Evolution of Personal Rapid Transit

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Abstract

The paper reviews the evolution of the PRT concept from its modern beginning in 1953. The early inventors, the projects, and the response of government are discussed. PRT activity diminished to almost nothing by 1980, but then revived strongly as a result of activity by the Northeastern Illinois Regional Transportation Authority. Their interest ignited enthusiastic activity on a growing front to the point that today one can truly say that the concept is coming of age.

Contents

Introduction

The evolution of Personal Rapid Transit (PRT) can be traced back to at least 1953. Some of the ideas embodied in PRT go back even to the last century, but were premature, briefly flowered and died. Since 1953 the evolution has been continuous, though fluctuating − continuous perhaps mainly because the concept of automatic control, essential to PRT, had been firmly established by the early 1950's; and fluctuating for reasons that had little or nothing to do with the technical feasibility of the idea or its potential value to urban society.

The development of automated urban transportation systems, among which PRT is considered to be the goal, has been a highly interactive process among a wide variety of professionals, politicians, and dedicated citizens. In examining the writings, it is clear that these people saw the need for a viable complement to the automobile, and they understood that such a complement could not be just more conventional transit. They were willing and able to invest freely of their own time and treasure to realize a dream.

Others, however, dreamed of a return to the glory days of the streetcar, the use of which had peaked in 1917 [1] and, due to preference for and availability of the automobile, declined in the 30 years thereafter as rapidly as it rose in the 30 years before. Many in the latter group saw that if the concept of PRT matured, the hope of return to the streetcar, even under a new name, would be gone forever. The resulting clash between the new and the old was severe and must be understood if the process of evolution of PRT is to be fully appreciated [2].

If PRT had advanced in a neutral environment, its evolution would have been far different. In fairness, however, one must add that some of the opposition to PRT came from people who genuinely thought it was not feasible for technical or other reasons. A full discussion of the opposition would require another paper [18].

An important part of the interest in PRT in the late 1960s and early 1970s in the United States was due to completion of the Apollo Moon Landing Program and the consequent need to find alternative government-funded projects, rather than a deep understanding of the need for alternative transit and the characteristics and requirements such systems would have to have to meet contemporary needs. In his budget speech to Congress in January 1972, in which he announced a federal PRT development program, President Nixon said: "If we can send three men to the moon 200,000 miles away, we should be able to move 200,000 people to work three miles away." For a variety of institutional reasons, the later turned out to be much more difficult.

A successful PRT developer will examine every technical, social, and economic argument of its infeasibility, and must be satisfied that each and every argument is either wrong or implies assumptions about certain physical parameters that need not be made. Many parameters and physical alternatives must be examined in development of a PRT system. I once made a list of 46 categories of trade-off areas that need attention in design of a PRT system and the various alternatives that could be selected in each [20]. Upon calculating the number of possible combinations among these classes of alternatives, I found roughly ten quadrillion (10^{16}) possible PRT systems, only a few of which could be viable. It is not surprising therefore that many PRT development programs failed because of lack of understanding of PRT as a system within an urban environment serving real needs and meeting requirements of safety, security, dependability, and ride comfort. Successful development of PRT required a theory of transit to guide choices [3], which was not available in the early 1970s.

Even if one becomes convinced, as I have, that with certain carefully selected features there is a technically and economically feasible PRT system, its development is a much more demanding task than the invention and development of a device that you can put on a table, say a personal computer. The unit of sale of a PRT system is large, there must be a consensus among many people that it is worth the expenditure of substantial resources, it does not easily fit within the jurisdiction of an existing bureaucracy, the time horizon for return on investment is long, and it has no clear military application. While a state's fear of an external enemy compels the development of new military systems, a civil industry's fear of becoming irrelevant, real or not, causes its leaders to argue against the development of new systems that they perceive to be disruptive.

During the past four decades, several billion dollars worth of work has been done on the development and application of automated forms of conventional rail or guideway transportation. This work was a necessary forerunner to PRT and has shown in many applications over decades that, notwithstanding a well publicized 1972 failure of a BART train, automated transit works in daily practice and has been accepted by the public. While it seems that almost every investment analyst who was an adult in 1972 was aware of the BART control-system failure and subsequent accident, very few were aware of the accident-free operation of many automated systems such as the Lindenwold-Philadelphia line, the Tampa and SeaTac systems, the Duke University system, and many others that have run routinely for decades with no sensational events to report.

If these more or less conventional systems work, why the interest in PRT? Because the combination of small, private-party vehicles and nonstop trips collectively offer the possibility of a degree of cost reduction, service, and accessibility not achievable with conventional forms of automated transit, in which large, scheduled vehicles stop at all stations. Moreover, because it uses very little land, is quiet, and does not pollute the air, an optimized PRT system offers the possibility of design of cities of livable higher density; and, because a proper design also uses little energy and material, it has been referred to as an essential technology in a sustainable world. A PRT system that meets all of the needs and requirements is a substantial technical challenge, but one that a growing number of people have seen is worth the effort. [24]

In this paper I trace the more important early contributions to the development of PRT that, as chairman of the 1971, 1973, and 1975 International Conferences on PRT [4], I was privileged to study. As a Professor of Mechanical Engineering in a Research University (Minnesota), I had access to a much wider variety of programs than possible for someone in industry working on a specific PRT program. I was and am a participant, not a social historian; therefore, notwithstanding my efforts to the contrary, this discourse must be to a degree subjective. A full treatment of the topics would require many books. For the sake of brevity, I have left out events and developments I would rather have included, and apologize to those who may feel I did not do them justice. Since many things were happening simultaneously, the discussion necessarily departs somewhat from chronological order.

Early Beginnings in the United States

There is little question that the basic ideas embodied in the system now called PRT came from many sources. PRT is a natural idea that has been invented and reinvented to my knowledge at least a dozen times and quite likely many more. Quite often I hear from a person who claims to have conceived the major ideas and is surprised to learn that others had been thinking along similar lines. Each of the inventors discussed below I am quite sure independently invented the PRT concept in varying degrees of detail, and with no awareness of the work of other inventors. My hat is off to them. I am not one of them. I began to learn about PRT beginning in Fall 1968 from UMTA sponsored reports [5].

<u>Donn Fichter.</u> To my knowledge, the earliest PRT inventor is Donn Fichter, who is now retired from the New York State DOT. As a transportation graduate student in Chicago, he started in 1953 to think seriously about cities and their transportation needs, and made his first sketches of a system he called Veyar [6]. He gradually developed a total system concept, not only a hardware system but a system integrated into a city, and in 1964 published his ideas in a book [7] in which all of the essential ideas embodied in PRT are explained. Having an appreciation for the problems of introduction of a new transit system into the cityscape as well as the transportation needs of individuals, he strongly stressed the necessity for the smallest and lightest-weight cars and hence the smallest and lowest cost guideways possible. He designed his car for one person. Although Fichter did not initiate the development of a hardware system, his well-reasoned and thorough explanations had considerable influence on later developments.

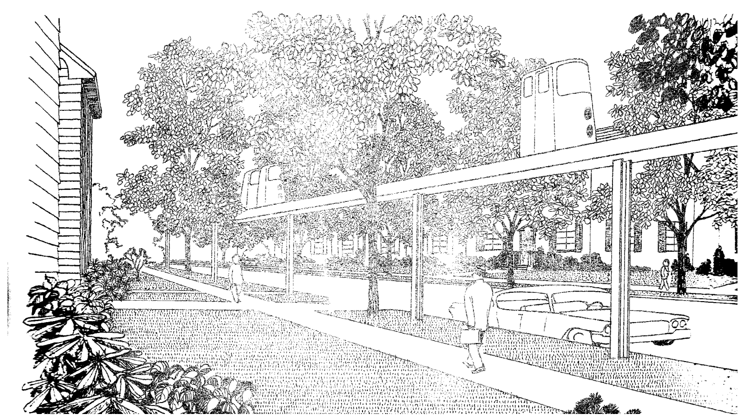

Figure 1. Donn Fichter's Veyar.

