Differing control approaches

While most systems can be expected to contain some degree of control hierarchy, there are also different control philosophies and to some extent, these influence how such a hierarchy is established. An example is the difference between deterministic and non-deterministic control.

With deterministic control (for example “synchronous” control), all vehicle motion is pre-planned from vehicle departure to arrival at the destination. In such a system, high level control and direct vehicle control are combined. Such algorithms offer the prospect of little or no congestion but have problems dealing with any irregularities (even something as simple as a passenger changing destinations – which may require a large number of recalculations in a system of any size). They may also suffer relatively low capacities. With non-deterministic control, vehicle motion is not pre-planned and congestion is possible, but the system still functions without high-level control and can handle faults well. In fact, some form of non-deterministic control is almost a necessity, to allow a system to recover from faults. Hybrid approaches may plan future motion up to some fixed time point or pre-plan trips but not directly control motion (by giving only suggested directions at diverges and/or suggested order at merges).

Another control method distinction is continuous control (or vehicle follower control) vs. pre-planned motion (or model follower control). In the former, control is based on feedback loops between proximate vehicles. This is closely related to classical control theory. Such control is essentially asynchronous and non-deterministic. In the latter, vehicle motion controllers attempt to track some ideal trajectory, which may be centrally allocated for the duration of the trip (deterministic) or based on local conditions (non-deterministic).

3 Communications

All control methods rely heavily on communications. Links may exist between any combination of vehicles, stations, guideway segments, local control infrastructure, and regional or central control infrastructure. In addition to control signals, the system will also require human communication links – at the least to cover emergency situations. These may be used to provide a lower-cost alternative to an in-vehicle console to permit riders to select a different destination after boarding. Additional data communications may be used to provide riders with information services (e.g. music, video, Internet, etc.).

Between fixed objects, many possible forms of communications exist, just as with any large network – copper, fiber optics, and various RF methods (including microwave and line-of-sight optical methods). For communications between the vehicles and infrastructure, possible methods include RF (which may include a leaky antenna in the guideway), inductive loop, and direct contact - most likely through the power-pickup. Between vehicles: radios, line-of-sight methods, and possibly even ultrasound might be used. Vehicle safety mechanisms might also use methods such as radar or ultrasound, to establish the presence of obstacles.

Note that different control philosophies and control levels have different requirements. High level control may transmit a large amount of digital traffic and routing data. Vehicle control may use one or more analog signals in a feedback loop. Low level control may consist of a system of simple magnets that trip interlock circuitry to verify free path (this last method was used at Morgantown).

Overall, PRT control systems are likely to require significantly higher data transfer rates than typical APM and other automated transit due to much higher vehicle densities, shorter headways, and more complex possible motion. Reliable data communications links are very important for system operation, but their operation may not be safety critical. As is common in many safety critical systems, vehicles could automatically stop (or possibly slow down and proceed on secondary systems such as radar or ultrasound) if communication links are down or corrupted. This is analogous to emergency brakes, which automatically engage if pressure is lost.

If the system can perform sufficiently well without ultra-high reliability communications systems, then it may be possible to adapt low-cost, mass-produced systems such as Bluetooth or wireless Ethernet, although establishing necessary levels of reliability will be up to system developers.

Emergency passenger communications systems should be adaptable from other modes of transit since PRT would not be expected to place much higher demands on such systems. The existing cellular phone network may also lend itself to such communications, if it is shown to have sufficient reliability (operation in tunnels would add an additional challenge).

The user environment

While many different approaches may yield a functional system, the service offered to end users is paramount to a successful system. This section focuses on user interface technology and its importance for passenger perceptions – beginning with a fare purchase and ending with arrival at the destination.

1 Fare collection

Given the flexibility of PRT, there are many possible fare scenarios, some of which may even co-exist on the same network. For example, a PRT network within a shopping mall may be free to patrons, or patrons may get their fares “validated” with a minimum purchase. Employers may provide workers with fare cards valid for travel to, from, and for work.

In most public transit scenarios, passengers would be charged a fare. If PRT is to seamlessly integrate with existing transport, existing considerations may dictate how the fare scheme would operate. At a minimum, PRT is likely to require some form of automated fare-data collection, but even here it is possible to envision a more conventional scenario: patrons insert their fare to pass through some barrier and then operate a vehicle console to choose a destination.

Many PRT advocates foresee sophisticated fare schemes, which provide users and operators with a much more flexible system. This would allow for improved station layouts without barriers (e.g. within buildings) and, in many cases, without personnel. Such a system is likely to include more sophisticated data management by the operator who would maintain a large database encompassing payment details, pre-paid fare levels, passenger profiles, etc. Civil liberty issues would be addressed by establishing which types of information the operator may track, and to what extent the operator may request voluntary information from users for the purpose of improving their service. The system may include different fare schemes for different types of passengers. Simple paper/magnetic passes could encode a single trip for infrequent users. Contact-free fare passes could identify the user to the system and allow for automatic destination selection based on time and location (e.g. a home to work trip for a regular commuter). Other enhanced service features could include automatic entertainment media programming based on rider preferences

Similarly to cars, and to a lesser extent to taxis, PRT fares are likely to be set by vehicles rather than by passengers – this would encourage groups to travel together where it makes sense.

