How Innovation can make Transit Self-Supporting[1]

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Introduction

In spring 1989 I was informed that during a luncheon attended by a Northeastern Illinois Regional Transportation Authority (RTA) Chairman it was agreed that "We can't solve the problems of transportation in the Chicago Area with just more highways and more conventional rail systems. There must be a rocket scientist out there somewhere with a new idea!" The Illinois Legislative Act that established the RTA had given the new agency an obligation to "encourage experimentation in developing new public transportation technology."

The new idea they needed was and is High-Capacity Personal Rapid Transit, a version of which is illustrated in Figure 1. A March 2006 European Union Report concludes: "The overall assessment shows vast EU potential of the innovative PRT transport concept" [1].

Figure 1. High-Capacity PRT

In April 1990 the RTA issued a request for proposals for a pair of $1.5 million Phase I PRT design studies. Two firms were selected and after the studies were completed the RTA selected one of the designs, similar to that shown in Figure 1, for a $40 million Phase II PRT design and test program. Unfortunately, that program was not directly successful, not due to any flaw in the basic concept of High-Capacity PRT, but to institutional factors. There is more and more evidence that HCPRT is an important answer to many urban problems.

The Problems to be Addressed

- Increasing congestion
- Dependence on oil
- Global warming
- Expensive & land-consuming parking
- Excessive energy use in transportation
- Many people killed or injured in auto accidents
- Overwhelming dominance of the auto

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- People who can't or should not drive
- Road rage
- Terrorism
- Excessive sprawl
- Large transit subsidies

Rethinking Transit from Fundamentals!

To address these problems, a new transit system must be

- Operational with renewable energy sources
- Low enough in cost to recover all costs from fares and other revenue
- Low in air and noise pollution
- Independent of oil
- Adequate in capacity
- Low in material use
- Low in energy use
- Low in land use
- Operational in all kinds of weather, except for extremely high winds
- Safe
- Reliable
- Comfortable
- Time competitive with urban auto trips
- Expandable without limit
- Able to attract many riders
- Available at all times to everyone
- An unattractive target for terrorist attacks
- Compliant with the Americans with Disabilities Act

Derivation of the New System

It will not be possible to reduce congestion, decrease travel time, or reduce accidents by placing one more system on the streets – the new system must be either elevated or underground. Underground construction is extremely expensive, so the dominant emphasis must be on elevation. This was understood over 100 years ago in the construction of exclusive-guideway rail systems in Boston, New York, Philadelphia, Cleveland, and Chicago. The problem was the size and cost of the elevated structures. We have found that if, as shown in Figure 2, the units of capacity are distributed in many small units, practical now with automatic control, rather than a few large ones, and by taking advantage of light-weight construction practical today, we can reduce the weight per foot of guideway by a factor

Figure 2. Guideway Weight and Size.

of at least 20:1! This enormous difference is worth pursuing.

Offhand it is common to assume that there must be an economy of scale, i.e., the cost of large vehicles per unit of capacity must be lower than the corresponding cost for small vehicles. Examination of data of Figure 3 show, however, that this is not so. Each point in Figure 3 represents a transit system. The two upper points correspond to systems developed by the federal government in the early 1970s when cost minimization was not a design criterion. For the rest of the systems shown, a line of best fit is close to horizontal, i.e., vehicle cost per unit of capacity is independent of capacity.

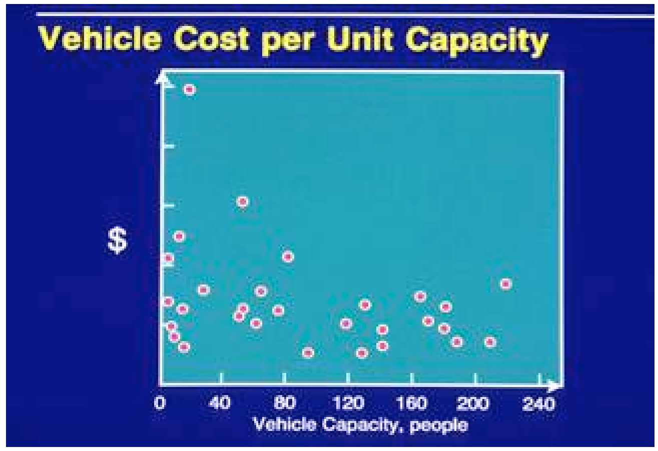

Figure 3. Vehicle Cost per Unit Capacity

With this finding in mind consider the cost of a fleet of transit vehicles. The cost of the fleet is the cost per unit of capacity multiplied by the capacity needed to move a given number of people per unit of time. The major factor that determines the capacity needed is the average speed. If the average speed could be doubled, the number of vehicles required to move a given number of people would be cut in half. The greatest increase in average speed without increasing other costs is obtained by arranging the system so that <u>every trip is nonstop</u>. The trips can be nonstop if all of the stations are on bypass guideways off the main line as shown in Figures 1 and 4.