<u>Monocab.</u> Also in 1953, a Dallas contractor, Edward O. Haltom, was faced with the task of constructing a monorail system. Monorails are not new. One was built and operated in St. Paul, Minnesota in the 1880's. Another, called Meigs Elevated Railway, was tested in Boston in 1885. A third begin operation in Wuppertal, Germany, in 1902 and has been in continuous operation ever since as the backbone transit system of the city right through the two World Wars. A major difficulty with monorails of the conventional type, Haltom found, was that with the stations on the main line the requirement that vehicles be allowed sufficient time to stop at each station meant that the spacing between vehicles had to be so long that it was only possible to get 20 to 40 vehicles or trains per hour past a given point. This meant that, if the system was to carry enough people per hour to make the venture worthwhile, each vehicle had to have a capacity of

several hundred people. To obtain this capacity large, heavy vehicles must be used and they must be trained. They therefore require large, heavy guideways. Haltom found that these large guideways not only drove costs outside the range of economic feasibility, but were so visually obtrusive that his project stalled.[1] Haltom reasoned that to reduce the guideway size and cost, he had to reduce vehicle weight substantially by using many small, automatically controlled vehicles running at close headways. The first version of his system, which he called Monocab, used six-passenger vehicles suspended from an overhead guideway, but it suffered the major disadvantage associated with most monorail systems—the switch. In his first version, switching required movement of the entire guideway. This was cumbersome, slow, unreliable, and limited the capacity of his system.

In the 1960s, Haltom sold his ideas to Vero, Inc. of Garland, Texas, at which time a new means of switching with no moving track parts was invented. A full-scale test track was built and operated at Vero in 1969. In 1971 Vero sold Monocab to Rohr Corporation. Rohr decided that a combination of magnetic suspension and linear induction propulsion was necessary [29] and developed and tested such a system on a test track in Chula Vista, California. The previous wheeled version, however, was demonstrated at Transpo72 at Dulles Airport (discussed below) and in 1973 was selected for installation in Las Vegas. A combination of factors including a 50% drop in the stock market in 1974 due to the oil crisis stopped the project. Boeing bought the patents from Rohr and continued to develop the system under UMTA's Advanced Group Rapid Transit (AGRT) program until that program was terminated in the 1980s.

Figure 2. Ed Haltom’s Monocab.

Monocab had the smallest guideway of any of the PRT systems of the early 1970s, but its hanging vehicles required that the guideway be higher in the air than required for a bottom-supported system, which coupled with the required cantilevered posts increased visual impact and cost [30]. This countered the natural advantage of a hanging-vehicle system in curves. I believe, however, that diversion to an undeveloped combination of magnetic levitation and propulsion was the major factor that delayed and ultimately ended the program.

<u>TTI, Inc.</u> In the late 1950's and early 1960's, a group at General Motors Research Laboratories had been working on ground-effects machines for the Army. These were air-suspended vehicles that could run on a variety of surfaces, but with such low power on paved roads that air suspension appeared applicable to transit. Since an air-suspended vehicle made no direct contact with the roadway, a new type of motor was required that did not use wheels for traction. The logical choice was the linear induction motor (LIM), and thus the combination of air suspension and

[1] I am well aware that a Monorail Society still functions.

LIM propulsion was born. The development program was impeded at General Motors because of anti-trust laws that made it difficult for GM to be involved in development of transit systems. As a result, the air-cushion-vehicle (they called it Hovair) development group separated and formed a corporation they called Transportation Technology, Incorporated. TTI developed the idea into what became one of the leading candidate PRT systems. They carried their system to full-scale testing in Detroit in 1969 and in 1972 moved to Denver at which time they became a wholly owned subsidiary of Otis Elevator Company and demonstrated at Transpo72, which is discussed below. In Denver they constructed a second test track and participated in the AGRT program until its funds were withdrawn.

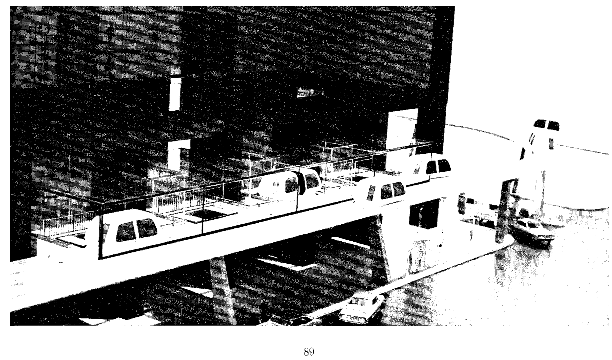

Figure 3. A model of the TTI PRT System.

An operating version of TTI's Hovair+LIM system has been in daily operation at Duke University Medical Center since the mid 1970s. The vehicles in the Duke system hold about ten standing passengers and shuttle between three points. The major problems with the TTI system were the visual impact and cost of the wide U-shaped guideway required to support an air-cushion vehicle, and the fact that it is a snow catcher, which made it unsuitable in northern climates. I also suspect that the lack during the 1970s of variable-frequency drives that markedly increase the efficiency of any induction motor must have been a contributing factor to their limited success. Otis has since sold several cable-drawn versions of their Hovair system.

<u>Alden staRRcar.</u> In 1960 William Alden, a graduate of the Harvard Business School, invented a system of small electric vehicles that could be driven from one's home to a guideway, then automatically on the guideway to a destination. This was quite possibly the earliest dual-mode-system proposal [25]. Alden called his system staRRcar, and formed a company called Alden Self-Transit Systems Corporation. Several years later it was realized that the development of a dual-mode system would be more difficult than a captive-vehicle PRT system, as a consequence of which the emphasis was shifted to wheeled captive vehicles driven by variable-speed hydraulic motors. Each vehicle had a seating capacity of six persons. Full-scale testing of staRRcar began on a test track in Bedford, Massachusetts in 1968 and the system later won a competition at Morgantown, which is discussed below.

An important feature of Alden's system was the invention of an on-board switch that made operation at short headway feasible. In 1968 they operated a 1/20th-scale model with ten vehicles and four off-line stations. The Alden system was essentially a series of cars, much like street vehicles, on a U-shaped guideway with power rails mounted on the inside surfaces of the U, making removal of snow by plowing impossible. Thus, the system required guideway heating, which on an annual basis in northern climates consumes several times as much energy as required to propel the vehicles. This operating-cost disadvantage plus the visual impact and cost of the guideways were factors that caused them to find no customers after Morgantown.

Uniflo. Another of the principal types of PRT had its beginnings in the mind of Lloyd Berggren in 1961 while he was working in the Planning Department of the Military Products Group at Honeywell, Inc. At that time Berggren's principal task was to try to develop ideas to diversify Honeywell's product line. He approached the problem of urban transportation from a system point of view by analyzing the weaknesses of present transport systems. He sought to lay down basic ideas that would enable a transport system to be competitive with the automobile, and thus arrived independently at all of the key features of PRT. He felt it was very important to keep the cost and weight of the vehicle to a minimum and thus felt it would be best to keep the motors in the track rather than on the vehicle.

Having a strong background in fluid-operated devices he saw how air jets could both suspend and propel the vehicles. This resulted in a very simple vehicle design—a passive people-carrying pod. All of the active propulsive and control components were in the track. Berggren's system had the advantage that electrical power is not required on board for propulsion and that a great deal of redundancy can be built into the control system. But it had the serious disadvantage that the vehicles had to be run in an enclosed tube, which ended up being 14 feet high and 6 feet wide—a considerable visual impact and expense. Berggren called his system Uniflo. He was able to obtain support to build a full-scale test track from Rosemont Engineering Company and later from Stone & Webster.