In most cases on most systems, patrons will pay for service and select a trip. Since PRT provides non-stop service anywhere in the network, the passenger will need to identify their destination. For example, they may approach an interactive ticket and information console in the station. For any larger PRT network with hundreds of destinations, the machine will probably require a computerized display with various input methods such as interactive maps, station indexes, or direct input of destination names or codes. Once the patron identifies their choice, they would make payment by an electronic method (credit/debit/fare card) or possibly cash (although this would be a significant cost factor in ticket machine design), and then collect some type of encoded token (which may be the credit/debit/fare card itself). This token would be inserted into the vehicle to identify the trip. To minimize station costs, it may also be possible to pre-purchase fare cards (e.g. from kiosks and stores), insert these into vehicles, and use on-board consoles to select destinations (which, in turn, would increase vehicle costs). With the advent of more sophisticated mobile phones, these could also be used for destination selection and fare payment.

2 Stations

In general, PRT stations are expected to be small, low-cost, and well-integrated in their local environment. Frequent users will take their design for granted, as their navigation becomes second nature. In a well functioning system, PRT vehicles will normally be waiting to serve customers, allowing regular patrons to proceed through the station in seconds as they board the first available vehicle. In general, passengers are not expected to linger in stations, although new passengers may spend some time to familiarize themselves with PRT operation and ticketing issues. Similarly, passengers with special needs may require additional time.

Stations should be designed to maximize their accessibility to people with disabilities and special needs.[v] This would include:

- good lighting
- large and symbolic signage
- tactile and audio feedback for visual impairments
- broad similarity between station designs and layouts (which are based on passenger movement models)
- elimination of barriers and well designed placement of any station furniture (including fare machines)
- visual and audio cues to operate fare machines and vehicles (e.g. flashing, beeping buttons, vehicle announcements)
- level or minimal grade transitions without significant gaps between the platform and vehicle
- elevators on elevated or underground stations.

With sophisticated identification techniques, such features may be tailored to respond to patrons with known needs (e.g. calling the elevator as a wheel-chair user approaches their destination).

Since passengers will generally not linger, this should improve actual and perceived safety at stations. Stations would be well lit, CCTV monitored, and possibly use some form of recognition software to establish if a passenger or other person were spending an inordinate amount of time. System operators could then be alerted to the situation, notify authorities where appropriate, and also use a PA–type system to query or instruct the person in question. If stations were perceived to be well-monitored, this would help to deter criminal activity and reassure passengers. The use of highly visible panic buttons both in station and on-board should provide further deterrence. This, together with the nature of unscheduled, unpredictable, and non-stop PRT service should help mitigate the threat of criminals forcing their way into vehicles. Certainly automobile drivers are in many respects at a comparative disadvantage.

Returning to a typical user scenario: after the patron has paid for their trip, the system must receive a trip request. For seasoned users, requesting a trip may be as quick as using a fare card to board the first available vehicle. Other possibilities include: the act of payment, the use of an information console to directly place a request, a simple call button, or even via a station operator. This last scenario might occur for special forms of transport such as freight or passengers with special needs. Once the system has received the request, it would issue instructions to a local vehicle regarding its new destination, or, if no appropriate vehicle is available at the station, it would direct an empty vehicle to meet the demand.

3 Vehicles

From a user perspective, PRT vehicles should be more comfortable than most existing forms of public transit. In addition to all the benefits of non-stop, on-demand service, users will have privacy, while still allowing for shared usage. Actual vehicle amenities will vary widely between different manufacturers and from installation to installation. At a minimum, all systems are expected to provide seated transport and accommodate wheelchair users and other forms of disability. Vehicles are expected to integrate well with stations and other aspects of the system – for example, the use of uniform symbols and cues, and tight alignment between vehicle floors and station platforms. All vehicles are also expected to meet general standards for the user environment including: ride quality and comfort, lighting, climate, and noise.

The minimal user interface is likely to consist of:

- a device (e.g. magnetic/chip card reader) to identify the trip and possibly the user
- a communications link between the vehicle and the operator - to provide information and instruction in emergencies and to change destinations if no other method is available
- a panic button to notify authorities and/or
- an emergency stop button and an emergency escape mechanism (e.g. hatch, window)

At present, PRT designs are placing value on utility and minimizing costs. Vehicle interiors are fairly Spartan and efficient. However, looking towards a future with large interconnected networks and long duration trips, it seems reasonable to expect that the time and opportunity afforded by a trip in private space with automated chauffeur, combined with advances in mobile technology, could be used to provide many additional improvements.

