Personal Automated Transportation:

Status and Potential of Personal Rapid Transit

Executive Summary

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by the Advanced Transit Association

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NOTE: This report is published in a group of documents. This is the summary only. The complete report is detailed on the web site: http://www.advancedtransit.org/pub/2002/prt/. Technology developers provided all illustrations in this section of the report.

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History and Potential

Personal Rapid Transit (PRT) is defined as direct origin-to-destination service with no stops, using small fully automatic vehicles on a dedicated guideway. It promises a low cost way to provide service that is widely dispersed throughout a region.

In 1989, after a one-year study, an ATRA technical committee prepared the report: “Personal Rapid Transit (PRT)—Another Option for urban Transit?” 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. Since 1989, these critical unmet needs and problems have gotten much worse. Therefore, PRT developers have continued their efforts to promote marketable PRT concepts, and many millions of dollars have been spent on development. Considering PRT’s potential, ATRA made the decision to produce this report to help encourage better understanding of PRT for meeting the needs of communities for better, more affordable, and more widely diffused transit service, and to analyze why existing mass transit options cannot make a dent in these problems.

Based on knowledge of the technical and social issues, the majority of the report team 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.

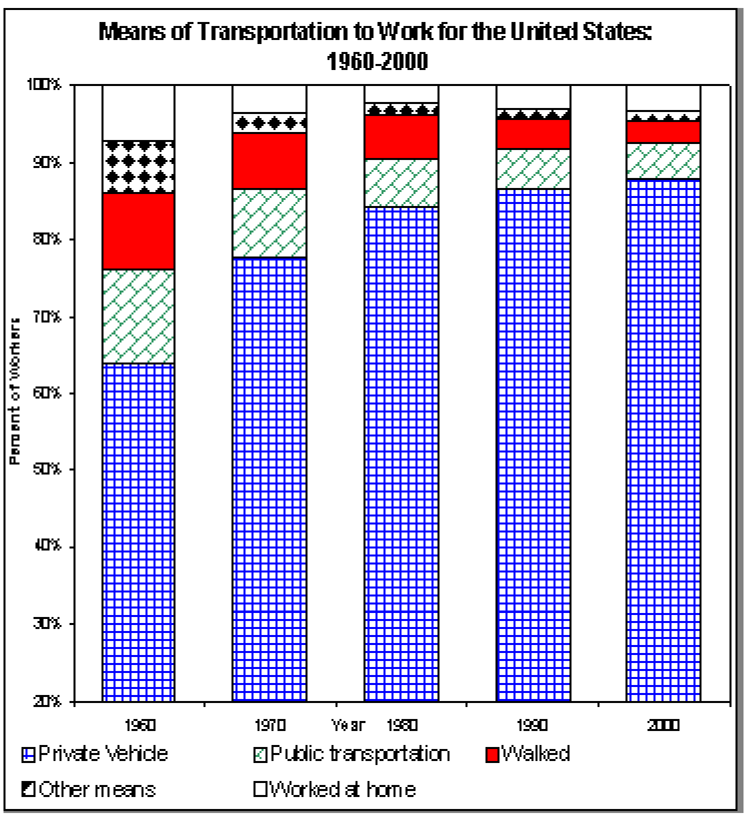
The team also has serious reservations about some of the systems presented. This report is not just a marketing effort to help “sell” PRT, but a critical look at the claims made by system vendors, and where they stand in their development process. The report is a non-profit activity and is not supported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

Rationale and Discussion

The Struggling Transit System

Public Transit

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 transit trips, 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 decreased steadily since 1960.[1]



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

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. Its main drawbacks are cost, environmental damage, poor safety, and time wasted in traffic congestion.

On the positive side, when everything goes well and traffic is light, the automobile is the model of transit service that transit 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. *Any public transit system that can not provide a comparable level of service to that provided by the automobile will not succeed by any reasonable measure.*

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: the poor, disabled, elderly, children and students.

Increasingly the benefits of car ownership 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 most places, 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.

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 and music lessons. 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 land, road capacity, and the safety problems will remain.

Trends in Public Transit

Problems with buses

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 capacity during peak hours becomes a waste of both buses and operators during off-peak hours.

Other problems include waits, connections, and safety at bus stops. 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.

Problems with trains (Light Rail and Heavy Rail)

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. The distinction in the names is largely historical.

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 only be built in corridors, instead of being distributed over the whole area of a 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.

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 it 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.[2]

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, 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.

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

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 are 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.

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.

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.

Please refer to the full report for the complete list of recommendations. Briefly, we propose that ***local governments*** update permitting requirements to facilitate deployment of PRT, and follow rigorous planning, modeling, and evaluation practices so that PRT systems are compared fairly with other systems on the basis of their ability to meet well-defined public goals. We call on the ***US Federal government*** to fund research and development of PRT, and to create a national Advisory Committee on advanced transit.

Other Information Found in the Complete Report

The report can be viewed or printed from the web site: http://www.advancedtransit.org/pub/2002/prt/

Main Report

- History of ATRA's study of PRT
- Rationale and discussion
- Technology details – 13 pages
- FAQ for skeptics
- Complete recommendations.

Technology Evaluation

- A detailed comparison of PRT systems in development. 98 pages.

Supplements

- PRT Ridership Analysis
- Innovative Transit Systems, Survey of Current Developments

Development Status

Purpose and Process

The purpose of this section of the report is to compare and evaluate the specific systems that are in a substantial engineering process. Evaluation criteria are developed under a set of categories. (Criteria are not listed in this summary, but only in the full report.)

Twenty-three vendors below were contacted and asked to participate in the study by answering 19 questions in writing about their systems. In addition, an open invitation was sent to two Internet listservs – transit-alternatives, and alt-transp.