Jet Rail. Another idea that contains some of the concepts of PRT is the Jet Rail System, invented and designed by George Adams, who was president of Mobility Systems Control, Inc. of Los Angeles. At Love Field in Dallas, Texas, Braniff Airlines had wanted an automated system to carry people from a remote parking lot into the Braniff terminal. Braniff executives had been aware of the Monocab system, but felt based on rough estimates that it would be too expensive to be a candidate. They felt that a much less expensive system for that limited application could be built and George Adams showed them how. He designed, built, and in 1972 began to operate an overhead monorail system that looks very much like Monocab. It had Monocab's early difficulty in switching because the wheels that support the vehicle straddle an I-beam, so that the entire beam had to be moved to switch. Jet Rail was automatically controlled and demonstrated that a very lightweight guideway could be built and would adequately support the vehicles. A LIM version of Jet Rail was developed and has been marketed by Titan PRT Systems, Inc.

Urbmobile. In the early 1960's, a dual-mode concept called Urbmobile began to be developed by Morton O. Weinberg and Robert A. Wolf at Cornell Aeronautic Laboratories. This system made an important contribution to the development of PRT mainly because the Cornell people recognized the need for operation at headways down to one half to one second to get adequate capacity. Having strong backgrounds in the technology of automatic control, they attacked the problems directly and were able to show how it would be possible to operate vehicles safely at such short headways. The Urbmobile system was, however, never built.

M. I. T. In the mid 1960's a PRT concept was developed by a large senior-engineering-design task force at the Massachusetts Institute of Technology. A report was published called Project Metran, which embodied most of the basic ideas of PRT and influenced its development.

Bartells. While Robert J. Bartells was Director of Planning for the City of Hartford, Connecticut, he conceived of all of the basic ideas of PRT and, in 1962, explained them in a paper. The importance of Bartells' ideas is that they came from a planner who was faced with the practical problems of improving the mobility of people in a city. Bartells continued his interest in PRT as Professor of Planning at Syracuse University and later in retirement.

Kieffer. During the middle 1960's, Dr. Jarold A. Kieffer, while Head of the School of Public Affairs at the University of Oregon, was asked to advise the Governor of Oregon on transportation planning. He too wrestled with the problems of solving urban transportation problems with train systems and recognized that the costs were so great that not enough of such systems could be built to make a significant contribution in most cities to reducing the needs for automobiles. After having thought about these problems intensely for a period, he and his wife took a vacation at a ski resort. While there one glance at a cable-suspended ski lift caused all of the basic features of PRT to manifest in his mind. In 1967, he wrote a paper in which he described his concept of PRT. As a founding member of the Board of Directors of the Advanced Transit Association he has continued to provide essential leadership in the advancement of PRT, a kind of leadership made possible by his extensive experience in a variety of important positions in the federal government.

The Urban Mass Transportation Administration

The Act. Up to 1964, PRT activities were going on more or less independently. There were very few people in influential positions who had ever heard of the idea of automating horizontal transportation with small vehicles. One exception was Congressman Henry S. Reuss of Milwaukee, Wisconsin. Congressman Reuss had become aware of PRT and Dual Mode systems in the early 1960's and at that time gave speeches in which he urged political support for the development of new transit concepts. Because of his interest, he was assigned to a subcommittee that developed the Urban Mass Transportation Act of 1964. Through his efforts, a Section 6 was added to the Act entitled Research, Development, and Demonstration Projects. The key paragraph of that section read as follows:

> "The Secretary shall undertake a study and prepare a program of research, development, and demonstration of new systems of urban transportation that will carry people and goods within metropolitan areas speedily, safely, without polluting the air, and in a manner that will contribute to sound city planning. The program shall (1) concern itself with all aspects of new systems of urban transportation for metropolitan areas of various sizes, including technological, financial, economic, governmental, and social aspects; (2) take into account the most advanced available technol-

> ogies and materials; and (3) provide national leadership to efforts of states, localities, private industry, universities, and foundations."

The HUD Studies. The work of the early inventors had finally produced an important political result! At that time the U. S. Department of Transportation did not exist and the Urban Mass Transportation Act therefore established the Urban Mass Transportation Administration as a unit of the Department of Housing and Urban Development. The new UMTA followed the directive of Congress and initiated a series of studies in 1966 to carry out Section 6 of the Act. Some 17 studies were authorized each at a level of $500,000, and became known as the HUD studies. The work was done mostly during 1967. The reports were finished in late 1967 and released in Spring 1968 while I was on an exchange visit to the Soviet Union working in an entirely different field, but almost daily experiencing a variety of mass transit systems.

The most influential of the HUD reports were these: 1) A study by Stanford Research Institute whose task was to develop on paper various new concepts from moving sidewalks to PRT to dual mode and to estimate their economic benefits for the United States; and 2) a study by the General Research Corporation of Santa Barbara. GRC's major task was to model alternative transport systems in actual cities to determine how they would perform compared to conventional systems. A team of 17 specialists in various fields chose Boston as a typical large transit-oriented city, Houston as a typical large auto-oriented city, Hartford as a typical small transit-oriented city, and Tucson as a typical small auto-oriented city. The results of these computer modeling studies strongly favored new transit systems. They showed that, with the projected population growth and growth of the use of automobiles, if only conventional transit systems were developed, the problems of cities would continue to worsen. Only by deploying personal transit systems would it be possible to reverse the direction of worsening congestion in our cities. The GRC study has been the most influential of the HUD studies for two reasons: The first is that the results were summarized in a very readable article in *Scientific American* [8]. This article has become a classic and has been the starting point for much more thinking about the problems of new transport technology. The second reason is that the GRC work convinced its chairman, Ben Alexander, of the importance of trying to create a national commitment to develop these new transport technologies. He talked to politicians and testified before congressional committees, in this way bringing PRT and Dual Mode more strongly into political thinking in Washington.

The HUD studies were summarized in a report, *Tomorrow's Transportation*, authored by William Merritt, who was at that time an UMTA official. The report was optimistic about the prospects for developing the new technologies in the United States, and influenced the start of a great deal of industrial work in the U. S. and elsewhere.

Then came an event that had unfortunate consequences for the development of PRT systems in the United States − a change of administration. The HUD studies were released only a few months before President Nixon's new administrators had warmed their chairs. It is far less important that the change was from Democrats to Republicans than that it was a change. Here was a new group of people heading UMTA that had no commitment, indeed no detailed understanding of the implications of the HUD studies. Moreover, R&D played a minor role in UMTA's agenda. Their main task was to prevent the collapse of existing transit systems in the United States and to do so by providing capital grants for the purchase of buses and rapid rail systems. The stage of development of the new systems was too early for them to make a contribution to immediate improvements, and the new administration wanted results prior to the 1972 elections. At the time UMTA was understaffed. When they received a flood of proposals from the 17 HUD-funded companies as well as from others for development of all kinds of new transit ideas, there was simply no way they could handle these proposals in an orderly manner. The reaction was to fail to consider any of them, which resulted in a great deal of frustration among people interested in new transit systems and a period of inaction at the Federal level.

In retrospect, it seems clear that placing both development of new systems and funding of existing systems in the same agency could only squeeze out the new systems. Existing systems had powerful lobbies at a time when federal money was abundant. The lobbyists were not about to be denied funds by competition from new ideas, and the lobbies for the new systems were relatively weak. If an agency responsible only for R&D in ground transportation had been established similar to the National Advisory Committee for Aeronautics, which was established by Congress in 1915 to study the problems of flight toward their practical solution, the evolution of PRT may have been more orderly, but because of the politics maybe not.