For small PRT networks with short trips (e.g. <5min), vehicles are unlikely to require significant amenities – their cost is likely to exceed any benefit to the user. As a network grows and trips become longer, amenities will become more important. They should replicate and improve on the amenities available in a typical automobile. They can also provide for additional sources of revenue – both via advertising and through additional user charges. One major PRT amenity is likely to be some type of information kiosk/console. It would perform many functions:

- control other vehicle amenities (e.g. radio station, climate control) and provide a video display and input device for other services (some examples given below)
- provide information about the system (e.g. system maps)
- provide information about the trip – such as information about facilities near the destination station. Such advertising could include various types of promotions and offers to PRT patrons such as reduced or free fares with qualifying purchase
- allow the user to change destination
- allow users to edit system profiles including electronic payment transfer and any type of service subscription

As trip length grows, such a console may be given additional capabilities, combined with other amenities such as:

- radio / music
- e-mail and internet portal
- power source, Ethernet connection, and small table (similar to those provided on airplanes or long distance trains) so users may operate their own laptops and similar devices
- video on demand service, games on demand service

- more detailed trip information such as historical info and a virtual tour guide (e.g. for special fares, users could be given a virtual guided tour of a city)
- on-board snack and beverage service

These amenities are not specific to PRT and are likely to develop in parallel with developments in other transport branches and in other forms of infrastructure. For example, third generation mobile phone networks may provide the necessary bandwidth to accommodate high-speed internet access and provide video on demand service.

For typical users of initial systems, after they have paid their fare and obtained a vehicle, they simply board the vehicle and sit down. The ride would be much like a long elevator ride with a better view. In nearly all cases, no action is required of the passenger. After a vehicle is "claimed", doors open and close automatically (although some systems foresee manual doors on most vehicles – this significantly reduces vehicle cost and may also speed operations), and the user would simply enjoy the ride. Upon arrival, passengers then rapidly proceed through a barrier-less station and get on with their day. Since PRT does not rely on batching, users won't have to push themselves out of crowded vehicles onto crowded platforms.

4 Freight

PRT stands for *Personal* Rapid Transit and this report reflects its role in public transport. However, the prospect of automated freight transport should not be overlooked. Even if the system is designed for passengers, some freight transport in off-peak hours could provide additional revenue. Many of the benefits which accrue via automation and small vehicles also apply to freight. Much freight is transported in larger-than-necessary batches to minimize labor costs. The use of more automated, smaller vehicles could improve efficiency measures and lower costs. It could also reduce warehouse space devoted to moving stock into stores and improve the flow throughout the chain of production by reducing transport uncertainties. This in turn allows reduced inventories, greater throughput, and shorter cycle times.

Details of how automated freight handling may occur exceed the scope of this document. Automated freight has not received adequate attention, just as with PRT, although there are already automated freight/material handling systems of various sizes in operation in specialized environments such as container terminals and factories. Automated material handling is a mature technology, requiring only a public automated transportation network to undergo some of the same changes that the Internet brought to computing systems.

With a combined passenger/freight system, many of the same principles apply to both subsystems: small vehicles, a dedicated guideway, off-line stations, lack of transfers, etc. Some criteria which are important for passengers may not be as relevant to freight. In particular, unless very small, cheap, and efficient vehicles can be developed, some level of batching is still likely to save on vehicle costs. A producer might fill and send a drone to many retailers in a small region, or a retailer might send a drone to many suppliers. Methods for optimizing such commodity flows are well known aspects of logistics and operation management.

From a technology stand-point, some aspects of the system would be generic – or dual-use. These include the guideway, much of the vehicle except the passenger/freight compartment, and most of the control system. In some cases, vehicles might be designed for both freight and passengers, while other vendors, such as MAIT, separate the bogie or carrier from the cabin, allowing for a reuse of carriers for both freight and passengers cabins. Stations are unlikely to be dual-use and freight may also introduce aspects of private vehicles and more complex fare schedules and collection methods. Vendors may wish to "own" a vehicle as it travels to many different destinations – and in some cases, vendors may customize vehicles or cabins due to nature of their freight. This would introduce different challenges such as vehicle parking and different optimization criteria for high-level algorithms (their operation would be different if a particular vehicle or small subset of vehicles must meet a particular demand vs. a large number of interchangeable vehicles). Of course, in many respects, freight vehicles have fewer requirements and might also operate under relaxed safety criteria when in proximity to other freight vehicles.

Dual Mode

One significant rift between advanced transport developers revolves around dual-mode vehicles vs. "pure" PRT with its captive vehicles. While each approach can claim various benefits and drawbacks, perhaps the greatest challenge is in predicting how the future of automated transport is likely to develop given so many different possible scenarios. This section will seek to describe the unique aspects of dual-mode systems, rather than critically evaluate the differences.

In dual-mode systems, vehicles can operate in different "modes" – specifically, they function as a conventional vehicle using standard automotive hardware on normal roads, and they also include control and any additional hardware to become an automated vehicle on a dedicated guideway. With vehicles such as Micro/Megarail, Frog and Ultra (the latter 2 are not initially considered dual mode, but since they use active steering, a pneumatic tire interface and include on-board batteries, such an extension is easy to envisage), switching modes might be as simple as moving onto an automated guideway, while the RUF design calls for the additional hardware of a monorail to provide for a more controllable surface.

Dual mode adds the challenges and benefits of near-door-to-door service using existing infrastructure and private vehicles. In a typical scenario, a user would purchase a dual-mode vehicle. It would have reasonable performance and range for local city driving. RUF also foresees the addition of a hybrid power source which would significantly enhance range. Just as drivers now often head for the nearest highway for longer-distance trips, dual-mode users would head for the nearest automated system entrance. Here, vehicles would undergo a mode shift – generally involving a type of vehicle "check-in" which would verify the vehicle's automated "roadworthiness". Drivers then release control to the infrastructure until they approach the exit nearest their destination and another hand-off occurs. Vehicles are then driven and parked at their destination, as with typical private transport.