The vendors were able to review the draft study and make corrections before final publication.

Basic description, geometry, and developmental status

Categorization of the systems

The systems can be conceptually grouped as follows. Contact information and web site links can be found in the full report.

Supported, simple PRT:

Austrans
Autran – also provides ferries for conventional cars
Cybertran
Megarail/Microrail – also provides ferries for conventional cars
Mitchell
Taxi 2000
ULTra – also provides pallets
Urbanaut

Suspended, simple PRT:

Higherway – PRT and dual mode
Pathfinder
SwedeTrack – also provides pallets

Other:

Frog / 2getthere – drives on roads
MAIT – concept for handling transport modules across multiple carriers
Ruf – dual-mode

Summary evaluation of development status

This table is a snapshot of the development status of each system – details follow below.

System	Funding to date (2001 M$US)	Development approach	Status
Austrans	5.3	established engineering firm	prototype built, engineering in progress and substantial parts completed
Autran	1.0	private inventor	preliminary design
Cybertran	5.0	US national lab	prototypes built, not final but substantial parts completed
Frog	confidential	small company	prototypes built, engineering in progress and substantial parts completed
Higherway	0.1	private inventor	preliminary design
MAIT	0.1	private inventor	simulation software written
MegaRail & MicroRail	1.0	small company	engineering in progress with limited prototype
Mitchell	2-4	private inventors	prototypes built, proof of concept and detailed engineering
Pathfinder	2.0	small company	preliminary design
Ruf	1.5	university/small company	engineering in progress; a short test track is operating with a maxi-ruf full scale mock-up
SwedeTrack	unknown	small company	preliminary design
Taxi 2000	32.6	university/small company	paper engineering including control system highly developed, but no prototype built yet
ULTra	<10.0	university/small company	prototype built, engineering in progress and substantial parts completed and tested, funding in place for passenger service
Urbanaut	"several"	private inventor	early engineering with mini-model built

Austrans

The Austrans guideway is a double steel rail, like conventional rail except it has a different cross section which allows a secondary wheel to grip the underside. The steel wheels are not flanged like conventional rail wheels, and they are angled out instead of parallel. The modifications to conventional rail make it possible to increase traction, reduce noise, and make sharper turns. Switching is functionally similar to conventional rail. The vehicle seats 9.

Status

Au$10 ($5.3 M US) million has been invested in Austrans R&D over an 11-year period with the bulk of that being spent since 1995.

The state of development is:

- first test track at Chullora, Sydney built and operational
- first prototype vehicle produced and currently undergoing development trials
- vehicle negotiates 8 meter radius curve as designed, brakes and accelerates as expected - about to proceed with testing ride characteristics when negotiating chicanes
- prototype switch constructed and undergoing development - operates in less than one second. Notable for lack of noise.
- station concept and specification completed
- proprietary simulation software developed

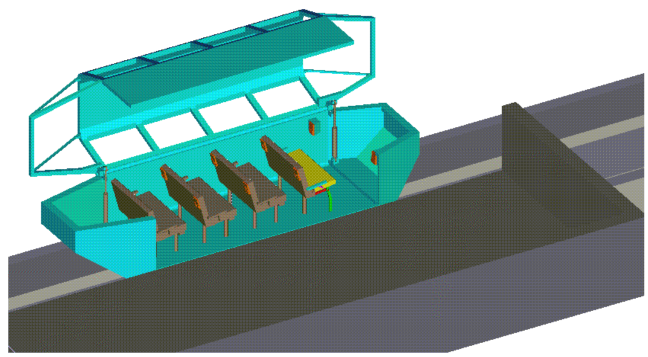
Evaluation

The system fell short on these evaluation points: (1) Rail surfaces are exposed to the weather and so the system may have reduced traction when ice is present. This would influence the safe following distance (which impacts capacity), and could limit grade-climbing ability. (2) Vehicle separations were not reported.

Summary: Austrans appears to be undergoing a rigorous development process, which is not yet complete. We have no reservations about its ability to perform as advertised with the information we have available.

Autran

Autran is a supported technology that resembles the simple supported systems, but also has pallet carriers for cars. The company envisions wide scale networks carrying freight containers, pallets and dual-mode cars as well as PRT/GRT cabins. The PRT vehicle seats 4. The GRT vehicle seats 8.



The guideway is a single box beam with a slot at the top. The wheel set is entirely inside the box beam.

Status

Expenses have not been determined but have been at least $50,000. The investment of time could be valued at over $1,000,000 if measured at rates that could have been charged to others.

Detailed engineering drawings have been made on carrier vehicles and guideways of the system, also for stations that load cars on pallets and for dual-mode cars. No full-scale prototype has been made, but models have been made to test critical aspects of the designs of vehicles.

Evaluation

The system fell short on these evaluation points: (1) The skyprint is “marginal”. (2) There is only one motor in the vehicle.

Summary: Autran is in the preliminary engineering stage.

Cybertran

The Cybertran guideway is a double steel rail, like conventional rail. Single axle propulsion bogies allow for tight turns with low wheel/rail wear and low noise.

The vehicle types have different seating arrangements, but only one body size is proposed. Seating ranges from 6 to 20. Propulsion units are designed to utilize a variety of motors and power transmission units, depending on speed range and power requirements of application. The long 11+m length is partly due to aerodynamic cones on both ends.

Status

Approximately $5,000,000 has been spent to date in developing and testing CyberTran. This sum includes grants and funding from the U.S. Department of Energy and the U. S. Department of Transportation, funding from private companies, equity funding from investors, personal funds expended by system developers, in-kind labor, *pro bono* evaluations, and donations of material and hardware.

Development and testing have been in progress for 12 years to date.