Activities in Other Countries

On various trips outside the United States I made many inquiries of developers of PRT and in the process sought to determine if any of the ideas were invented independently there. In every case I found that the stimulus came from contacts with U. S. inventors or later from study of the HUD reports. There were probably at least three reasons: 1) the impacts on the urban environment of large numbers of automobiles became a serious problem in the U. S. before it did in most other countries, 2) the frontier spirit that prevailed in the U. S. provided a climate of tolerance for mavericks rather than forcing them by social pressure to conform, and 3) during the 1950's, all of the other leading industrial nations were recovering from World War II.

Cabtrack. The British Cabtrack System, a true PRT system, was initiated by activities of L. R. Blake, who then worked for Brush Electric Company. Blake had gone to the United States and examined the Alden staRRcar, Urbmobile and some other automated transit systems. In 1967, he wrote an article [9] in which he described his own synthesis of his findings into a system he felt was suitable for British cities and towns. He called his system "Autotaxi." Blake's work started as a private venture and was later sold to Brush Electric.

Figure 4. Cabtrack.

Brush executives later convinced the Minister of Transport to carry on the idea. A joint arrangement was made with a National Research and Development Board to fund 50% of the work of developing Cabtrack to the state of a test track. The total budget was £250,000.

The Royal Aircraft Establishment at Farnborough Hants had established an urban-transport group and was asked to study Autotaxi. They renamed it "Cabtrack." The first phase was a nine-month study with a comprehensive report issued in December 1968. As a second phase the RAE got an 18-month contract and then further contracts that culminated in testing of a one-fifth-scale model. The last report was issued in March 1974. The RAE work was the first comprehensive system study of PRT by a large government organization and considered not only technical development but extensive demand and layout analysis. They examined a wide variety of control schemes and became confident of operating at a minimum headway of 0.6 sec. A contract was awarded to Robert Matthew, Johnson-Marshall & Partners, a large British architectural firm, for a study of the integration of Cabtrack into a section of London. The results of that study were reported in May 1971 issues of the *Architects' Journal* and at the National Conference on PRT in Minneapolis in November 1971 [4]. It was the earliest serious study of the visual impact of overhead-guideway automated transit systems.

In early 1972, after a new election in Great Britain and the appointment of a new Minister of Environment, the Cabtrack program was stopped. I heard that the new Minister read of the Cabtrack program through the newspapers before he had any detailed briefing. His reaction was strongly negative and he refused to approve extensions of the program. The British Cabtrack program was the earliest serious development program in the world on high-capacity PRT and the final reports are still of great value both in methodology and results. It is a pity that they were never summarized in readily available book form.

<u>CVS.</u> The Computer-Controlled Vehicle System (CVS) is a one-second-headway, 2000-lb, four-passenger-vehicle PRT system developed in Japan beginning in 1968. Scale models were built, a 1000-vehicle network was simulated, and a full-scale test facility began operating in 1972 in a suburb of Tokyo with 4.8 km of guideway and 60 vehicles. Extensive planning and costing studies were done including one for Baltimore in the late 1970s. The CVS program was discontinued for a number of reasons. As an external observer, I became aware of the following: 1) The size, cost and visual impact of the guideway—three meters wide by about 1.8 meters deep; 2) problems of traction in wet and icy weather; 3) a rough ride; and 4) lack of understanding of how to obtain adequate capacity in stations by use of multiple berths and simultaneous loading.

Figure 5. CVS

The system was designed too quickly following the HUD studies and without adequate understanding of the elements required for success. The guideway was left as something that could be optimized later, but as time went on it became the millstone that sank the project. In 1983 a group of Japanese engineers sponsored by the Japanese government visited the United States in part to study progress in PRT. They recognized the need for guideway optimization, but by then the lack of a market for CVS as it stood was too much of a barrier for their top management to overcome. Unfavorable results are very difficult to overcome within a given organization.

Cabintaxi. In 1970, the German Ministry of Science and Technology became aware that two firms, Messerschmitt-Bölkow-Blohm (MBB) and DEMAG, had independently been working on concepts of PRT very similar to each other, each having been inspired by the HUD reports. As a result the Ministry urged these firms to pool their resources and begin funding a joint venture DEMAG+MBB at a level of 50% of their total efforts. This gave industry much more incentive and the government much less need for detailed supervision than the U. S. practice of 100% federal funding of similar programs.

A thorough program of analysis of a variety of alternatives for suspension, switching, motor design, cabin size and track size led them to a configuration of three-passenger cabs, one set hanging under a beam and the other set supported above. The vehicles ran on solid rubber tires and were propelled by two-sided linear induction motors, one on each side of the vehicle, which permitted operation at headways as close as one second. Based on extensive study of control strategies, they selected an analog, asynchronous control system instead of digital synchronous or quasi-synchronous control, saying that while quasi-synchronous control is easier to simulate, asynchronous control is more flexible under practical conditions such as adjusting to speed changes and possible stoppages.

Full-scale testing began in May 1973 and by October 1974 the system was demonstrated successfully to the German press and to the Minister of Science and Technology. A large variety of tests on reliability, maintenance, and human factors were performed in preparation for offering the system for deployment in cities. Also the team undertook an ambitious planning program to study the deployment of Cabintaxi in Freiberg and Hagen. These studies convinced the team that the project could be successful and could be deployed in German cities.

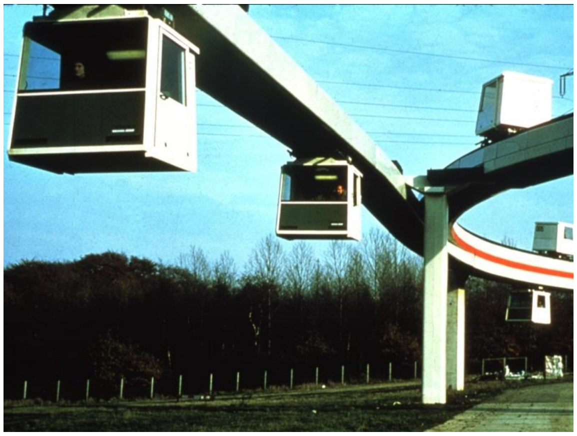

Figure 6. Cabinentaxi.

In 1975 at team from the Raytheon Missile Systems Division, to which I consulted, investigated several PRT development programs and decided to try to license Cabintaxi for deployment in the United States. That program came very close to succeeding but was canceled in July 1976 in favor of MSD's primary business, however, DEMAG+MBB continued to market in the United

States, with me as their U. S. representative.

In the late 1970's Cabintaxi in both 3- and 12-passenger versions was tested in a comprehensive study funded by the State of Indiana of automated guideway transit systems for the Central Business District of Indianapolis, which considered AGT systems using 100, 60, 40, 20, 12 and 3 passenger vehicles. The total system cost per passenger-mile decreased directly with vehicle size and the system was strongly supported by a wide range of business, governmental, and civic organizations.

In the meantime a program was underway in Germany to build a demonstration of the 12-passenger version of Cabintaxi in Hamburg. Due to an economic crisis in 1980 that required drastic cuts in expenditures, the German government withdrew support, yet continued marketing efforts have been undertaken in the United States. From today's perspective, it is most unfortunate that the Cabintaxi program was terminated in Germany because it could have shown that PRT works and could now be providing much improved transportation in many cities. The system is described in a comprehensive assessment report [10].