In some scenarios, the network includes a dense, PRT-like mesh near the center. Instead of leaving the network, users would exit at a station and a vehicle would be automatically parked and retrieved on user demand. Within this dense network, "pure" PRT vehicles could also operate. Finally, the system may also combine aspects of mass transit such as dual mode buses (e.g. Maxi-RUF) which seek to combine the flexibility of bus routes with the improved capacity and speed of automated guideways.

An alternative methodology is to ferry private vehicles using an automated carrier system. Here, vehicles would park on a carrier which contains the propulsion and control systems. Such a "piggy-back" system which can accept a reasonable cross-section of car sizes is likely to drive up guideway and carrier size and costs. Not requiring special vehicles with limited road capabilities is of course a significant benefit.

From a technological standpoint, dual mode is not a significant departure from "pure" PRT. The road-interface requirement has many obvious implications for vehicle and guideway design. There are also obvious differences in the various user interfaces. Vehicles would likely have some on-board console to control vehicle operation on the network and drivers are likely to subscribe to a service contract rather than the many possible fare scenarios outlined earlier.

Perhaps more important is how dual mode systems would grow – would they tend to move towards high-density meshes which would become very "PRT-like" with a high-density of stations? In such a case, the additional individual and system costs of private vehicle ownership might favor the eventual displacement of dual-mode towards a growing PRT network. Alternatively, the system might develop roughly parallel to highway-type densities, where station and network density is insufficient to attract pure PRT traffic and the system primarily functions to enhance travel speeds of private dual-mode vehicles.

Looming over all PRT and dual-mode scenarios is the possibility of fully automated conventional vehicles. While many serious technological and legal hurdles remain, sophisticated control mechanisms could eventually permit private and/or public vehicles which can run on normal streets and obviate the need for dedicated guideways. However, there are advantages to dedicated guideways, so this wouldn't necessarily always be the goal.

Many of these issues are only likely to be resolved through experience.

Endnotes:

This section contains some useful web-sites as a starting point for further exploration of various topics presented in this section.

An excellent starting point for any study of advanced transportation systems is Prof. Jerry Schneider's website – with links, articles, and pictures of just about every PRT, GRT, dual-mode, and other innovative concepts in any stage of development (or lack thereof): http://faculty.washington.edu/jbs/itrans/ Of course, ATRA also has a useful site at: http://www.advancedtransit.org.

[i] Some information on linear motors as applied to maglev is available in a technical article at: http://ntl.bts.gov/DOCS/TNM.html.

[ii] A passenger-service maglev operated at Birmingham airport (UK) from 1984 to 1995. A bit more info (and some pictures) is available at: http://www.bbc.co.uk/birmingham/news/022001/15/maglev.shtml.

[iii] An excellent web-resource on automated transit control systems is at: http://www.tsd.org/cbtcprojects.htm. It includes links describing the control systems of all the systems mentioned:

- BART: http://www.fta.dot.gov/library/technology/attc.html, home page is: http://www.bart.gov/index.asp
- DLR: http://www.xs4all.nl/~dodger/tech.htm, home page is: http://www.dlr.co.uk/.
- Morgantown: http://www.fta.dot.gov/library/technology/personal-transit/index.html, university site is at: http://www.wvu.edu/virtualtour/morgantown/prt.html.

[iv] Igmar Andreasson describes techniques to achieve this in "Quasi-Optimum Redistribution of Empty PRT Vehicles", presented at the 6th Conference on Automated People Movers. A rather technical FAQ on linear programming / optimization with many links to optimization sites: http://www-unix.mcs.anl.gov/otc/Guide/faq/linear-programming-faq.html. Many websites related to shortest-path algorithms exist as well. One of the best known algorithms was conceived by Dijkstra and searching on his name provides a broad assortment of information on the topic.

[v] There is quite a bit of detailed information on the Americans with Disabilities Act (ADA) guidelines on the web – for example at: http://trace.wisc.edu/docs/adaag_only/adaag2.htm - which includes sections on transit. A more readable guide on accessible public building construction (specifically, libraries in Australia) is at: http://www.openroad.net.au/access/dakit/printdis/pdhandout3.htm.

FAQ for Skeptics

A "FAQ" is a set of "Frequently Asked Questions". This FAQ is divided into topic areas. Each question is phrased skeptically, in order to show what some common causes for concern are.

Cost and Efficiency

Sounds really expensive!

Compared to what? Like any infrastructure, PRT will have significant costs, yet we do not consider building houses without plumbing or wiring. Recognition of the value of an improvement justifies the expense. Long before an investment in massive transit networks, however, PRT will have to prove itself in smaller applications.

Once demand makes deployment inevitable the expense of PRT will fall far below costs for comparable capacity on other forms of mass transit. Compared to conventional transit, PRT can reduce costs - by recognizing the dominant role infrastructure plays. Small vehicles allow small, light and cheap guideways. Small elevated guideways allow small footprints in the right-of-way. Everything works together to reduce the total impact and cost of the system.

Won't a bunch of really little cars (mostly carrying one person) be more inefficient and cost more than running trains and buses?