The first CyberTran test vehicle was built and tested at the Idaho National Engineering and Environmental Laboratory (INEEL, a U. S. Department of Energy R & D laboratory) in a year long program from September 1989 to September 1990. Testing and evaluation of the concept continued at the INEEL over the next 8 years with tests on self steering, automated control, vehicle manufacturing techniques, development of a second test vehicle, and evaluation of various guideway designs, passenger handling issues, and safety systems.

Two test vehicles have been built and tested for a variety of operational parameters. Test tracks have been built in Idaho and California for specific tests and a new test track is being planned. Five different test series have been performed with the two test vehicles.

A prototype of the elevated guideway has been fabricated and tested. Design of the prefabricated elevated guideway support column has been verified for use in high seismic zones such as the San Francisco Bay area.

The control system has been defined with computer testing and hardware simulation of the system demonstrated. System operation has been defined and computer simulation of passenger handling has been performed.

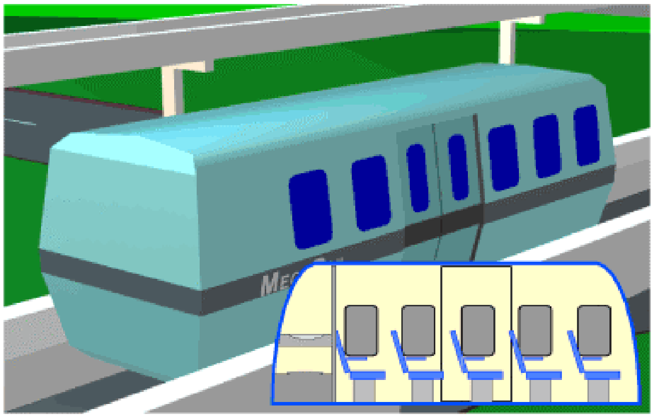
Evaluation

The suitability of Cybertran for use as PRT is restricted due to its long headways of 15 seconds and resulting low capacity. Cybertran apparently has a higher speed intercity market niche in mind, which is different than the urban lower-speed niche envisioned by ATRA. Nevertheless, it could be used as PRT. The system fell short on these evaluation points: (1) The skyprint is large. (2) Rail surfaces are exposed to the weather and so the system may have reduced traction when ice is present. This would influence the safe following distance (which impacts capacity) and could limit grade-climbing ability. (3) Vehicle separations are very large, so the system would have very low capacity in PRT service mode.

Summary: Cybertran appears to be undergoing a rigorous development process, which is not yet complete. We have no reservations about its ability to perform as advertised, with the information we have available.

MegaRail

The MegaRail guideway consists of two steel box beams side by side. Wheels are inside the boxes, and the axle passes through slots on the sides of the beams. This configuration provides weather protection for the traction surface, communications, and power pick-up, and it prevents derailment. It also allows for a very small skyprint. The rail beams are self supporting with no superstructure. Wire mesh spans the space between the rails for use as an emergency walkway, but this is designed to block very little light. MegaRail is a multifunction concept, offering pallet transport for cars, plus GRT and PRT service.



Status

The total value of funding and services committed to development to date has been approximately one million dollars (US). A similar level of additional development funding is planned over the next year. Low level work has been in process for several years, but the development effort was stepped up sharply in mid-2000 following award of a basic U.S. patent covering the system.

A small-scale operating car was built and successfully tested to validate the vehicle steering and switching approach. Detailed engineering drawings for the vehicle, rail and guideway have been prepared. A 1/5-scale prototype is now being built. In addition to the small-scale models, a full-size section of MicroRail guideway has been fabricated, erected, and static load tested.

MegaRail and MicroRail are covered by U.S. and Australian patents and several other international and U.S. patents are pending.

Evaluation

The system fell short on this evaluation point: There are no front windows.

Summary: MegaRail/MicroRail appear to be in a significant engineering effort, but the funding level indicates an early stage of development.

MicroRail

MicroRail is the little brother of MegaRail, and is basically the same thing, only smaller. Vehicles seat 4 passengers. The maximum speed is lower (100 kph) and is more in line with the needs of urban PRT service. Pallets are not offered, but dual-mode cars are envisioned.

See the status and evaluation information for MegaRail.

Mitchell

The Mitchell guideway consists of two parallel 0.15 m x 0.15 m steel I-beams spaced 0.91 m apart, side by side. Each beam is a running surface for the vehicle's wheels. Crossbeams are used to tie the two rails together and transfer load to the piers.

The guideway contains many small motors that physically push the vehicles along. The motors are the basis of the propulsion, braking, and control system.

The small 1-2 passenger vehicle is primarily a passive shell. Its only active component is the switching mechanism.

Status

The development of this system was started in 1967. MTS has built three one passenger sized test tracks. Each track was a 200m loop with one off-line boarding station. The first two tracks suspended the vehicle from the guideway, the latest supported the vehicle. The operational speed was 24 kph.

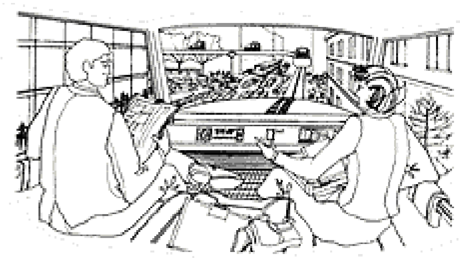
According to the company, "The principals have invested over $300,000 and 42 man-years in the development of Mitchell Transit Systems." The development of this system has now covered a span of over 20 years with limited and interrupted funding.