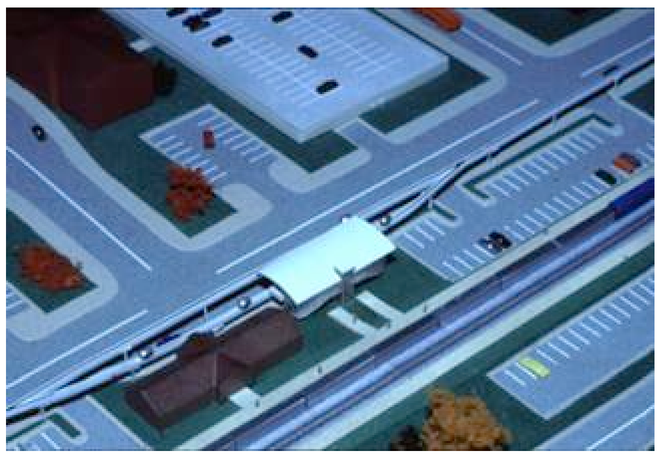

Figure 4. An Off-Line Station

<u>Off-Line Stations are the Key Breakthrough!</u>

- As just mentioned, because of increased average speed, off-line stations minimize the fleet size and hence the fleet cost.
- Off-line stations permit high throughput with small vehicles. To see how this can be so, consider driving down a freeway lane. Imagine yourself stopping in the lane, letting one person out and then another in. How far behind would the next vehicle have to be to make this safe? The answer is minutes behind. Surface-level streetcars operate typically 6 to 10 minutes apart, and exclusive guideway rail systems may operate trains as close as two minutes apart, whereas on freeways autos travel seconds apart, and often less than a second apart. An example is given on page 6.

- Off-line stations make the use of small vehicles practical, which permit small guideways, which minimize both guideway cost and visual impact.
- Off-line stations permit nonstop trips, which decrease trip time and increase the comfort of the trip.
- Off-line stations permit a person to travel either alone or with friends with minimum delay.
- Off-line stations permit the vehicles to wait at stations when they are not in use instead of having to be in continuous motion as is the case with conventional transit. Thus, it is not necessary to stop operation at night – service will be available at any time of day or night.
- There is no waiting at all in off-peak hours, and during the busiest periods vehicles are automatically moved to stations of need. Computer simulations show that the average wait time will be less than one minute.
- Stations can be placed closer together than is practical with conventional rail. With conventional rail, in which the trains stop at every station, the closer the station spacing, the slower the average speed. So to get more people to ride the system, the stations are placed farther apart to increase average speed, but then ridership suffers because access is sacrificed. The tradeoff is between speed and access – getting more of one reduces the other. With off-line stations one has both speed and access.
- Off-line stations can be sized to demand, whereas in conventional rail all stations must be as long as the longest train.
- All of these benefits of off-line stations lead to lower cost and higher ridership.

The Attributes of High-Capacity PRT

- Off-line stations
- Adequate speed, which can vary with the application and the location in a network
- Fully automatic control
- Hierarchical, modular, asynchronous control to permit indefinite system expansion
- Dual-redundant computers for high dependability and safety
- Smooth, accurate running surfaces for a comfortable ride
- All-weather propulsion and braking by use of linear induction motors
- Switching with no moving track parts to permit no-transfer travel in networks
- Minimum-sized, minimum weight vehicles
- Small, light-weight, generally elevated guideways
- Vehicle movement only when trips are requested
- Nonstop trips with known companions or alone
- Propulsive power from dual wayside sources
- Empty vehicles rerouted automatically to fill stations
- Well lit, television-surveyed stations
- Planned & unplanned maintenance within the system
- Full compliance with the Americans with Disabilities Act

The Optimum Configuration

During the 1970s I accumulated a list of 28 criteria for design of a PRT guideway [2]. As chairman of three international conferences on PRT, I was privileged to visit all automated transit work around the world, talk to the developers, and observe over time both the good and the bad features. The criteria listed in Figure 5 are the most important. From structural analysis I found that the minimum-weight guideway, taking into account 150-mph crosswinds and a maximum vertical load of fully loaded vehicles nose-to-tail, is a little narrower than it is deep.

Figure 5. The Optimum Configuration

Such a guideway has minimum visual impact. A minimum weight elevated structure is a truss, as shown in Figure 6. A stiff, light-weight truss structure will have maximum natural frequency and will be most resistant to the horizontal accelerations that result from an earthquake. Extensive computer analysis of the structure has produced the required properties.

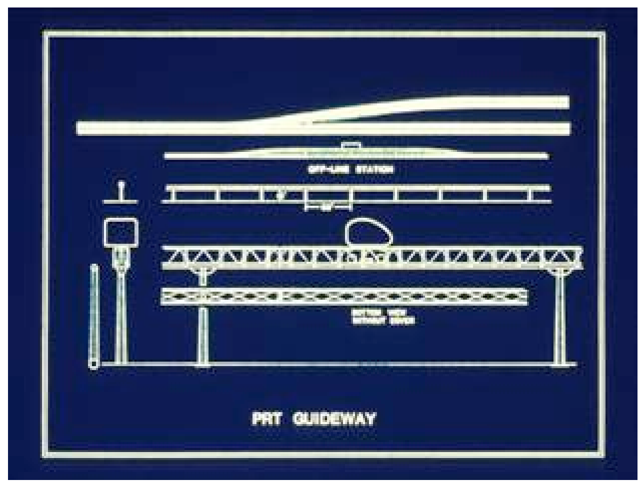

Figure 6. A Low Weight, Low-Cost Guideway

I compared hanging, side-mounted, and top-mounted vehicles and found ten reasons to prefer top-mounted vehicles. Considering the Americans with Disabilities Act, the vehicle had to be wide enough so that a wheelchair could enter and face forward. Such a vehicle is wide enough for three adults to sit side-by-side and for a pair of fold-down seats in front for small people. Such a size can also accommodate a person and a bicycle, a large amount of luggage with two people, a baby carriage plus two adults, etc. [3]

As shown in Figures 5 and 7, the guideway will be enclosed with composite covers, with a slot only four inches wide at the top to permit the vertical chassis to pass, and a slot eight inches wide at the bottom to permit snow, ice, or debris to fall through. The covers permit the system to operate in all weather conditions, they minimize air drag, they prevent ice accumulation on the power rails, they prevent differential thermal expansion, they serve as an electromagnetic shield, a noise shield, and a sun shield, they permit access for maintenance, and they permit the external appearance to be whatever the local community wishes. The covers enable the system to meet nine of the 28 design criteria. Figure 8 shows an application of PRT in Minneapolis, which was laid out and has been promoted by a Minneapolis City Councilman. Such an application provides a degree of service for all people, including the elderly and disabled, not possible with conventional transit, and can be built and operated without public subsidy.