No. It is inefficient to run large vehicles with small numbers of passengers. This means that it is inefficient to build large systems that can only be used to get to certain places at certain times of the day. It is inefficient to expect large vehicles to share right-of-ways with other types of traffic. Capital investment has been a lesser component of productivity for a very long time now. The major expense to business and society is the cost of people's time. It is inefficient to expect passengers to rearrange their schedules and their destinations around preconceived notions of efficiency. It is most efficient to provide cost-effective widely-available infrastructure that only operates when there is demand, and always operates when there is demand.

Small vehicles can't possibly have enough capacity!

That contradicts everyday experience! By almost any measurement for much of the world, single and low occupancy vehicles carry by far the largest share of all trips.

As a reasonable estimate, Light Rail (LRT) can carry 3500 seated passengers per hour (or 6400 at "standing room only" levels of crowding). Two freeway lanes of single-occupancy-vehicle(SOV) traffic can carry the same number of seated passengers (according to the U.S. AHS website at http://ahs.volpe.dot.gov/). It is reasonable to believe that automated operations on a PRT guideway can easily match this since the AHS people are projecting more than 8,000 SOV passengers per hour (traveling at 55 mph) by using automation.

All this traffic happens on one or two corridors. It is impractical to space freeway lanes apart for greater coverage of a region, but more than practical to space PRT guideways to form a grid for maximum access to the service. Each improvement from automation, each additional guideway segment multiplies the capacity and the coverage provided by the PRT system.

Appearance

<u>Elevated transit is ugly!</u>

It can be as beautiful as a sleek airport terminal or ugly as a highway overpass (or vice versa). PRT will almost certainly not look like massive 1900's elevated rail structures or 1960's interstate skyways. There have been many design concepts to integrate PRT into the urban landscape.

Artist's rendering of how PRT might integrate into the urban landscape of Gavle, Sweden. (graphic courtesy of Peter Kautzky of FFNS Architects, Gavle)

A more modern rendering of a PRT system operating along a street in Cincinnati (Taxi2000 system, courtesy of the SkyLoop initiative. For more info see: http://www.skyloop.org/, graphic courtesy of Bob Broadbeck)

While civil engineers, architects, landscape artists, and urban planners will bear ultimate responsibility, PRT will give them much more flexibility compared to present systems. Smaller, lighter guideways allow shallower and/or longer spans, and possibly tighter curves. These attributes mean running PRT into and through buildings may become common. Shown below is a computer rendering of what such a station might look like.

A computer montage of a PRT system operating within a hotel. Courtesy of SkyLoop (also part of the SkyLoop – PRT initiative, graphic by Bob Broadbeck).

A functional transit system – the Las Colinas people mover, integrated into a shopping mall.

Feasibility

Are the components proven?

Like any new system, the final implementation is sure to cause some hiccups. The underlying hardware is largely proven - many automotive and transit subsystems should require minimal alteration, others will need to be scaled appropriately. Raytheon Corp. has already built and tested one prototype PRT system. One aspect where high-throughput PRT is likely to push the envelope compared to present automated transit is in communications and control.

It may be cute but it won't scale up!

This is where communications and control are important, but once again, existing infrastructure should give us some indication of the possibilities. From the road and rail systems which tie together everything from neighborhoods to countries, to the information delivered through the internet, there are many examples of scaled infrastructure which should provide hope and examples of what works and what doesn't. At some point, standardization will become important for scalability, although without an existing revenue system, concerns about scalability seem premature.

It is unproven!

Every necessary technical component already exists. Aside from scale, similar systems have been operating safely and reliably for almost thirty years (Morgantown). There is no question that PRT systems are within the reach of our society.

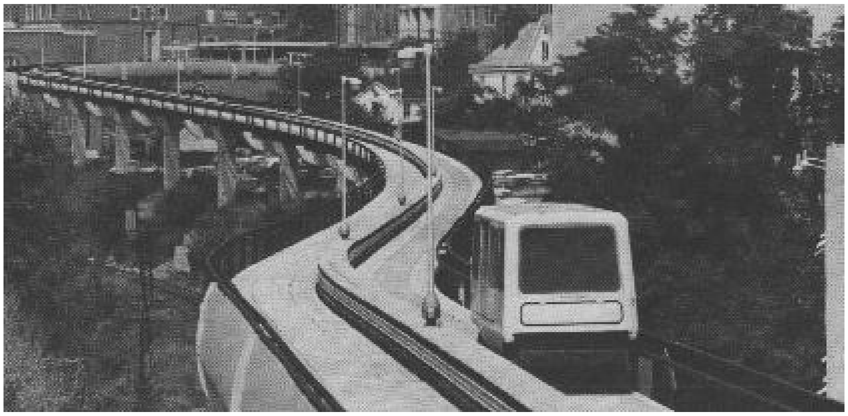
Likewise, proof is a matter of perspective. “Proven” urban transportation systems, including buses, trains, and HOV lanes, have all proven that they can not effectively address the problems of congestion.

So while technically yes, PRT is “unproven”, fear of change should not eliminate innovation and there are plenty of proven systems to guide deployment of initial PRT installations:

The lowly elevator: Probably the most common and oldest form of automated transport. While initially a quite dangerous mode, many safety and control improvements quickly made safe, automated elevators a reality. Today, few people think twice about boarding and operating such a massive, expensive piece of machinery.