Evaluation

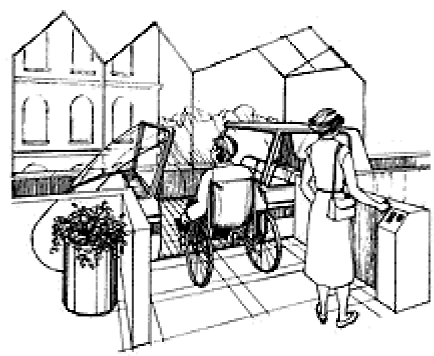
The system passed all evaluation points.

Summary: Mitchell claims its system is 95% complete. We are unable to validate this, although it would prove to be a very low-cost development effort. If 42-man years of labor were included, the development cost would likely be more in line with other systems. We did not understand some aspects of the design.

Taxi 2000



Taxi 2000 operates on top of a guideway narrower than the vehicle. The guideway is a single box beam with a slot on the top and bottom. The entire wheel set is inside the beam and the cabin is above the beam. The wheel set consists of a short front axle and a short rear axle, with four main wheels, plus several lateral guidance and switch-related wheels. The vehicle seats 3.



Status

The design of Taxi 2000 began in 1982. Over $32 million in cash and in kind investment has gone into Taxi 2000.

The Taxi 2000 technology was licensed, altered and further funded and developed by Raytheon. This altered system was called PRT 2000. It progressed to a final working demonstration system in full scale before the project was canceled. Raytheon may also wish to sell that system, but declined to participate in this study.

Quoting the company, "All the research and development work required has been done. Designs for all subsystems have been developed. Programs have been written to study lateral and pitch motion of the vehicles, from which sizes and placement of wheels and other components have been determined. The guideway in straight and curved sections has been analyzed by computer... Preliminary drawings have been done. What remains is to hire an engineering team to update all specifications and build a test system."

"None of the components of the system are developmental - all can be procured directly. The software to operate the whole system has been developed, which we believe is unique. Taxi 2000 has won international competitions sponsored by SeaTac, WA (1992), the Chicago RTA (1993), and the Cincinnati Sky Loop Committee (1998) – see www.skyloop.org. No other PRT systems have won any competitions in which we have participated."

Recently, Taxi 2000 has raised $500k (of $1M sought) for the prototype construction, and component manufacturers have been lined up.

Evaluation

The system passed all evaluation points.

Taxi 2000 is by far the most funded development effort of those listed in this report. Many of the more specialized issues identified as researched and solved by Taxi 2000, such as computer modeling of the vehicle motion, detailed study of forces on each component and required stiffness, etc., were not even mentioned by most other vendors as issues to study, indicating that they may not have gotten that far yet.

Taxi 2000 has not yet built a prototype, but the amount of effort to date (plus the apparent success of the PRT 2000 prototype, which was initially based on Taxi 2000) suggests that a prototype would go likely smoothly according to design.

Summary: Taxi 2000 has undergone extensive engineering, and still needs to build a test system. We have no reservations about its ability to perform as advertised, with the information we have available.

ULTra

ULTra operates on a guideway with a road-type surface and small curbs on each side. The guideway is passive. Power is only supplied in stations or as necessary for recharging vehicle batteries. The small 4-passenger vehicle is car-like with 4 rubber tires. It is battery powered. The company plans future dual mode cars for the same guideway.

Status

ULTra has been in development since 1995. Total investment now approaches $10M

A prototype vehicle was completed March 2000, under UK Government funding.

ULTra won the UK Department of Transport innovative transport competition and is consequently funded for full system design manufacture and test. Two test tracks have been completed, a simple track in Bristol and a more complex figure of eight track in Cardiff with overhead and at-grade sections, and station loop. Testing has been in progress since April 2001. Two types of vehicles have been tested.

The National Assembly of Wales has voted funding to Cardiff County Council to install an operating ULTra system in Cardiff carrying its first passengers by 2005.

Evaluation

The system fell short on these evaluation points: (1) Vehicle separations are not reported. (2) There is only one motor in the vehicle. (3) Rail surfaces are exposed to the weather and so the system may have reduced traction when ice is present. This would influence the safe following distance (which impacts capacity), and could limit grade-climbing ability. (4) There is active guidance, without a passive safety steering feature. (5) The speed is slow, at 40 kph.

Summary: ULTra appears to be undergoing a rigorous development process, which is approaching completion. It appears likely that passenger service will be offered, as the necessary funding has been awarded for this. We have no reservations about its ability to perform as advertised, with the information we have available.

Urbanaut

The Urbanaut guideway (or runway) is a flat surface with a narrow metal stabilizer rail (or fin) running along the center. The guideway is half the vehicle width. The thickness of the guideway is determined by structural considerations only. Vehicles are car-like with 4 rubber tires. They ride on top of the guideway. The smallest vehicle seats 6.

Status

Urbanaut has over the last 10-15 years invested several million dollars in the technology. 3 U.S. patents have been issued on vehicles, propulsion, switching and guideways. Patents have been applied for in many countries. No outside funding has been received in the U.S.

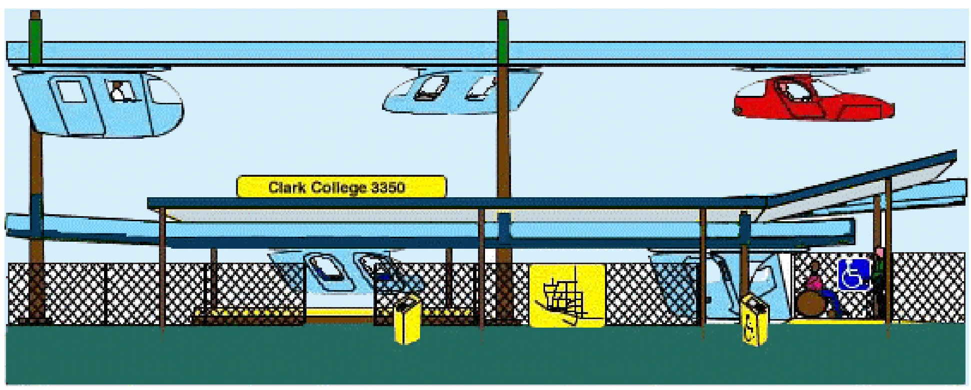
Extensive ProEngineering data, costs, including marketing analysis have been made for all aspects of the Urbanaut concept. A 1:10 Scale operational prototype technology center has been installed incorporating testing of all features, and design for future development and improvement.