Figure 7. The Covered Guideway

Figure 8. An Application in Minneapolis

<u>Is High Capacity Possible with Small Vehicles?</u>

Consider a surface-level streetcar or light rail system. A typical schedule frequency is 6 minutes. The new so-called light rail vehicles have a capacity of about 200 people. So with two-car trains the system can move a maximum of 400 people every 6 minutes. As shown below, high-capacity PRT can operate with a maximum of 120 vehicles per minute or 720 in 6 minutes carrying up to five people each. However, if there was only one person per vehicle, the HCPRT system would carry 720 people in 6 minutes, which is almost twice as many people per hour as the light rail system can carry. Since the light rail vehicles are never full for a whole hour, HCPRT has an even higher throughput margin over a light-rail system. A comprehensive discussion of the throughput potential of HCPRT lines and stations has been developed [4].

In 1973 Urban Mass Transportation Administrator Frank Herringer told Congress that "a high-capacity PRT could carry as many passengers as a rapid rail system for about a quarter the capital cost" [5] (see next page). The effect of this pronouncement was to ridicule and kill a budding federal HCPRT program. The best that can be said is that PRT was thought to be too good to be true. But PRT was not an idea that would die. Work continued at a low level, which is the main reason it has taken so long for PRT to mature.

During the 1990's the Automated Highway consortium operated four 16-ft-long Buick LeSabres at a nose-to-tail separation of six feet at 60 mph on a freeway near San Diego. The nose-to-nose separation was 22 feet and 60 mph is 88 ft per sec, which gives a time headway or nose-to-nose time spacing of 22/88 or a quarter second. Four vehicles per second is twice the throughput needed for a large HCPRT system. The automated highway program was monitored by the National Highway Safety Board.

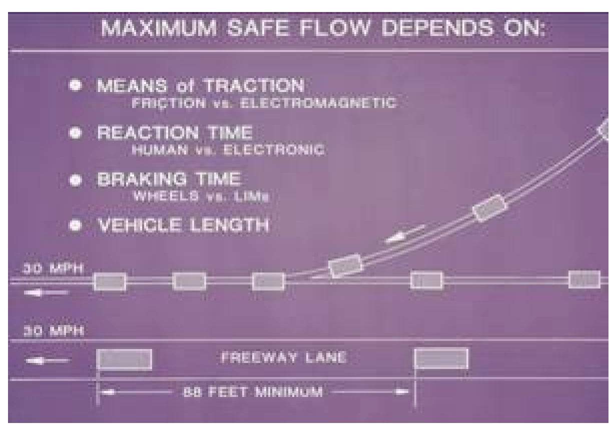

Figure 9. How to achieve maximum flow.

CURRENT OPTIMUM HEADWAY ON PRT SYSTEMS

Mr. CONTE. What is the present optimum headway capacity that has been developed for PRT's?

Mr. HERRINGER. The shortest headways demonstrated by a federally funded PRT development were realized at TRANSPO 1972. Both the Ford and Monocab systems were capable of 8 second headways. German and Japanese high capacity PRT developments, in the full scale prototype test phase, are aiming for minimum headways between one-half and 1 second.

TARGET FOR HIGH CAPACITY PRT DEVELOPMENT

Mr. CONTE. What areas are being investigated for purposes of increasing the capacity of PRT systems and how far in the future are the results and benefits?

Mr. HERRINGER. Higher capacity will significantly improve the cost effectiveness of PRT as an urban transportation choice. By increasing capacity, more revenue passengers can be carried on the expensive guideway investment, thus improving capital utilization. A useful measure of capital utilization in a transportation system is the system cost per lane mile divided by the passenger capacity in seats per lane mile per hour. This number is about $800 for a rapid rail system and approximately $200 for an advanced high-capacity PRT system. This means that a high-capacity PRT could carry as many passengers as a rapid rail system for about one quarter the capital cost. I would like to introduce the following table in the record to clarify these points:

[The following follows:]

CAPITAL COST COMPARISON BETWEEN PRT AND RAPID RAIL

System	Capacity (seats per lane hour)	Cost (millions per lane hour)	Cost (dollars per lane mile per seat per hour)
Washington Metro (648 seat trains, 120 s headways)	19,500	15.2	780
Dallas/Fort Worth "Airtrans" PRT (16 seat vehicles, 18 s headways)	3,200	2.6	812
Planned PRT development (12 seat vehicles, 3 s headways)	14,400	4.0	360
High-capacity PRT (4 seat vehicles ½ s headways)	28,800	6.0	208

The table indicates that shorter headways permit high-capacity operation with smaller vehicles, thus permitting essentially nonstop service at all times.

UMTA recognizes the advantages of shorter headways to achieve higher PRT capacities and better service. The planned PRT system development program (for possible application in Denver) will achieve headways in the 3-second range. This system will be available for urban deployment in approximately 3 years. A DOT program leading to the development of a short, one-half to one-second headway, high-capacity PRT system will be initiated in fiscal year 1974.

TSC'S AC PROPULSION SYSTEM

Mr. CONTE. What is the innovative a.c. propulsion system that TSC plans to develop and test?