Other driverless transit: By the 1960's, computer technology advanced to the point that it could deal with more complex "horizontal elevators". The automated transit age began, along with early PRT attempts. By the early 70's, automated rail systems, such as San Francisco's BART system, came into existence. Today there are many such transport systems - both heavy rail metros and automated people movers. Some APM and metro systems benefited from PRT research, and their experiences will assist PRT development.

Lessons from Morgantown: The automated transit system at Morgantown University in West Virginia is probably the most PRT-like system in revenue operation (it's even called PRT). For over 25 years it has proven to be a safe, reliable form of transport. While technically it is considered Group Rapid Transit (GRT) – as vehicles are fairly large and are shared between users – it does demonstrate the benefits of off-line stations, automated control, and demand-responsive operation (if somewhat limited). A new PRT system would be expected to operate on a more complex network, improve capacity, and use much lighter vehicles and infrastructure.



Morgantown, WV, USA. Group Rapid Transit system in operation.

Lessons from Raytheon: Over the last few years, Raytheon Corp. built and demonstrated that it is possible to build a system which meets all the passenger criteria for PRT. They successfully completed a test track complete with several vehicles and the necessary control hardware and software. While the resulting vehicle and infrastructure are more massive than hoped for, they prove the concept and provide guidance for new systems.

Safety/security

Sounds like a great target for vandalism!

To the extent that vandalism plagues any urban environment, yes. Various technological and psychological methods exist to deter and limit exposure to vandalism. These include: placing stations within other structures, such as shopping centers or hotels with their own security personnel. With good reporting methods, high vandalism regions and times-of-day may be tracked and used to efficiently allocate monitoring resources and also alter system operation to reduce opportunities for vandalism. For example, the operator may decide to hold waiting vehicles outside the station. Since PRT should have low wait times, intelligent CCTV systems may also be used to establish loitering persons for closer scrutiny by system security.

I don’t want to be stuck in a box when the power goes out!

While some people won't ride elevators for various reasons, most do. PRT will be the same. PRT may choose to use multiple, independent power feeds, similar to many existing electrified rail systems. A more decentralized possibility also exists: given the minimal power requirements, vehicles could easily carry batteries to overcome brief disruptions and, at least, bring passengers to the next station.

Why will PRT be safe?

- Placing the guideway apart from other forms of traffic minimizes dangerous encounters between vehicles and people.
- Private trips minimize dangerous encounters between people.
- Human error is largely eliminated by automated operations.

How can PRT handle accidents way up in the air?

As with elevators, PRT accidents are highly unlikely. In the event that you are trapped aboard a stopped PRT vehicle simply wait for help or use the on board phone to call for help.

How can it be safe with all those cars so close together and hundreds of them running everywhere at the same time?

In large systems, safety of the whole is ensured by establishing safety rules which apply at the vehicle level - for example, the "rules of the road", or the system of interlocks which detects trains and operates signals to ensure sufficient separation. While PRT will require different safety rules from trains or cars, the basic concept is the same and automation will eliminate most sources of error.

What will prevent a terrorist from using PRT to send explosives?

In many respects, security and liberty are at odds, and PRT will not be immune to these often conflicting goals. Many of the general methods used to ensure public safety will be applicable to PRT with similar caveats. These might include passenger identification and screening techniques. Some new technology may provide for less intrusive monitoring - such as chemical sniffers. While 100% security is illusionary, prudent safeguards should be employed.

Those little cars sound like a good place for muggers to hide out.

Actually, this is unlikely. Even if an assailant could hide in a vehicle or coerce a passenger to board, the vehicle environment is fairly unpredictable, which should provide deterrence: the assailant's presence might be captured by vehicle sensors or CCTV equipment; his/her trip would almost certainly be tracked, which might include some form of identification; the victim's and vehicle's destination would be random, and any change of course would cause further risk of detection. Stations might pose a greater risk -

How can the stations be safe without security guards?

In the same way that many public spaces become safe (or at least, are perceived to be safe) - by increasing passenger volume, reducing wait times, and by installing good lighting, CCTV monitors, and help/call buttons.

Service Aspects

How is PRT different from other forms of public transportation, like trains, monorail, or bus?

PRT technologies focus on providing passengers the amenities that passenger want, instead of expecting passengers to accommodate themselves to crowds, schedules, and fixed routes. Among the benefits:

- PRT mainly provides trips to individuals but also accommodates small groups of people traveling together by choice.
- PRT will run 24 hours a day and seven days a week.
- PRT will provide nonstop trips.
- PRT trips begin when you are ready to leave.

Since PRT won't come to my home, why would I use it instead of my car?

If you live in an apartment complex or downtown, PRT may very well come to your home. If PRT does not come to your home you will most likely continue to use your car. If you drive to a location served by PRT, you may use PRT by preference before returning to your car to go home. Here are some reasons:

- No traffic jams
- No traffic tickets
- No parking
- No dark parking lots
- No fender benders
- No stop lights
- Less expense
- Less worry about drinking
- No driving
- Never truly lost

Will I have to ride with strangers?

No.

What if I change my mind about my destination while I am already en route?