Evaluation

The system fell short on these evaluation points: (1) The curve radius is very large. (2) Running surfaces are exposed to the weather and so the system may have reduced traction when ice is present. This would influence the safe following distance (which impacts capacity), and could limit grade-climbing ability.

Summary: Urbanaut is in the early stage of development. It is unclear what the depth and success of the engineering effort is to date.

Higherway



Higherway is a suspended technology offering PRT service, as well as dual mode vehicles. The guideway is formed into a shape that has a box-beam-type part (like several other systems) with various flanges and a utility duct added on in an integrated piece. There are several models of vehicles in development; only the Dove (standard, 2 passengers) and Pelican (wheelchair accessible, 1 passenger) vehicles are mentioned in this report. Specially made dual mode cars and cargo carriers are also in design. The Dove has two seats, one in front of the other (tandem seating). Each rider has a separate door and automatic safety restraints.

Status

Less than 5 years and $5000 have been invested, plus unpaid time by the inventor, which could be valued at $100,000.

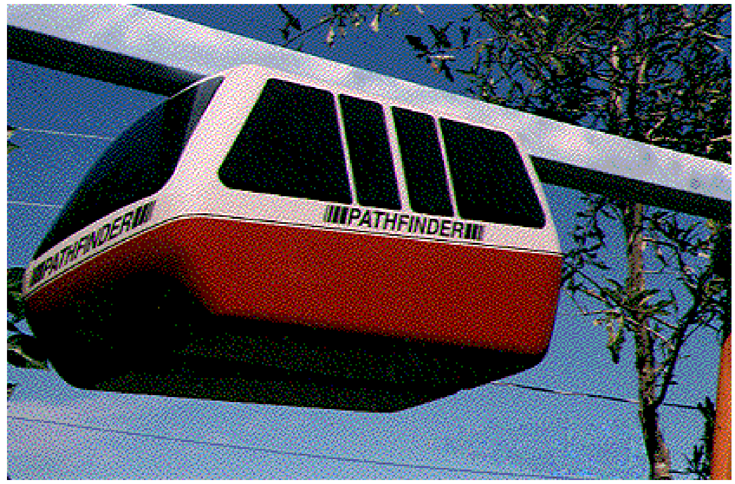
Evaluation

The system passed all evaluation points, at this early stage of development.

The design relies heavily on previous work by the Aerospace Corp., Taxi 2000 and Skytran.

Preliminary design and analysis have been performed, but the system is not fully engineered.

Pathfinder



The Pathfinder guideway is a very small box beam with a narrow slit on the bottom. It is passive and unelectrified in most sections. The vehicle holds up to 4 passengers. The power unit and wheels are inside the box beam, and the cabin hangs from a narrow support that passes through the guideway slot. The vehicle is battery powered and recharges in stations. Switching is done by the vehicle.

Status

Pathfinder Systems has been in development since the 1960's. During this time they have conducted engineering, marking studies and supported local governments in PRT feasibility studies. They estimate expenditures of over $2 million.

Quoting the company, "Pathfinder Systems has completed preliminary engineering and product definition studies. We are in position to begin a three-phase development program of component development, prototype assembly and test and production design and test, as funding becomes available. According to our 1998 studies, an initial system could, under the right conditions, be in service in about three years."

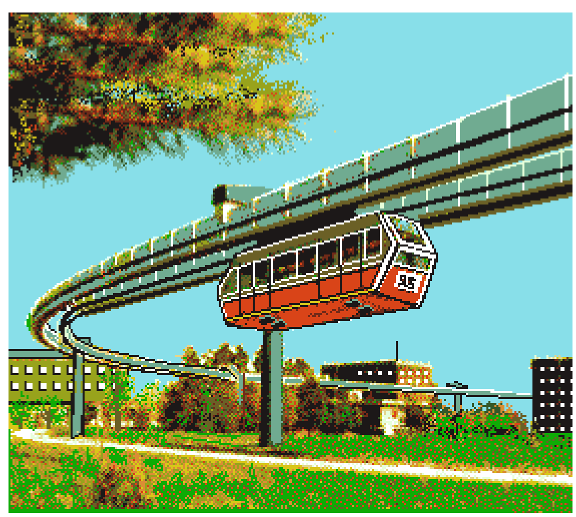
Evaluation

The system passed all evaluation points.

Summary: Pathfinder has started the engineering process but it is still early in development.

SwedeTrack

The SwedeTrack guideway is a box beam with a narrow slit on the bottom. Three sizes are proposed. Each size corresponds with a maximum vehicle width, a maximum load, and a diverse set of vehicle sizes. The vehicles are composed of two or three parts that can be interchanged. The "drive wagon" (bogie, wheel set) is inside the box beam. An elevator component hangs from the drive wagon. The passenger or freight cabins hang from the elevators. The vehicles range in capacity from one passenger on up to large vehicles.



Status

Funding has been received from the city of Gothenburg, Stockholm and the Information Technology Delegation.

Evaluation

The system passed all evaluation points, at this early stage of development.

Summary: SwedeTrack is in preliminary design, or more appropriately, concept definition.