System Features needed to achieve Maximum Throughput Reliably and Safely

The features needed are illustrated in Figure 9.

1. All weather operation: Linear induction motors (LIMs) provide all-weather acceleration and braking independent of the slipperiness of the running surface.
2. Fast reaction time: For LIMs the reaction time is a few milliseconds. With human drivers the reaction time is between about 0.3 and 1.7 seconds.
3. Fast braking: Even with automatic operation the best that can be done with mechanical brakes is a braking time of about 0.5 sec, whereas LIMs brake in a few milliseconds.
4. Vehicle length: A typical auto is 15 to 16 feet long. A HCPRT vehicle is only nine feet long.

These features together result in safe operation at fractional-second headways, and thus maximum throughput of at least three freeway lanes [6], i.e., 6000 vehicles per hour.

During the Phase I PRT Design Study for Chicago, extensive failure modes and effects analysis [7], hazards analysis, fault-tree analysis, and evacuation-and-rescue analysis were done to assure the team that operation of HCPRT would be safe and reliable. The resulting design has a minimum of moving parts, a switch with no moving track parts, and uses dual redundant computers [8]. Combined with redundant power sources, fault-tolerant software, and exclusive guideways; studies show that there will be no more than about one person-hour of delay in ten thousand hours of operation [9].

How does a Person Use a PRT System?

Figure 10. Pick a Destination and Pay the Fare

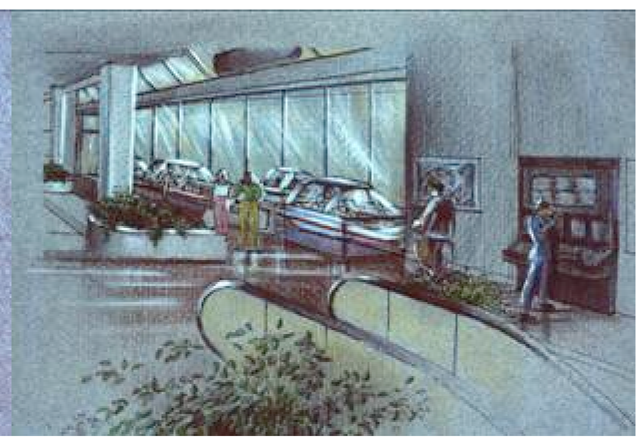

Figure 11. Transfer Destination to Vehicle

A patron arriving at a PRT station finds a map of the system in a convenient location with a console below. The patron has purchased a card similar to a long-distance telephone card, slides it into a slot, and selects a destination either by touching the station on the map or punching its number into the console. The memory of the destination is then transferred to the prepaid card and the fare is subtracted. To encourage group riding, we recommend that the fare be charged per vehicle rather than per person. The patron (an individual or a small group) then takes the card to a stanchion in front of the forward-most empty vehicle and slides it into a slot, or waves it in front of an electronic reader. This action causes the memory of the destination to be transferred to the chosen vehicle's computer and opens the motor-driven door. Thus no turnstile is needed. The individual or group then enter the vehicle, sit down, and press a "Go" button. As shown in Figure 12, the vehicle is then on its way nonstop to the selected destination. In addition to the "Go" button, there will be a "Stop" button that will stop the vehicle at the next station, and an "Emergency" button that will alert a human operator to inquire. If, for example, the person feels sick, the operator can reroute the vehicle to the nearest hospital.

Figure 12. Riding Nonstop to the Destination

Why will PRT attract riders?

- With a network PRT system there will be only a short walk to the nearest station.
- In the peak period, the wait time will typically be less than one minute. In the off-peak periods there will be no wait at all.
- The system will be available any time of day or night.
- The ride time will be short and the trip time predictable.
- A person can ride either alone or with chosen companions.
- Everyone will have a seat.
- The ride above the city will be relaxing, comfortable, and enjoyable.
- There will be no transfers.
- The fare will be competitive.
- There will be only a short walk to the destination.

A number of investigators, some of whom are mentioned in Reference 2, have developed models to predict ridership on PRT systems. Accurate methods are needed because the system needs to be designed but not over-designed to meet anticipated ridership.

Status

At the present time, mid 2006, all of the technology needed to build HCPRT, including all of the control hardware and software, has been developed. All that is needed in the United States is the funds (about $10 million) to build a full-scale test system. Such programs are already underway overseas. HCPRT is a collection of components proven in other industries. The only new thing is the system arrangement. The system control software has been written and excellent software tools are available for final design verification and development of final drawings needed for construction. Because there has been no U. S. federal funding to support the development of HCPRT during the past three decades, few people in the United States have been able to continue to study and develop these systems. This problem is likely the major factor that caused the collapse of the Chicago RTA PRT program. However, thanks to continued efforts of members of the Advanced Transit Association (www.advancedtransit.org), there is a sufficient number of people able to lead HCPRT development – it does not take many.

Figure 13. The Aerospace Corporation PRT System [10]

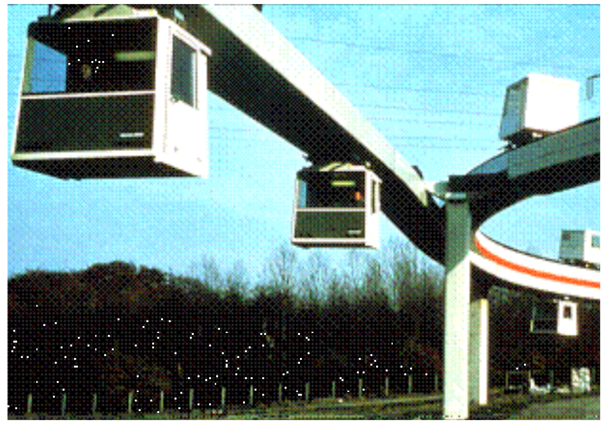

Figure 14. Cabintaxi [11]

The two leading HCPRT development programs during the 1970s are illustrated in Figures 13 and 14. The Aerospace program ended in the mid 1970s because of the lack of federal funding, and the Cabintaxi program (DEMAG+MBB) ended in 1980 when the Federal Republic of Germany had to divert a substantial amount of money to NATO programs. These HCPRT programs provided the bulk of the background that was needed to continue PRT development during the next two decades. Without these programs, I don't believe we would be talking about PRT in any form today. The world owes them thanks for their pioneering efforts.