Aramis. This PRT system began with four-passenger vehicles running on rubber-tired wheels and propelled by a unique variable-reluctance motor. The ideas began in the mind of Frenchman Gerard Bardet, who started his work in 1967 with a budget of 10,000 Francs. In May 1970, the French aerospace firm Engins Matra bought the patents and began their own development work. In late 1970, Matra received its first contract on Aramis from the French agency DATAR. Full-scale testing of the vehicles began in April 1973 at Orly International Airport and by summer 1974 the first phase of proof testing of the basic concept was finished. In early 1974 Matra received a contract from the Paris Metro Authority to begin preparations for a public demonstration of Aramis in a suburb of Paris. The first phase of this program was to be a 16-month program to prove the safety and reliability of the system.

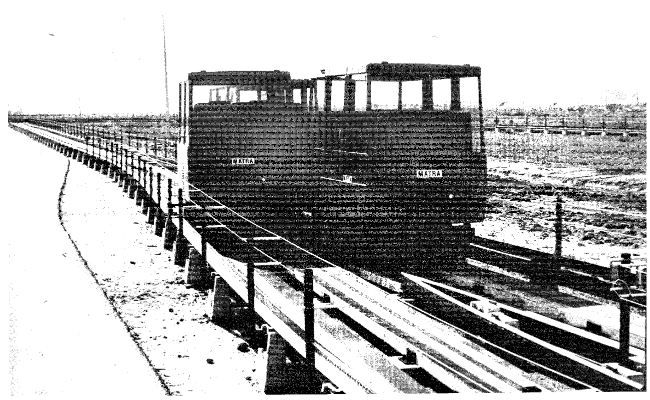

Figure 7. Aramis.

Aramis was unique among PRT systems in that the vehicles were to be electronically trained in platoons in which the vehicles were controlled to a separation of about 30 cm using ultrasonic and optical sensing. Any vehicle could be switched out of a platoon into a station by means of an in-vehicle switch and vehicles would leave stations between platoons and catch up to the last platooned vehicle. An important result of the Aramis program was demonstration that it was possible to attain rapid-rail capacities at stations by simultaneous loading and unloading of a series of vehicles. Aramis was designed to be a circumferential system around Paris, but, because of the platooning feature, was not well suited to network operation. Because braking was through wheels, it is quite possible that it was difficult to control the close spacing in wet weather. Later it was decided to increase vehicle capacity to ten, which was a serious mistake [11]. With ten-passenger vehicles, there are serious problems of personal security and virtually impossible station operations [11]. The Aramis PRT program is the only one to my knowledge that has been the subject of published sociological report [12].

Gothenburg. The leadership of the Gothenburg Transport Authority was stimulated by the British Cabtrack project. A transport study had been underway for Gothenburg and there was a strong belief that the solution could not be a subway because of very high costs, particularly because most of the sub-structure in Gothenburg is solid rock. A study was undertaken to plan a PRT system and a great deal of enthusiasm for the project developed. By March 1973, however, the Gothenburg authorities had reviewed enough of the international work on PRT to conclude that none of the systems were far enough along for early deployment. They chose, therefore, to extend their tram system for the time being and to wait and watch the developments in new technology. The work was significant in that it was sponsored by the city planning authority that, by making inquiries throughout the world, became very knowledgeable on new transit technology and showed that at least in one city the transit authority would be willing to consider new systems. Since 1990, interest in PRT in Sweden has revived with a series of studies sponsored by the Swedish Government that compare PRT very favorably with conventional transit [19], [26]. The Swedes have not liked to continue the name PRT and have instead coined the name “Pod-Car” for this technology.

Canada. In 1967 the Canadian Ministry of Transport sponsored a comparative study of transport alternatives for Canadian cities. The contract was awarded to Norman D. Lea and Associates of Toronto. They studied the future of Canadian cities if only conventional highway and transit technology was built and compared this with the future that could exist if PRT systems were to be developed. They didn't like the term PRT and instead used the term "Programmed Modules" to emphasize the use of the system for freight hauling as well as people movement. Their studies indicated that approximately half the revenue on a Programmed-Module system could come from freight movement. In a study of an automated network for Vancouver they concluded that if the system was used for freight movement as well as passenger movement a 50¢ fare would pay all of the costs. In about 1973, an Ontario provincial corporation was formed called Urban Transportation Development Corporation to develop a PRT system. Unfortunately, conventional rail people had too much influence over the project and turned it into 40-passenger steel-wheel, steel-rail vehicles propelled by linear induction motors. The guideway to support such large vehicles was large enough and expensive enough that the market for it has been limited.

The Aerospace Corporation

The Aerospace Corporation is a not-for-profit corporation established by the United States Air Force for the purpose of monitoring contracts on development of ballistic missile systems. In the 1960's, Aerospace employed about 3000 scientists and engineers in various areas of aerospace technology and had one of the finest collections of system-engineering talent in the entire world. In early 1968, its Board of Trustees wanted to try to determine how to make use of aerospace technology to solve urban problems.

A broad examination of such problems led by Aerospace Vice President Dr. Jack H. Irving led to the conclusion that the most promising direction for their efforts would be in development of high-capacity PRT based on many of the ideas contained in the HUD reports. They embarked on a very comprehensive program of systems analysis of the requirements for a PRT system and careful tradeoff analysis of components. They concluded that the problem of visual impact would be of prime importance in deploying the systems in cities and therefore chose a narrow, U-shaped guideway that permitted the vehicle's chassis to ride inside the beam with the cabin above. They chose to support the cars on two wheels in tandem. To reduce noise, increase reliability, reduce time of braking and acceleration, and make braking independent of the coefficient of friction, they chose to drive the vehicles with a pair of linear pulsed d. c. motors, which interacted with permanent magnets in the guideway. At the merge and diverge sections they used a no-moving-parts electromagnetic switch. These were new devices invented by Aerospace engineers and were tested in a one-tenth-scale model. The motor had the advantages that it could be controlled completely by solid-state circuitry and had an efficiency of about 88%.

During the period from 1968 to 1971, The Aerospace Corporation developed the entire system concept to a more advanced state than anyone else in the United States. By computer simulations they proved the feasibility of large PRT networks with many thousands of vehicles operating at headways as low as one sixth of a second at 60 mph. They performed economic and patronage analyses of PRT for Los Angeles and Tucson, Arizona, and lectured widely on the advantages of PRT. In the mid 1970s they summarized their work in a book [13].

Figure 8. The Aerospace Corporation PRT.

In 1973, a group at the University of Minnesota, called the Task Force on New Concepts in Urban Transportation that I coordinated proposed to the Minnesota State Legislature a test of the Aerospace PRT System at the Minnesota State Fair Grounds. In 1974, the Minnesota Legislature passed an act (S. F. No. 2703) that directed the development of a plan for an automated small-vehicle fixed-guideway system that would provide demand-activated origin-to-destination service. Aerospace submitted a strong bid, but, notwithstanding a Legislative mandate, the attraction of immediate capital grants for conventional systems prevented their selection by the Metropolitan Transit Commission.

Since The Aerospace Corporation is not-for-profit, it cannot manufacture. The Aerospace Board of Trustees felt, however, that the ideas were sufficiently important as a means of solving urban transportation problems that they urged the Department of Transportation to fund further studies related to high-capacity PRT (HCPRT). They also presented their ideas to the Office of Science and Technology (OST) in the Executive Office of the President where, during 1971, a group of 30 NASA system engineers were assisting in the development of a New Technologies Opportunities Program.

If The Aerospace Corporation had not entered the PRT field, I doubt if we would be talking about PRT today. Someday the world will recognize that they are owed a great debt of gratitude, unfortunately now after Dr. Jack Irving has passed away.