Frog

Frog is a technology that can be used to provide PRT service, but its primary intention (at least initially) is to provide feeder service to existing mass transit stations. Unlike some other systems, Frog is intended to be viable in very small applications, such as a single parking lot. Vehicles drive on a standard road surface with no physical guidance at all. Extensions of the track can easily be realized by adding reference points to the track (magnets) and editing the layout in the supervisory computer. Mixing with other traffic will become possible in the long run using this technology, but not at present.

Status

Development of the technology started in 1984. Development of the vehicles for passenger transport started in 1995. The development department is constantly upgrading the hardware and software. The number of man-years and the development costs are confidential.

SuperFROG, the control system, has been totally developed and operational for over 10 years for indoor industrial applications and outdoor industrial and people mover applications.

Two pilot projects, with a total of 7 vehicles seating 10 passengers each, have been installed and have been operating since 1997 and 1999 respectively. One of these pilot projects will be continued and expanded with new, second generation vehicles in 2003. Another system will be installed in the beginning of 2002, using vehicles seating 4 to 6 passengers. For this system two prototypes have been built for testing purposes. In total 25 vehicles will be operational at this site.

Evaluation

The major obstacle to implementing Frog as PRT is that its originally intended market niche is apparently to serve ground level short-distance group transit needs exemplified by parking shuttles. In order to be used as PRT, the smaller vehicle would be used, and grade-separated roadway would be built. This would be doable but is apparently not the company’s current focus.

The system fell short on these evaluation points: (1) There is only one motor in the vehicle. (2) Rail surfaces are exposed to the weather and so the system may have reduced traction when ice is present. This would influence the safe following distance (which impacts capacity), and could limit grade-climbing ability. (3) There is active guidance, without a passive safety steering feature.

Summary: Frog may be undergoing a rigorous development process, which is not yet complete. However, we do not have enough details to be able to evaluate their level of effort and success to date. The company has a transit system in operation, but not offering true PRT service.

MAIT

MAIT is a company that will not actually provide a PRT system, but is designing a standardized vehicle transfer mechanism that will allow a passive cabin to move among many different, separately developed, transport carriers.

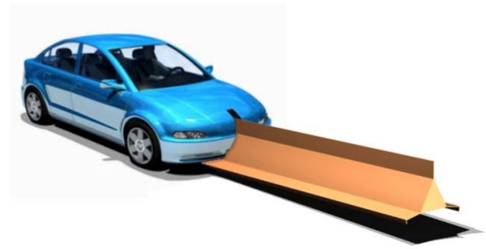
The carriers could be low speed or high speed, entrained or not. They could be road trucks, automated guideway carriers, or any other vehicle type. The thing in common with all carriers is their attachment mechanism.

The loads, or charges, could be passenger cabins or freight containers. They could also be designed in many different ways, but would have a standard attachment mechanism.

MAIT is not included in many of the evaluation sections in this report because it is not in itself a complete PRT system.

Ruf

Ruf is a dual mode system offering both individual cars and buses (called maxi-rufs). Unlike any other system evaluated in this study, Ruf is pure dual mode, as opposed to PRT with a dual mode option. In order to include Ruf in this report, we are evaluating it solely on the basis of how well it can perform in PRT mode, which is not its primarily intended usage. The system may suffer in this evaluation because of that mismatch of goals.



The Ruf monorail guideway cross section is a triangle with the flat side on the bottom and pointed on top. The guideway is passive and contains no switches. The vehicles have a triangular (prism-shape) cutout on the bottom which fits the guideway. Vehicles have two sets of wheels. The road wheels are standard auto tires. The guideway wheels make contact with both sides of the triangular guideway. Externally only the road wheels are visible. The guideway shape facilitates the transition from road driving to guideway driving, without having to stop.

Status

RUF has been under development in Denmark since 1988. It has been funded by private and public money. The total development cost so far is in the order of magnitude of $1.5 million. Two EU programs are now supporting RUF with additional funds.

A fully functional test track and a 1:1 operating Ruf has been built and is currently being tested at the University of Applied Sciences in Ballerup outside Copenhagen, Denmark. The test vehicle is able to show most of the basic functions of a Ruf, but more development is still needed.

A 1:1 mock-up of the maxi-ruf has been built and a 200 m expanded test track has been planned and prepared for. The ground is available and ready and the material has been donated by the Danish Steel Works, so it is ready to be erected.

Software has been written for simulations, travel demand and flow, and energy use.

Evaluation

The system fell short on these evaluation points: (1) The curve radius is marginal. (2) Rail surfaces are exposed to the weather and so the system would have reduced traction when ice was present. This would influence the safe following distance (which impacts capacity), and could limit grade-climbing ability. (3) There is active guidance in switches, without a passive safety steering feature.

Summary: Ruf is in the early or middle stage of engineering and appears to be undergoing a rigorous development process.

Evaluation of visual/geometric factors

In order to make a comparison of the visual obstruction of the various systems, we invented a term and measure for the purpose. A "skyprint" of an elevated guideway is the amount of the sky it blocks when viewed from a 45 degree angle from beneath. In order to make the comparison independent of the viewing distance, it is not stated in degrees, but rather distance (in meters).

All systems had smaller skyprints than any elevated rail system. The largest skyprints are Cybertran (3.0 m) and Autran (2.3 m). Higherway, Mitchell, Pathfinder, and Ruf have skyprints under 1 m, and the others are between 1 m and 2 m.

Other factors are similar in most systems, in terms of the ability to fit into an urban landscape. All systems have the option of a small curve radius, except Urbanaut.

Evaluation of development status

You cannot purchase a working PRT system off the shelf today, because all the vendors specify that they need more development funding. However, instead of continuing further PRT engineering effort in isolation, we recommend that several gaps between potential vendors and customers be bridged:

The first gap is policy, including regulations covering rights of way, visual rights, liability, safety, and a long list of factors for which there are no current regulations, and that are not on government agendas currently. The effort required to close the policy gap is potentially much larger than the effort of PRT vendors to redesign systems to meet clear requirements. So, in this area, the engineering isn't the main issue.