A third important PRT-related development program conducted during the 1970s still operates in Morgantown, West Virginia. I call it "PRT-related" because it has characteristics of PRT but uses 20-passenger vehicles, and thus is more correctly classified as Group Rapid Transit. Contracts were let in December 1970 to get the system operating only 22 months later. Since there was almost no knowledge of the theory of PRT systems in 1970, many decisions were made that increased size, weight and cost. The gross (fully loaded) vehicle weight is about 11,800 lb and the operating headway is 15 seconds.

Figure 15. Morgantown

The next figure, Figure 16, shows the Raytheon system that was developed beginning in 1993 with matching funds from the Northeastern Illinois Regional Transportation Authority. As a result of cost overruns, this program died, mercifully in my opinion, because the lack of experience on the part of the development teams resulted in a vehicle four times the weight and a guideway twice as wide and twice as deep as that which came out of the RTA's Phase I PRT Design Study. As a result the capital cost of a system proposed for Rosemont, Illinois, more than tripled and the operating costs were correspondingly high and uncertain. The gross weight of the Raytheon system was about 6600 lb and the operating headway was about 3 seconds.

Figure 16. Raytheon PRT 2000

Figure 17. An Optimum HCPRT Design

The next system, shown in Figure 17, is one I designed for Taxi 2000 Corporation. It opened to the public in April 2003 and over the next year thousands of rides were given flawlessly to an enthusiastic public over a short piece of guideway. The fully loaded vehicles have a maximum gross weight of about 1800 lb and I designed the control system so that multiple vehicles can operate at half-second headways. This system, as we understood it in 1989, was the basis for the winning proposal in the RTA program. Unfortunately, when the Phase II program got underway in October 1993, prior work, including work done in the Phase I program, was mostly ignored, which resulted in major weight and cost overruns and program cancellation.

Figure 18 shows the gross weights of the systems shown in Figures 15, 16, and 17. Cost data were available on the cost per mile of each of these systems. Deflating these costs to the same year, I found that the system cost was very nearly proportional to the vehicle weight. The challenge then is to keep costs down by using the smallest, lightest-weight vehicles practical. They permit the smallest, lowest-cost guideways and are fully practical with today's technology.

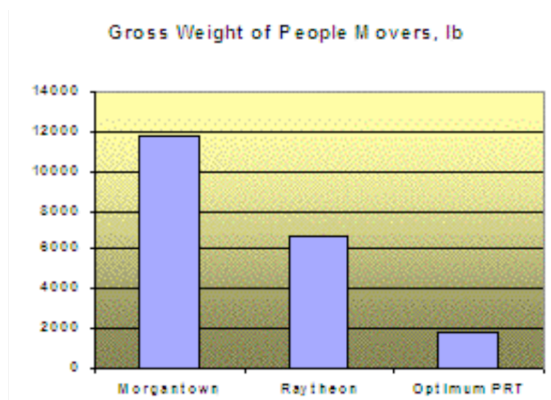

Figure 18

Figure 19 shows three PRT system currently under development. The picture on the left is ULTra, (www.atsltd.co.uk), which is being developed at Bristol University in the United Kingdom. The great news in fall 2005 was that the British Airport Authority announced that they will build the ULTra system at Heathrow International Airport. The center system is Vectus, which is being developed by the Korean steel company Posco (www.vectusprt.com). They announced last fall that they will build a test system in Uppsala, Sweden. The picture on the right is Microrail (www.megarail.com). It is one of a family of automated guideway transit systems under development by Megarail Corporation of Dallas, Texas. Currently they advertise a trained version under manual control.

Figure 19. ULTra, Vectus, and Megarail PRT Systems

Economics of PRT

Figure 20 show the Minneapolis light rail system called the "Hiawatha Line." The newspapers announced that its capital cost was $720,000,000 and that the ridership would be about 20,000 rides per day. That works out to $36,000 per daily trip. Since the annual cost for capital amortization and operation is about 10% of the capital cost and the yearly ridership will be roughly 300 times the daily ridership, the annual cost divided by the annual ridership works out to $12 per trip. The average trip length is roughly 6 miles, so the cost per passenger-mile is about $2. This compares with the total cost per mile of an automobile of around 40 to 60 cents.

Figure 20. Minneapolis-Airport light rail

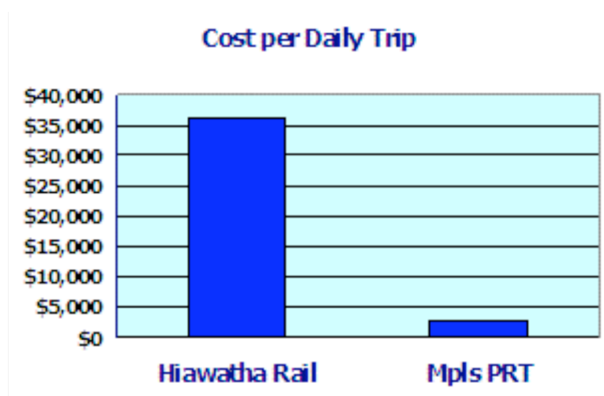

Figure 21. Cost Comparison

We laid out and estimated the cost of a PRT system for downtown Minneapolis. It is compared with the Hiawatha light-rail line in Figure 21. Our estimate was about $100 million capital cost and a professional ridership study showed about 73,000 trips per day. Because this system has not yet been built, let's double its cost. Then on the same basis the capital cost per daily trip would be $2740 and the total cost for each trip would be $0.91. On this PRT system the average trip would be about two miles so the cost per passenger-mile or break-even fare would be about $0.46.