U. S. Government Involvement

Dr. Lawrence A. Goldmuntz, Director of Civilian Technology in OST, enthusiastically urged a program to develop PRT along the lines proposed by Aerospace, as a result of which such a program became the lead of a series of new technology initiatives to be developed, and was announced by President Nixon in a speech printed on the front page of the January 21, 1972 issue of the *New York Times*. UMTA was directed to divert $20,000,000 of its funds to development of a high-capacity PRT system, but the directive was ignored, following which OST asked NASA to prepare a PRT development program. By Fall 1972, DOT officials had been convinced to approve the program and to cooperate with NASA. But after the November 1972 presidential election, President Nixon replaced all of his appointed officials. Notwithstanding a "Memorandum-of-Understanding" party at NASA Huntsville, the NASA PRT program stalled within UMTA, while UMTA planned its own program.

On March 27, 1973 the new UMTA Administrator Frank Herringer announced his own HCPRT program with the following statement to the Transportation Appropriations Committee of the House of Representatives [14]: *"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."* [See the next page.] In contradistinction to frequent comments that PRT is useful only as a low-capacity circulator, Herringer also told Congress that "a high-capacity PRT could carry as many passengers as a rapid rail system for about one quarter the capital cost." He then directed his staff to prepare the required Request for Proposals.

Herringer's statement was backed up by studies by his R&D staff, a group of mostly former Aerospace engineers. Note the advances in computer performance in the 35 years since 1974: Computer memory per unit area has doubled every 18 months for at least 40 years, so in 35 years it has doubled over 23.3 times, giving an increase in memory of over $2^{23.3}$ or over ten million times. In regard to computer speeds, in 1990 a processor speed of about 100 kilobytes per second was common. Today 12 gigabytes per second is state-of-the-art. This is an improvement in speed of 120,000 to 1 only in the past 19 years. During the same period computer hardware reliability has increased by leaps and bounds. Similarly, computer design tools and software techniques needed to improve system reliability are orders of magnitude better than they were in 1974. Thus, in terms of computer power, what was considered feasible in 1974 is remarkably easy today, and there are many more engineers who understand the details. Arguments that high-capacity PRT can't work are obsolete.

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?

As a result of marketing activities of the various companies that were developing PRT systems with private funds, interest in PRT had been growing in many U.S. cities. In September 1973, Denver citizens voted a one-half percent sales tax for a PRT system after experiencing some of the longest waits for gasoline in the country and after the characteristics of true PRT had been described in many articles in the Denver press. Six months later the Minnesota State Legislature passed an act, already mentioned, for a plan for a PRT system. Thus arguments made today that it was too early in the early 1970s for PRT in the United States have no validity.

The UMTA RFP for a high-capacity PRT system was ready to go with a press release in August 1974; however, a new UMTA Associate Administrator for R&D, George Pastor, was appointed. As a result of heavy lobbying from the conventional rail industry and from representatives of automated systems that saw no chance of recovering their investments if the UMTA program proceeded Pastor diverted the funds into an innocuous technology development program. Charles Broxmeyer, who was a manager in the UMTA R&D office was furious that the HCPRT program had been canceled. In Fall 1974, he showed me the press release and told me that The Aerospace Corporation was to be the lead in the program and that my group at the University of Minnesota was to be involved. UMTA had already awarded us several important contracts in the areas of visual impacts, control and safety, all related to HCPRT.

Having come from aerospace engineering at Honeywell, it took me a while to realize that in civilian technology the bad can drive out the good. Urban transportation is a big business with many players having devoted their careers to it. New ideas threaten careers and businesses, as a consequence of which any change in modes of transportation, however promising, must be gradual. At a time when it had become possible to receive substantial federal grants for planning and building conventional transit systems and when businesses involved in transit did not see how they could be involved in the new systems, they opposed them. It became clear that federal money can be a curse as well as a blessing.

The above-mentioned GRC study (see p. 8) concluded very positively that if only conventional transit systems were to be deployed congestion would continue to worsen, as has been true, but if the new PRT systems could be deployed it would be possible to reduce congestion and to create much improved urban environments. Coming new into the field and armed with the GRC study, it seemed obvious to many of us that a serious development program on HCPRT needed to be a national priority.

In retrospect it is clear that such a program could be undertaken publically only when there would be a consensus among leaders that conventional transit cannot significantly improve the urban environment and cannot reduce congestion by a significant degree. The world may be reaching that point [15]. If undertaken by a government, an HCPRT program would have to be placed in an agency devoted to R&D, like NASA, which is led by career officials that are not replaced after every election and have no role in funding existing systems. Yet people in existing transit agencies and businesses must be kept informed of the new program and must be given opportunities to participate in a meaningful way.

Morgantown

In the late 1960's, Professor Samy Elias, Head of the Industrial Engineering Department at the University of West Virginia in Morgantown, had become aware of PRT systems and was aware that there were several PRT test tracks in operation in various parts of the United States. Morgantown is situated in a mountain valley along the Monongahela River. It was at that time a town of 20,000 people and the home of a State University with 20,000 students in three campuses in different parts of the city. The students were transported between campuses in buses that traversed the main street of Morgantown along with both town traffic and through traffic. All went through the center of the city and created congestion similar to that in a much larger city.

Professor Elias believed that a PRT system would be a logical solution to the movement of students between campuses and would be much less expensive than a conventional fixed-guideway system. With support from the University, the city, and the West Virginia Congressional Delegation, Elias was able to obtain $50,000 from UMTA for a comparative study of three different systems: Monocab, the Alden staRRcar, and Dashaveyor, a system not previously mentioned because with its in-track switching it was not suitable for PRT operation. The result was selection of the Alden staRRcar as the most suitable system for Morgantown. Political pressure from West Virginia was strong enough that the newly formed Department of Transportation and its Secretary John A. Volpe took seriously a follow-on proposal to proceed with plans for an operational system.

At that time, several of the companies involved in PRT development were saying that only about two years would be needed to build an urban demonstration from the state of development at that time. Close on the heels of Apollo success it was common for engineers to say: "We can do the difficult today and the impossible tomorrow." Unfortunately, non-engineers believed them. With the two-year period in mind, Volpe saw that it would be advantageous politically to have the system operating before the presidential election in November of 1972. A political deadline was therefore set. The system had to be in such a state of readiness by October 1972 that the President could ride it and use it as an important example of progress being made by his administration. Technical difficulties of meeting such a deadline were shoved aside.

Figure 9. The Morgantown “PRT” System.

Upon visiting the Alden Self-Transit Corporation, UMTA officials decided that they were far too small to be entrusted with a Federal Demonstration Program. They therefore asked Jet Propulsion Laboratory, a NASA lab in Pasadena, California, to be the system manager, and a contract with them was signed in December 1970. At the same time UMTA selected Boeing in Seattle to be the vehicle manufacturer, Bendix Company of Ann Arbor, Michigan, as the control system supplier, and F. R. Harris Engineering Company [31] of Stanford, Connecticut, to do design and construct the guideway, stations, and other fixed facilities. None of these firms had ever done anything similar and had much to learn, yet there was little time for learning. They had to make quick decisions. JPL asked for funds to support a team of engineers to do the kind of systems analysis they had done in space programs, but UMTA allowed no time or budget for such analysis. They were to be only a "money pass through." Consequently JPL resigned from the program in August 1971 saying that "they could not maintain their reputation for technical excellence and be involved in such a program."

In the great hurry mistakes were made that caused the system and its costs to grow by a factor of four, which was almost the only fact reported by the press. The result was a major black eye to PRT generally and a loss of confidence in PRT in Congress as well as in foreign governments. Yet the Morgantown system is still in continuous operation and was an important factor in convincing Gayle Franzen, Chairman of the Northeastern Illinois Regional Transportation Authority, to recommend to his Board a new PRT program in 1990.