Use the vehicle console to change your destination. Fees will be adjusted accordingly. In the event that you suffer an emergency, PRT vehicles will include a "911" capability to immediately deliver you to an emergency facility.

If it goes to all these places, it seems like it would take five minutes just to figure out where to tell it to take me.

Like telephones or the Internet, PRT will support a very large number of destinations. We will solve the problem in the same way, by providing an on-line directory service. Like telephones or the Internet, most people will know their favorite destination codes by heart.

What if I have groceries or need to get lumber?

Most PRT systems will fit three or four people, so there should be plenty of room to carry groceries (though if you also have two kids with you, there will be less room for groceries, of course). Putting 2 x 4s or a 4 x 8 sheet of plywood would be difficult in a regular PRT car, but special cars can be designed to handle those types of loads.

How do I avoid having to carry everything with me when I'm making two or three trips with packages.

Lockers could be provided at stations. Alternatively, a place for storing and retrieving a PRT car could be provided.

What if there are no cars waiting when I get to the station?

As with an elevator, push the call button and wait. Unlike an elevator, this should be an unusual event.

How long will I have to wait for a car to pick me up?

Most often a vehicle will be waiting for you. On a well managed PRT system the wait should be no more than the wait for an elevator.

Recommendations

For all of the reasons documented in this report the ATRA Technical Committee unanimously agrees that Personal Rapid Transit is an excellent option for improving public transportation in urban and suburban regions. As aids to the consideration of Personal Rapid Transit for early and widespread deployment, we further propose the recommendations that follow.

Recommendations for local governments and transit authorities

1. Set the minimal technical and service requirements that are necessary to ensure that a privately operated PRT system meets public goals, such as environmental and safety goals (not a wish list, just the absolute minimums). As a baseline, see the suggested minimum requirements below. This can be done without taking on any risk, commitment, or funding any development. This simple public act by one city would improve the investment climate for PRT.
2. Update permitting requirements to sanction PRT and establish public review procedures for PRT operation, whether the operator is a public or private entity. This does not force cities to approve any particular PRT proposal.
3. In a town hall or other planning process, educate the public of the benefits of PRT:
    - 3.1. that risks of PRT deployment are very low compared to other transportation projects,
    - 3.2. that (except in revenue operation) the concepts are proven,
    - 3.3. and that the system can start very small yet still be useful.
4. Obtain a non-binding vote of confidence for the concept from a local or regional planning organization, or at least a relevant citizen board. This act would incur no risks but wold improve the investment climate.
5. In the planning process, and especially when comparing transportation modes (e.g. studies that compare LRT, PRT, and buses), planners should use a robust planning strategy. Specifically:
    - 5.1. Make sure that the plan calls for a solution to well-identified sets of problems, such as access, safety, air quality, and congestion. Each goal should have a quantifiable way to measure it, such as standard pollution measures or average commuting travel times.
    - 5.2. In order to produce realistic reliable and convincing results of the demand for both traditional transit and PRT ridership, the planner ought to consider the following behavior mechanisms:
        - 5.2.1. The trip frequency (with a model for numbers of new trips if the ease of travel improves substantially)
        - 5.2.2. The trip destination (with a model that considers the probability of trips to areas where travel is easier)
        - 5.2.3. The mode choice (with a model that considers the potential for growth in trip frequency due to new and better transit alternatives)

5.2.4. The route choice (with route choice modeled by each transit mode such as bus, LRT, other mass transit, and for PRT)

5.2.5. The behavior of travelers as fully considered in terms of his/her evaluation of walk, wait, transfer and in-vehicle travel times including all time components outside the system, such as access and egress time.

5.3. Require that "least cost" analysis be performed accurately and that the results be used as a basis for financial decisions.

5.4. Insist that any present-value analysis prominently display the discount rate used and justify that rate.

5.5. Insist that costs be compared "apples to apples", including capital costs, interest costs, land acquisition costs, construction costs, operating costs, maintenance costs, and expansion costs.

5.6. Document what will happen to congestion and how, when, and where that effect on congestion will happen, under each of the scenarios being compared. Estimate the effect of each scenario on each of the other quantifiable goals. Use relative metrics such as percentages of the overall traffic, rather than absolute traffic numbers (that may seem large while representing very little). Make the models, assumptions, and data available for review by peers. Examples: *What percentage will road traffic decrease under each scenario? How much will air pollutants decrease, as a percentage of the total? What percentage of total traffic deaths will be eliminated?*

5.7. A rigorous planning process will help cities avoid technology that has already demonstrated an *inability* to solve congestion or meet the other well-identified goals.

5.8. Use equivalent approaches (5.1 – 5.7) to take into account overall resource costs associated with each alternative, including land use optimization, effects upon existing traffic, and any degradation of the environment.

Recommendations for US government

- Create a National Advisory Committee on Advanced Transit, to promote a vision of advanced transit and transportation systems in keeping with currently unrealized technological possibilities, and in keeping with the business and security requirements of an advanced economy. The mandate would be similar to that of the National Advisory Committee for Aeronautics that promoted early airplane developments, and that NASA replaced in 1958.
- Create an agency in the US, similar to the EDICT agency in Europe, which funds demonstrations of innovative technologies.
- Fund applied research on "lean" transit systems to develop standard measures for effective transit systems and to develop enabling standards for vendor interoperability, open markets, and effective use of diverse technologies.