What would be the cost per passenger-mile on a built-out PRT system? Figure 22 shows the cost per passenger-mile on a square-grid PRT system as a function of population density and for values of the fraction of all vehicle trips taken by PRT, called the modal split, from 0.1 to 0.7. Several studies cited in Reference 2 suggest that an area-wide PRT system with lines a half mile apart would attract at least 30% of the trips. On this basis, one can estimate from Figure 22 the population density needed for a PRT system to break even. As mentioned in Figure 22, revenue will be obtained not only from passenger trips, but from goods movement and advertising as well – roughly half is a reasonable estimate, meaning that a passenger would have to pay only half the amount determined from Figure 22. For example if the population density is 6000 persons per square mile (Chicago density is about 13,000 people per square mile) and the mode split to PRT is 30%, the total cost per passenger-mile is about 40 cents, of which the passengers would pay about 20 cents.

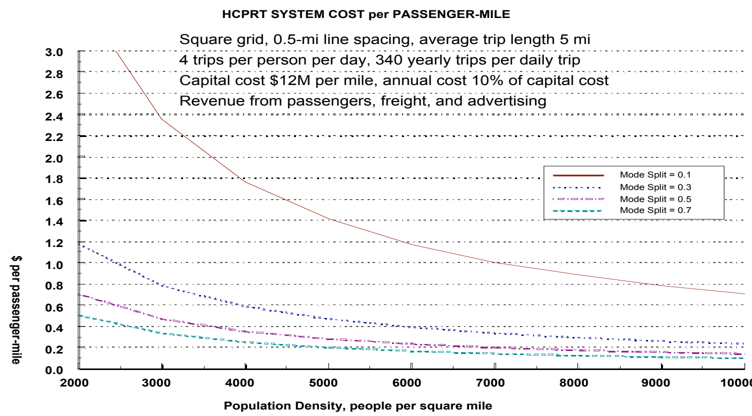

Figure 22.

Land Savings

Figure 23. A Freeway Running at Capacity.

Figure 24. The People riding.

Figure 23 shows a freeway running on the left side at capacity, which is about 6000 autos per hour [12]. This is a three-lane freeway with the fourth lane just an acceleration lane. Figure 24 shows the people riding. In over 90% of the autos there is only one person, occasionally two, and very occasionally three. Figure 25 shows all of the people moved to the center and Figure 26 shows the PRT vehicles in which they could be riding. This pair of guideways can also carry 6000 vehicles per hour – the throughput of the entire three-lane freeway. We would normally put these guideways along the fence lines so that the stations would be near people's destinations, but the figure illustrates the land savings. A typical freeway width from fence line to fence line is about 300 feet. The two PRT lines in the middle of Figure 26 take up only 15 feet of width, giving a width reduction per unit of capacity of 20:1 or 5% of the land area. But, land for a PRT system is required only for posts and stations, which is only 0.02% of city land. The land underneath the PRT guideways can be used for walking or bicycle trails and would not interfere with animal crossings. The auto requires about 30% of the land in residential areas and roughly 50% to 70% of the land in downtown areas. This enormous land savings permits development of safe, low-pollution, energy-efficient, quiet, environmentally friendly, high-density living.

Figure 25. All people moved to center.

Figure 26. All riding PRT.

Figure 27 illustrates the tiny fraction of land required by a PRT system, which can carry substantially more people per hour than the arterial streets shown. An area formerly cleared for surface parking could be restored into a park or garden, thus making the inner city more people-friendly and reducing the summer temperature because concrete and asphalt absorb sunlight and immediately release it as heat, whereas plants soak up solar energy in plant growth. As they grow, plants also remove carbon dioxide from the air.

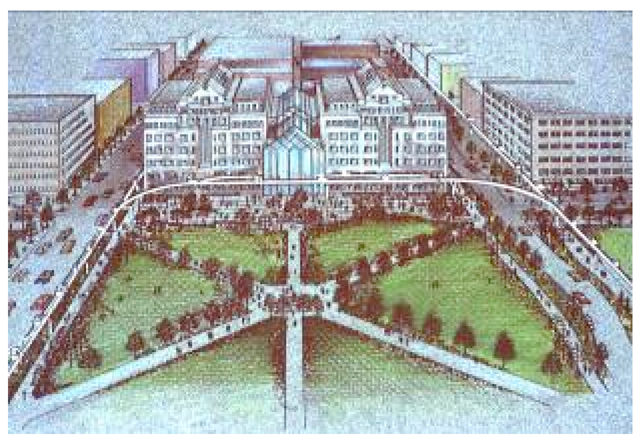

Figure 27. A restored park thanks to PRT.

Energy Savings

Minimum energy use requires very light-weight vehicles; smooth, stiff tires for low road resistance; streamlining for low air drag; and efficient propulsion, all of which can be designed into a PRT system if the designer wishes to do so. Moreover, unlike conventional transit, in which the vehicles must run to provide service whether anyone is riding or not, PRT vehicles need run only when people wish to travel. Studies have shown that this on-demand service reduces the number of vehicle-miles per day of operation needed to move a given number of people by more than a factor of two, which lowers the energy use and operating cost in proportion [13].