The second gap is investment risk. Once regulations and public/private contracts are established , private investment money becomes more protected, and therefore more available.

Based on their knowledge of the technical and social issues, the majority of the report team 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. We believe some of the systems are ready for full scale demonstration projects for practical use. In fact, ULTra is embarking on such a project at the time of this publication.

We promised the vendors not to publish any points or ranking of the systems, but this does not mean that we are trying to "equalize" them. Of course, some systems are much further along in their engineering than others.

Other evaluation points

Vehicle, passenger comfort

Wheelchair accessibility

All vendors proposed wheelchair accessible vehicles.

Vehicle size

All vendors meet the basic requirements of 2 seated passengers.

Vehicle weights are generally reasonable and in the range of 100 to 200 kg per seat (empty).

Passenger capacity ranges from 1 to 20. Some vendors have pointed out that their studies indicated no substantial savings in decreasing vehicle size below 3-6, so a 1- or 2-passenger vehicle may have no particular benefit. A vehicle holding 6 or more passengers would very rarely be used to capacity in PRT mode, and larger ones are probably intended for GRT service.

Accelerations

Most systems reported normal accelerations in the range 0.2 – 0.25 g. Those that go up to 0.5 g would be beyond a comfortable limit for normal operations, according to traditional transit approaches. However, 0.5 g is common in airplanes. If permitted, these higher accelerations could reduce the length and cost of on-ramps.

Propulsion system, grade, traction

There are several different kinds of motors and drive systems proposed, classified as follows:

1. in-vehicle rotary motors using power continuously supplied by the guideway (most systems)

2. in-vehicle rotary motors using battery power, with a system for recharging batteries (Frog, Pathfinder, and ULTra)
3. linear motor, with passive side mounted on guideway and powered side mounted on vehicle, using power continuously supplied by the guideway (Taxi 2000)
4. guideway-mounted motors that physically push the vehicles (Mitchell)

Evaluation of propulsion systems

- Grade-climbing – Among systems where grade-climbing ability is reported, all meet the suggested minimum of 10%.
- All-weather traction – Several systems raised concerns for the committee about all-weather traction. Systems having rail surfaces (or road-like surfaces) exposed to the weather would have reduced traction when ice was present.
- Battery recharge time – Frog, Mitchell, Pathfinder, and ULTra use batteries which are recharged in stations. In order to add credibility to these systems, vendors should demonstrate with a simulation model that the available recharge time is sufficient to keep up with demand.

Switching and steering

There are two classes of switches. In guideway-based switching, the guideway physically moves, similar to train and monorail and almost all other transit systems ever built. In vehicle-based switching, the guideway has no moving parts, and the vehicle moves a wheel or other device to cause it to either follow the left track or the right track.

Most of the systems use vehicle-based switching. One system uses a combination of the two.

The committee sides with the majority of developers in the thinking that a vehicle-based switch is an improved design over a conventional rail switch. Its advantage with regard to vehicle spacing is that two or more vehicles can be in the diverge area of a switch at the same time and be going different directions. If any moving parts are used in the guideway, the leading vehicle has to completely traverse the diverge section, and then time must elapse for the switch action, plus enough time for switch verification and an emergency stop should the switch or sensor fail, prior to the next vehicle entering the diverge section.

Control, reliability, capacity, related information

Theory

Headway is the spacing from one vehicle to the next. ***Safe stopping distance*** is the distance that is required between vehicles, such that if the leading vehicle stops unexpectedly, the following vehicle can stop safely without colliding. In rudimentary theory, safe stopping distance increases proportionally to the square of the speed. The time between vehicles traveling at a safe stopping distance increases proportionally to the speed. Therefore the higher the design speed, the lower the capacity, other factors being equal. Car drivers typically exhibit the unconscious behavior of increasing their following distance proportionally to the square of their speed at speeds over 50 kph, confirming the basic theory.

In the case of highways, the ***load*** is an independent variable: the number of cars entering the highway is uncontrollable. The speed of the resulting traffic flow depends on the load: the more cars, the slower they go. With PRT, however, load is a controlled variable, so that congestion does not occur. If the demand for the system is more than the capacity (at the optimal speeds) then the riders must wait at the origin until there is room. Then, once there is room, the trip proceeds without delays.

Safe stopping distance is not necessarily a requirement between *every* vehicle. There are two kinds of emergency stops: brick-wall, or sudden stops, and gradual stops. Brick-wall stops would occur if a tree or other large object fell on the guideway. Gradual stops would occur under most classes of vehicle or communications malfunction. If a vendor can show that brick-wall stops are very unlikely, and that collisions caused by brick-wall stops are not fatal, then the risks of a system that operates below safe stopping distance (for brick-wall stops) is a justifiable risk to take. We propose customer-oriented requirements on this topic in the safety section of this study.

When studying PRT, ***capacity*** should refer to vehicles, not passengers. Vehicle loading is likely to be the same for any system running in PRT mode, regardless of vehicle size. For the purposes of this report, we are assuming that the systems billed as PRT, as well as those systems with larger vehicles (such as Austrans and Cybertran) will all be running in PRT mode, that is, serving only one passenger at a time or a group wishing to travel together.

Note the difference between two types of capacity:

- Line capacity – generally measured as the number of vehicles passing a point on the guideway per hour (e.g. 2,000 vehicles/hr).
- Network capacity – the number of passengers that can be served in a PRT network per hour or per day. Or, this can also mean the average of all line capacities for a given network.