Recommendations for operators[6]

- Assign a third party review engineer to use *Fundamentals of Personal Rapid Transit*, (Jack Irving et al, D.C. Heath, Lexington Books) to check any proposed technology and installation plan. This is relevant because most planners, transportation engineers, and decision-makers are unfamiliar with the unique features and benefits of PRT. The knowledge that has been collected from years of study by various organizations is extensive, but not widely distributed. Many inaccurate assumptions about transit could be avoided with a careful project review using existing literature.
- Obtain a permanent license from the technology owner (developer), which includes specifications necessary to deploy and extend the system using multiple competitive manufacturers.

Suggested requirements for transit permitting

A documented and public government process should authorize transit systems. We propose that such permitting should focus upon public rights and public safety, rather than upon matters of finance or level of service. Those matters will be under *operator* scrutiny, since the operator is responsible for the financial integrity of the system. The public *permitter* who is *not* financially accountable should resist the urge to overspecify business or market requirements, and focus on those requirements that are necessary to protect the public.

The bulleted requirements below are divided into sections to show how the requirements relate to public rights and safety. Some are minimum requirements, and others are preferences, which could be used to either subjectively or quantitatively qualify systems for permitting. For example, a permitting agency could decide to issue a permit for a system that meets any five out of ten preferences.

Protection of urban form and character

- System fits into urban form aesthetically, at least as well as roads and other existing transit. (preference)
- Guideway skyprint less than 3 m (absolute) and preference given if under 2 m, and strong preference if under 1 m.
- The system should minimize real or perceived barriers dividing neighborhoods. (preference)
- The system should be planned in a way that is sensitive to changes in future land use based on new transportation options. The best systems should be movable to new areas and removable in areas where city growth has made them obsolete. (preference)

Protection of existing uses of public property

- Guideway supports would fit into existing street rights-of-way without eliminating a traffic lane or a lane of on-street parking. (strong preference)
- Stations can be building-integrated or stand-alone. (strong preference)
- The system should not impede other transportation, e.g. roads. (strong preference)
- Impact to historic structures should be avoided. (preference)

Protection for private property

Protections for private property parallel those for public property and urban form. Additionally:

---

[6] Operators may be a regional transit authority, a semi-public utility, or a private company. If private, the operator could be same company as the system developer, or could be a separate company.

- Established rights of solar access, visibility, or noise must be honored or compensated. (However, the private property owner may specifically wish to provide a station and an easement for the system.) (absolute requirement)
- Construction impacts should be minimal. (preference)

Safety

(All safety items are minimum requirements.)

- No deaths should occur in the first 10^9 km of operation. Death should be demonstrated to be less than one case in 1 x 10^9 km thereafter.
- Minor injury should be demonstrated under test operation to be less than one case in 1 x 10^6 km.
- The safety methodology should be validated by an independent firm to confirm that the above accident rates are realistic.
- Beam stiffness, strength, etc. engineered properly for local conditions (such as earthquake zone).
- Vehicles must permit emergency egress.
- Egress must be available from all points on the guideway, whether by walkways and ladders, helicopters, or rescue trucks.
- Vehicle must be fire resistant.
- The system must not impose hazards on people outside the system; i.e. the guideway right-of-way must be fully protected from other uses by being elevated, fenced off, or otherwise protected.
- Civil structures located near roadways must resist the force of a crash of the heaviest vehicle permitted on the roadway, OR must be built to withstand impacts according to the local regulations.
- A validation of safety methodology must be performed prior to the first passenger served, and an ongoing proof of safety must be conducted. However, it may be achieved in a variety of ways, which may change during revenue operation. (For example, safety may be ensured initially by running very slow with very large separations, and then gradually running faster and closer as more analysis demonstrates safe and reliable operation.)
- Downed or impassible guideways must be detected, and no more than two vehicles may enter the danger zone from each direction after the condition occurs. (This requirement limits the number of unaffected vehicles unnecessarily thrown into a danger situation, but does not limit the size of the original event.)

Equity

- System is wheelchair accessible, and offers an equivalent level of service to wheelchair users. (absolute requirement)
- System must make provision for use by the blind and the deaf.

Environmental protection

- Energy use less than average car with single occupant (SOV). (preference)
- Noise (external) no more than SOV. (preference)
- Use of the system will improve air quality, as demonstrated by a simulation model showing substantial capture of prior auto traffic. (preference, or as required by applicable laws)
- Impact to wetlands or other sensitive land should be avoided. (preference, or as required by applicable laws)

Protection of public expense

- Complete construction is funded according to the funding plan, and nothing is left to public expense to clean up, such as resurfacing affected roads, environmental mitigations, etc. (preference)
- Multiple manufacturers must be available from which to procure components; therefore, the manufacturing specifications must be available to the operator. (This requirement protects the public from one class of operating failure that could conceivably force public expense to dismantle an inoperable system.) (preference)
- Inoperable vehicles do not disable the whole system, and can be removed from the guideway without demolition. (absolute requirement)
- When and if the system diverts 10% or more of auto traffic, the public permitter reserves the right to enforce reliability requirements, so that in the event of failure, an insufficient public road system is not overburdened. (absolute requirement)

(END OF DOCUMENT)