Figure 28 gives a comparison of the energy use per passenger-mile of eight modes of urban transportation – heavy rail, light rail, trolley bus, motor bus, van pool, dial-a-bus, auto, and PRT [14]. Data for the first seven modes are averages from federal sources. The energy use for kinetic energy, road resistance, air drag, HVAC, and construction are shown. In summary PRT will be more than twice as energy efficient as the auto system, which in turn is almost twice as energy efficient as the average light rail system.

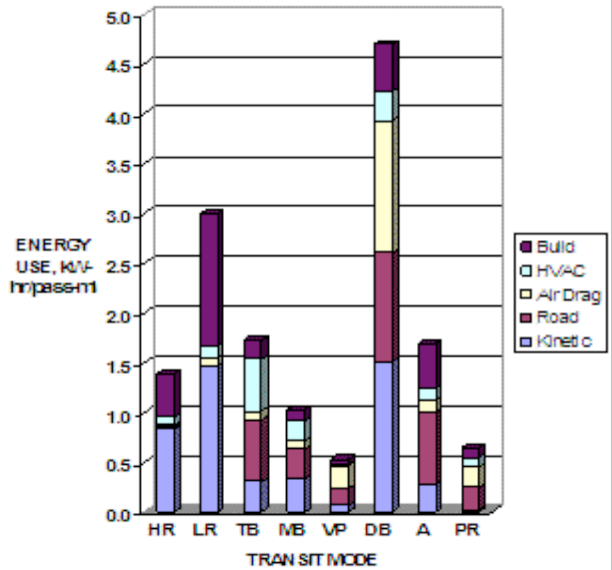

Figure 28

<u>Benefits for the Riding Public</u>

- The system will be easy for everyone to use. No driver's license needed!
- The vehicles wait for people, rather than people for vehicles.
- The trip cost will be competitive.
- The trip will be short, predictable, and nonstop.
- There will be minimum or no waiting.
- Everyone will have a seat.
- The system will always be available at any hour.
- The vehicles will be heated, ventilated, and air conditioned.
- There will be no crowding.
- There will be no vehicle-to-vehicle transfers within the system.
- The ride will be private and quiet.
- The chance of injury will be extremely remote.
- Personal security will be high.
- The ride will be comfortable.
- There will be space for luggage, a wheelchair, a baby carriage, or a bicycle.

<u>Benefits for the Community</u>

- The energy use will be very low.
- PRT can use renewable energy.
- Deployment of PRT will reduce transit subsidies.
- PRT can augment and increase ridership on existing rail systems.
- PRT will be attractive to many auto users, thus reducing congestion.
- Seniors, currently marooned, will have much needed mobility and independence.
- The system does not directly pollute the air. Being more energy efficient than the auto system and by using renewable energy, total air pollution will be reduced substantially.
- By spreading the service among many lines and stations, there will be no significant targets for terrorists.

- As to accidents, no one can say that there will never be an accident, but the rate per hundred-million miles of travel will be less than one millionth of that experienced with autos.
- There will be huge land saving: 0.02% is required vs. 30-70% for the auto system.
- PRT will permit development of more livable high-density communities.
- The ride will be pleasant for commuting employees, thus permitting them to arrive at work rested and relaxed.
- PRT will permit more people-attracting parks and gardens.
- PRT will permit safe, swift movement of mail, goods and waste.
- PRT will provide easier access to stores, clinics, offices and schools.
- PRT will provide faster all-weather, inside-to-inside transportation.
- PRT will enable more efficient use of urban land.
- By making the inner city more attractive, urban sprawl will be less likely.

Reconsider the Problems

High-Capacity PRT addresses all of the problems listed on pages 1 and 2, of which peak oil and global warming are much in the news. According to Andrew Euston, now retired from the U. S. Department of Housing and Urban Development where he was Coordinator of the Sustainability Cities Program, PRT "is an essential technology for a Sustainable World."

Significant PRT Activity

- A series of studies of PRT in Sweden in 1990s resulted in the statement: "Our recommendation is therefore clear—a PRT system provides such a broad range of desired qualities that it should be given highest priority in research, development, testing, and demonstration for implementation in the urban environment." Göran Tegnér, Business Manager International, TRANSEK Consultants Company, Solna, Sweden. *Infrastructure,* Vol. 2. No. 3, (1997).
- As mentioned, the British Airport Authority plans to build a PRT system at Heathrow International Airport to carry people and luggage between parking lots and terminals.
- As mentioned, the Korean steel company Posco plans to demonstrate their PRT system called Vectus in Uppsala, Sweden.
- In fall 2005, the Korean Railroad Research Institute announced that they will invest $57 million in the development of PRT.
- The New Jersey State Legislature has funded a study very favorable to PRT, which is expected to be released very soon.
- The Dubai International Financial Center sent out a request for information for a PRT system in August 2004.
- The leadership of a large mall called DestiNY USA planned for Syracuse, New York, has stated that they need a PRT system in and around their facility.
- The City of SeaTac, Washington, spent about $1 million on studies of PRT during the 1990s and awaits a viable PRT system.
- Official research by the European Union concluded in March 2006 that "operational PRT is urgently needed, affordable, and will help achieve important equity objectives. PRT systems are attractive solutions to problems in Central Europe." [15]

Development Strategy

- Seek first private applications.
- Fund full-scale PRT tests, which can now be done for less than $10 million, provided that the program is led by a person of knowledge and commitment.
- Inform consultants, planners, and financiers about PRT.
- Perform specific PRT planning studies.
- Teach the engineering, economic, and planning sciences of PRT.
- Emulate other public works on which companies bid and win projects based on competence and by giving the buyer assurance of multiple sources of supply.