Transpo72

UMTA decided to sponsor an international transportation exhibition at Dulles International Airport in May 1972. They called it "Transpo72." Exhibits of many companies on a wide range of transportation problems and solutions were to be presented and UMTA leaders decided that the development of PRT would be encouraged by exhibits of leading PRT systems. UMTA allotted $6,000,000 for this purpose to be split equally among four different PRT developers chosen from competitive bids, and it was expected that each company would match the funds they would receive. The successful bidders were TTI; Monocab; Dashaveyor, developer of a wheeled vehicle with an in-track switch; and Ford, a new entry. Ford called its system ACT for Automatically Controlled Transportation. Uniflo was to have been the fourth exhibitor so that UMTA could exhibit one LIM propelled vehicle, one air propelled vehicle, one hanging system, and one normal-looking wheeled vehicle; but the industrial might of Ford Motor Company prevailed, so that a second wheeled vehicle, but with an in-vehicle switch, was substituted.

The expectation of UMTA was that by exhibiting a minimum piece of guideway and one station, city leaders would obtain sufficient information and confidence to purchase one of these systems for installation under the UMTA capital-grant program. It was even said that the criterion for acceptance of one of these systems would be an application by a city for a capital grant. The time schedule given the companies to exhibit in May 1972 was, however, so short that there was no possibility of making any technical advances in the Transpo72 systems. Each developer had built and operated a full-scale test track on his own site and all that could be done was a slight bit of re-engineering.

Unfortunately, the developers were so busy improving their hardware that they paid inadequate attention to integrating their systems into communities. As a result, attendees at Transpo72 had little understanding of how these systems would be used, and the companies had a variety of ideas that tended to confuse non-technical planners and decision makers. As a result, Transpo72 did not produce the anticipated requests for capital grants.

A large number of cities, however, did request to be considered as sites for 100% federally funded demonstrations of the various systems, but none were ready to put any of their own money into such a system. One could not help but come away from Transpo72 feeling that the $6,000,000 invested could have been better spent in a more highly directed and carefully worked out systems development program. Apparently, however, notwithstanding a directive from the White House, UMTA did not believe that was their role. They saw their role rather in stimulating the private manufacturers to develop their own systems. They were of course subjected to a great deal of lobbying.

1974 to 1981

September 1974 was a turning point for PRT development. People interested in PRT could no longer get federal grants, yet the interest would not die because an unmet need existed and it was well understood by people working on PRT that the reason was not technical unfeasibility but turf protection. A third international PRT conference was held in Denver in September 1975 leading to a third volume of papers called PRT III [4], but attendance had peaked with the second conference in May 1973.

The organizing committee of the PRT conferences met at the Denver conference to develop a permanent organization, and in 1976 the Advanced Transit Association (ATRA) was formed. ATRA held a well-attended conference in Indianapolis in April 1978 and printed its proceedings, which form a valuable addition to the literature.

A major problem had been that a wide and confusing array of ideas had been advanced with insufficient underlying theory based on cost-effectiveness to help make selections among all the alternative features possible in designing a specific PRT system. Experience showed that a PRT system would not sell if it were only a marginal improvement in cost and performance over conventional light rail. When various developers, except for The Aerospace Corporation and the DEMAG+MBB team, were asked why they picked certain features, the answers were too often vague or entirely lacking. For example, a number of development organizations decided on four-passenger vehicles without giving anything but the most cursory discussion of the reasons for the selection and why it was better than some other number. Yet there are a variety of factors including safety, cost, capacity, traveling habits, and personal security that should enter such a decision and can enter only if a comprehensive understanding is attained [17].

After having worked at the Colorado Regional Transportation District on the largest study of transit alternatives ever attempted and then for a year and a half at Raytheon on a PRT development program, I had accumulated enough material to try to fill the need for underlying theory by writing a textbook [3], and have continued to update the material to the present time with papers published in the *Journal of Advanced Transportation* and elsewhere, many of which are now available on www.prtnz.com and www.prtinternational.com.

In the late 1970's, through vigorous efforts of two Indiana legislators, Dr. Ned Lamkin and Richard Doyle, the Indiana Assembly appropriated $300,000 for a study of automated transit in Indianapolis including PRT. This study has been mentioned above in the discussion of Cabintaxi. After the Cabintaxi program was terminated, my colleague Raymond MacDonald and I began thinking about a PRT system that would meet all of the requirements and criteria we had accumulated, but was yet to be developed.

1981 to 1990

I started such a development program in September 1981 at the University of Minnesota by assigning the project to my senior mechanical engineering design students. To avoid the serious and often fatal flaws of other systems, we realized that a successful PRT system had to be one that took advantage of all prior work. The University of Minnesota Task Force of the early 1970s, after extensive analysis of the requirements, concluded that the system closest to being right was the Aerospace PRT system. By 1981 it was clear that the technological advances that had occurred since the late 1960s could make it even better. By the spring of 1982, the ideas for the new system had developed to the point that patent applications were filed. In June 1982, the University of Minnesota Patent Office gave me a grant of $100,000 to work full-time for a year with two graduate students on the design and costing of the new system. As of the current date, all of those patents have expired, so the information is available and usable by anyone.

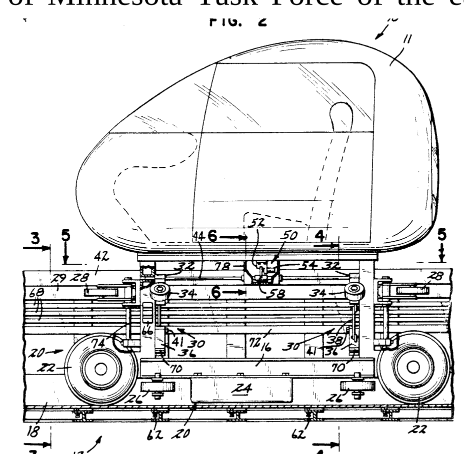

Figure 10. University of Minnesota PRT.

In June 1983, with the help of University of Minnesota officials, a company, later called Taxi 2000 Corporation, was formed to further the ideas. Early in 1984, Davy McKee Corporation of Chicago became interested and funded the development until mid 1985. In August 1986 I was attracted to Boston University and found that it was easier in Boston to assemble a team of competent engineers willing to devote substantial amounts of their own time to further the ideas. In 1988 ATRA published a report [16] of a broadly based Technical Committee on PRT that became a key factor in increasing the credibility of the PRT concept. With the endorsement of the ATRA study, and with the help of Raytheon executives, we were able to attract the interest of the leadership of the Chicago-Area Regional Transportation Authority (RTA), who had come to the important conclusion that they could not solve their transportation problems with just more roads and more conventional rail systems. They realized that they needed something new and in fact they had been mandated by the Illinois State Legislature to look at new systems.

The PRT Program of the Northeastern Illinois Regional Transportation Authority

The RTA's interest led them in April 1990 to release a request for proposals for a pair of $1,500,000 Phase I PRT design studies. Twelve proposals were received, and for Phase I two teams, Taxi 2000 Corporation with Stone & Webster as prime contractor and Intamin, A.G., were selected to develop parallel PRT designs. For Phase II, which started on October 1, 1993, the RTA selected the Taxi 2000 system with Raytheon Company as prime contractor to design, build and operate a test PRT system – intended to be a $40,000,000 program. One of many publications by the RTA to announce their initiative is shown on the following page.