Capacity isn't the key issue when choosing a transportation solution. Higher capacity isn't necessarily better. The issue with regard to quantity of service is: how much does it cost (how many guideways and stations) to serve the actual ridership demand? The vehicle separation (corresponding to line capacity) is one input into a model that can predict the answer.

Evaluation of separation and speed

There is great variation here in design approaches. ***Speeds*** range from 32-50 kph on the low end of design speed, to 150-200 kph on the upper end of maximum speed, with one extreme case, Mitchell, claiming a theoretical maximum of 480 kph. Most systems claim to be able to go over 100 kph, and there is no reason to doubt this, since many trains and light rail and other systems in operation achieve this speed.

Vehicle separations are mostly in the range 0.5 –2.0 seconds (s), with two systems at 5 s. CyberTran is much higher, and would therefore have very low capacity in PRT service mode. On the low end, Higherway, MegaRail, MicroRail, Mitchell, and Ruf claim sub-second separations. These systems rely on physical traction to maintain safety at the close spacing. Taxi 2000, at 0.5 s spacing, does not depend on physical traction, since the linear induction motor accelerates and decelerates the vehicle.

Evaluation of control and related factors

The basic requirements of a control system are that it must (1) safely react to failures, (2) not rely on a central control tier, and (3) isolate and continue to operate around disabled areas. It is far beyond the scope of this study to evaluate whether the proposed systems will meet these requirements. It is noted that the control strategies are remarkably similar, and that on the surface, there are no apparent problems with any of the approaches.

Development of the control system is an expensive item that has not been completed by most vendors (see section on Development Status)

Environmental, energy

External noise

It appears that noise will not be a problem for any system, based on a few estimates and a knowledge of the technology compared to other vehicle types. Basically, electric motors, light vehicles, and smooth running surfaces are a feature of every system, and these ingredients are a good recipe for a quiet system.

Energy use

Estimates for PRT energy consumption have a fairly broad range. All systems plan to operate electrically, eliminating vehicular air pollution. Vehicles are generally expected to exceed current passenger vehicle efficiency levels, although some larger vehicles have significant energy requirements.

A current passenger car uses about 370 Wh/km, after converting energy units to their electrical equivalent. By comparison, proposed PRT systems will use from about 60 Wh/km to 390 Wh/km.

Safety

All systems take safety very seriously, but there is of course no safety data from operations. Because safety could not reasonably be demonstrated with a small test system, it would have to be demonstrated in revenue operation. The catch is, of course, that a revenue system would not be permitted until safety standards were demonstrated. There is a way out of this catch, however. A system operator wishing to install a new system can start out with longer headways or other control system measures until enough data accumulated to prove the reliability, then shorten the headways and increase capacity later. This approach would meet public safety the requirement while allowing testing during revenue operations.

In addition to this approach of demonstrating actual safety statistics, an independent engineering firm would have to validate the safety methodology of the system vendor.

Cost and value

Component costs

We asked the vendors to provide cost information on vehicles, guideway, and tradeoffs.

***** Please do not compare these cost numbers directly, because different systems may classify costs differently. Contact the vendor for their latest cost estimates for a particular application. *****

Responses from vendors were as follows:

System	Guideway (M$/km)	Vehicle (k$)	Notes, Justification
Austrans			not supplied
Autran	1.3 (e)	20	costed by principal in company
Cybertran	3.1 (bep)	100	costed by four separate large firms and based on prototypes
Frog (CyberCab)	unknown	63	based on pilot project
Higherway	2.0	unknown	preliminary estimate
MegaRail	1.3 (ep)	18	preliminary estimate
MicroRail	0.8 (ep)	15	preliminary estimate
Mitchell (ADA)	1.5 (ep)		cost based on bids by manufacturers of the prototypes
Pathfinder	12-15		includes stations; estimated by principals in company
Ruf	2.2	20	estimated by principal in company
SwedeTrack			unknown
Taxi 2000	1.6 (ep)	26	costed by a university and three other large firms
ULTra	1.5	50	actual cost of prototype
Urbanaut	4.5 (ep)		

Notes on table – what costs are included in estimates

(b) bi-directional

(e) electronic guideway based control system
(p) power substations, transformers

Component cost evaluation

A review of the component costs yields these results for PRT in general:

- Most guideway costs are in the range of $1.5 to $3.0 M per km
- Most vehicle costs are in the range $26 to $50 k.
- We note that a lot of work has gone into costing, and that the results of those separate studies for different systems yield costs in the same ballpark. Therefore we accept the cost ranges given as legitimate by a factor of 2.
- Central control, communications, switches, and a maintenance facility are small costs compared to guideway construction (assuming at least 10 km of network), so can be left out of preliminary estimates.

Capital cost of 10-km system (system-independent)

A customer could reasonably expect to procure PRT at the rates listed below, or could use these for urban planning purposes. The customer could multiply the final result for a 20-km system, 30-km, etc. for a very informal method of costing PRT. The table is listed for 10-km, which is the distance of all the network segments added up.

Component	Unit Cost	Number	Total (k$)
Guideway – straight	2,300 k$/km	8	18,400
Guideway – curved	3,400 k$/km	2	6,800
Vehicle	38 k$ each	100	3,800
Stations @ 2/km	250 k$ each	20	5,000
TOTAL			34,000

Therefore capital costs might be around $34 M for a 10-km network. (for preliminary planning purposes)

That's $3.4 M per km, or a little over $5 M per mile.

Developer Contact Information

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Urbanaut	Einar Svensson svensson@empnet.com no web site	

[3] 2getthere is a new subsidiary of Frog Navigation Systems, but in this report we continue to use the name Frog since the change was made while the report was in development.

System Name	Contact Person, email, web address	Postal address, Phone (USA unless otherwise noted)
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(END OF SUMMARY REPORT)