For further information read the paper "The Case for PRT," which can be found on www.advancedtransit.org.

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15. See note #1.

* These papers can be downloaded from http://kinetic.seattle.wa.us, others available from the author.

Credits for the Figures

Figure 1. Woobo Enterprises, Ltd., Seoul, Korea

Figure 2. University of Minnesota Graphics

Figure 3. Stone & Webster Engineering Corporation

Figure 4. Phase I PRT Design Study, Chicago RTA

Figure 5. Automated Transportation Systems, Inc.

Figure 6. University of Minnesota Graphics

Figure 7. Taxi 2000 Corporation

Figure 8. www.cprt.org

Figure 9. University of Minnesota Graphics

Figures 10, 11, 12. Minneapolis Architectural Illustrator

Figure 13. The Aerospace Corporation

Figure 14. Photo taken by the author

Figure 15. Photo taken by the author

Figure 16. Photo taken by the author

Figure 17. Photo taken by Short Elliott Hendrickson, Inc.

Figure 18, 21, 22. The author

Figure 19. www.atsltd.co.uk, www.vectusprt.com, www.megarail.com

Figure 20. www.metrocouncil.org

Figures 23, 24, 25, 26. William A. Wilde, Reference 12

Figure 27. Minneapolis Architectural Illustrator

Figure 28. Author's paper, Reference 14

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Following his undergraduate work he developed methods of structural analysis of supersonic-aircraft wings at the Structures Research Division of NACA (now NASA), and contributed to the design of the F-103 wing. He then moved to the Honeywell Aeronautical Division where he designed aircraft instruments including the first transistorized amplifier used in a military aircraft and performed computer analysis of autopilots for military and space applications. While there he invented and led the development of a new type of inertial navigator now used widely on military and commercial aircraft, and also led the advanced development of a solar-probe spacecraft.

In 1963 he joined the Mechanical Engineering Department at the University of Minnesota and later directed its Industrial Engineering Division. He chaired a Symposium on the Role of Science and Technology in Society; initiated, managed and lectured in a large interdisciplinary course "Ecology, Technology, and Society;" coordinated a 15-professor Task Force on New Concepts in Urban Transportation; and chaired three International Conferences on Personal Rapid Transit (PRT) following which he was elected first president of the Advanced Transit Association.

During the 1970s, Dr. Anderson consulted on PRT planning, ridership analysis, and design for the Colorado Regional Transportation District, Raytheon Company, the German joint venture DEMAG+MBB, and the State of Indiana. For several years he was Distinguished Lecturer for the American Institute of Aeronautics and Astronautics. He lectured widely on new transit concepts and was sponsored on several lecture tours abroad by the United States Information Agency and the United States State Department. In 1982 he was presented with the George Williams Fellowship Award sponsored by the YMCA and presented for public service, and the MPIRG Public Citizen Award.

In 1978 he published the textbook *Transit Systems Theory* (D. C. Heath, Lexington Books), which he uses in his course "Transit Systems Analysis and Design." In addition to engineering students, enrollment in this course has included professional transportation engineers from across United States as well as from Sweden and Korea. In 1981 he initiated and led the development of a High-Capacity PRT system through five stages of planning, design and costing. He developed computer programs for vehicle control, station operation, operation of multiple vehicles in networks, calculation of guideways curved in three dimensions to ride-comfort standards, study of the dynamics of transit vehicles, economic analysis of transit systems, and calculation of transit ridership.

In 1986 he was attracted to the Department of Aerospace and Mechanical Engineering at Boston University where he taught engineering design and transit systems analysis and design; and where he organized, coordinated and lectured in an interdisciplinary course "Technology and Society." On his own time, he organized a team of a half-dozen engineers and managers from major Boston-Area firms to further develop High-Capacity PRT. In May 1989, the Northeastern Illinois Regional Transportation Authority (RTA) learned of his work together with Raytheon Company and, as a result, initiated a program to fully develop PRT. This led to a $1.5M PRT design study led by Stone & Webster Engineering Corporation, followed by a $40M joint development program funded by Raytheon Company and the RTA. While at Boston University, he developed the Maglev Performance Simulator used by the National Maglev Initiative Office, U. S. Department of Transportation, to study the performance of high-speed maglev vehicles traveling within ride-comfort standards over the curves and hills of an interstate expressway.

Following the RTA program, Dr. Anderson gave courses on transit systems analysis and design to transportation professionals in the U. S. and Europe and engaged in PRT planning studies including simulations of PRT and automated baggage-handling systems. He further developed PRT technology culminating in a full-scale vehicle operating automatically on a short segment of guideway (Figure 17). In 1996 he chaired an international conference on PRT and related technologies in Minneapolis. In 1998 his work led to acceptance of his PRT system as the preferred technology promoted for the Greater Cincinnati Area by a committee of Forward Quest, a Northern Kentucky business organization. In 2005 he formed PRT International, LLC to commercialize High-Capacity PRT.

For his patents on PRT, the Intellectual Property Owners Foundation named Dr. Anderson an Outstanding American Inventor of 1989. In 1994 he was Distinguished Alumni Lecturer at North Park College in Chicago. In 2001 he was elected Fellow of the American Association for the Advancement of Science for his work on PRT. He registered as a professional engineer in Minnesota and Illinois, authored of over 100 technical papers and three books, and is listed in 36 biographical reference works including *Who's Who in America* and *Who's Who in the World.*