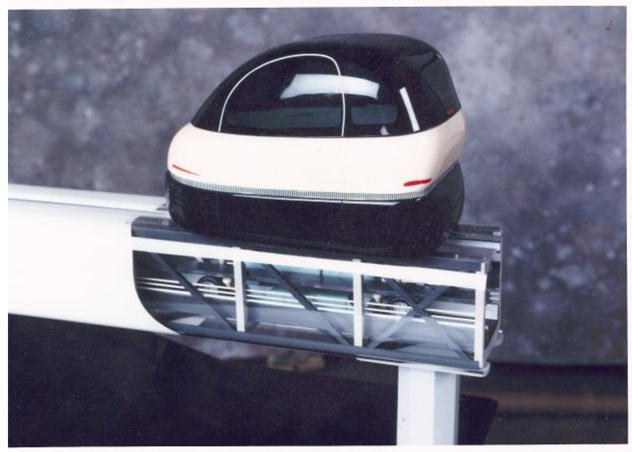

Figure 11. Going into Phase II.

Unfortunately Raytheon set aside all of the prior work and decided that they could build a superior PRT system using engineers with no prior experience in PRT. Notwithstanding our strong protests, they built a test system with a guideway twice as wide and twice as deep as that which came out of the Stone & Webster study, a vehicle weight that had quadrupled, and a cost that more than tripled. Moreover, they made the mistake of abandoning the linear motor for conventional rotary motors [27]. The consequence was that in late 1998 the RTA Board set aside the issue of funding a Phase III demonstration in Rosemont, IL, and talked no more about PRT. A year later Raytheon announced that they abandoned the PRT business. This was tragic. In January 2000 Raytheon restored Taxi 2000's rights to its technology with a statement by one Raytheon manger: "Ed, taking my Raytheon hat off it would be a crime if you can't build your system." They knew they had erred. Some of them were ashamed. They suffered from the not too uncommon problems large companies have in managing new projects. Wise management at Lockheed-Martin understood the problem and solved it by establishing their famous "Skunk Works," which produced some remarkable new airplanes. Similarly IBM got into personal computers by establishing a separate group far away from headquarters and devoted to make the PC a new line of business. The difference was in the degree to which the direct management of a new project thoroughly understood the need and was given unhindered control of the development process.

Figure 12. Coming out of Phase II.

THE FUTURE

"Traditional mass transportation responses have failed to meet mobility needs in areas of rapid development. As our suburban service areas approach gridlock, new answers must be found and new technologies examined."

Thomas J. McCracken, Jr.
RTA Chairman

The Regional Transportation Authority, (RTA) responding to its statutory obligation to pursue new and appropriate mass transit technologies for the Northeastern Illinois region, is designing an experimental transportation system to improve suburban mobility:

Personal Rapid Transit

Personal Rapid Transit (PRT) will provide an innovative addition to the existing family of mass transportation modes.

Personal Rapid Transit is well-suited to the needs of today's growing suburban activity centers. These areas have population and development densities that are too small and widely dispersed to support traditional rapid transit, but too large and concentrated to rely exclusively upon use of the automobile. PRT will provide much of the spontaneity, flexibility and privacy of the automobile, without suffering from and adding to ground-level congestion and pollution.

Personal Rapid Transit will offer:

- Small cars seating four passengers each.
- Wait-times of less than three minutes.
- On-demand service and fully-accessible off-line stations, permitting riders to proceed directly to their destinations without intermediate stops.
- Light-weight guideways which are unobtrusive and aesthetically pleasing.
- Fully-automated, computer-programmed travel.
- Maximum passenger safety.

Chicago Tribune 5-14-90

Getting personal with rapid transit

So here comes Gayle Franzen, chairman of the Regional Transportation Authority, with an idea so startling and futuristic in concept that it immediately was labeled as something out of Buck Rogers. It is, in fact, so wildly different from traditional transportation standards that Franzen and the RTA are absolutely correct in their determination to put it to a test.

It is personal rapid transit, a technological leap in line with the RTA's mission of exploring new ways of helping people get around. It recognizes the reality that the metropolitan area is beset by traffic congestion that eventually could cripple its economic growth. It recognizes that the traditional means of transportation are limited as solutions and that the suburbs are the testing ground for new answers.

Trains must operate on fixed schedules with little flexibility on century-old routes, and the cost of building new routes is prohibitive. Buses get caught in traffic, and—as Pace has discovered in its venturesome experiments—sometimes do not catch passengers. Cars. You know about cars. We have met the enemy and it is us, one by one, creeping in desperation.

Personal rapid transit is a means with a 21st Century difference. In simplest form, it is a procession of computer-operated small cars zipping along on lightweight, elevated guideways to individually chosen destinations. The cars hold from one to no more than five persons and can move at intervals of as few as five seconds. The use determines the schedule; whenever someone shows up to hop in, a car takes off.

The cars offer the personal privacy of an automobile without the disadvantages: traffic, pollution, danger, parking. The idea is to appeal to the psychology of drivers to wean them away from their automobiles as a means to supplement existing mass transit. And best of all, a system probably could be built at a small fraction of the cost of a traditional rail line.

The basic concept and technology have been around for years, and versions of the idea are already in operation. The difference with the RTA concept is scaling cars down to personal size, with the hope of someday building a first-in-the-world network on a huge scale.

The RTA is cautious about this, but as serious as money about giving it a try. It is prepared to award two $1.5 million contracts to mass transit and engineering firms to study the concept, using actual locations in three suburbs as models. If the studies pass the test of economic and technological feasibility, an experimental system of up to two miles would be built in one of the suburbs, concentrating on dense areas where great numbers of people move daily.

As one example, a system could link a Metra railroad station with an office or shopping complex.

The concept has brought refreshing whoops of delight from officials in several suburbs. It's enough to encourage the RTA to hope for a spirited competition among suburbs to be chosen for the experiment.

If the experiment actually happens and is successful, loosen the springs of imagination. The system could be replicated in locations throughout the suburbs, and in the grandest vision the guideways could be built in a vast network along existing, crowded highways and abandoned railroad rights-of-way—linking suburb to suburb and countless stops along the way.

Yes, it would look a lot like those scenes from Buck Rogers films—or "Star Trek." But that is the idea: to boldly go where no one has gone before, testing for the first time a new way of getting from here to there.

Post RTA

Surprisingly, perhaps, the collapse of the Chicago initiative did not discourage interest in PRT. Interest in PRT that had been expressed by the second largest transit organization in the United States via monthly newsletters, editorials and articles in the Chicago press (see the above Chicago Tribune editorial) could not be ignored. The RTA woke up many people to the potential of PRT. The first serious result was that using the earlier specifications in a comparative study with buses and light rail a 17-person steering committee serving SeaTac, Washington, voted unanimously in 1992 for PRT. Then the Swedish Transportation and Communications Research Board funded a series of studies of PRT in Swedish cities [19] that produced very positive results *if* the cost and visual impact of the system approximated the work of the Chicago Phase I PRT Design Project.

Figure 13. Vectus PRT in Uppsala.

Almost at the same time, due to the influence of Ray MacDonald, a Korean company WooBo became interested and performed a series of studies of PRT for their cities, which likely led to Posco's development of Vectus PRT. Also, at almost the same time the Internet began to be available to anyone who owned a personal computer so that publicity about the work exploded. New companies and individuals in many countries who had been working on various forms of PRT were represented at the International Conference on PRT and Other Emerging Transportation Systems, held in Minneapolis in November 1996, and at more recent conferences.

Cincinnati. In 1996 Dr. Chuck Roth of the Cincinnati Metropolitan Area got so interested in the Taxi 2000 system that he dropped what he was doing and spent almost full time during the next two years urging consideration of this system. In September 1998 a committee of 20 business and planning leaders supported by a businessmen's organization later called "The SkyLoop Committee" voted unanimously, I think it was, to select Taxi 2000 over about 50 other elevated systems as their preferred technology. (www.skyloop.org) Unfortunately, the Cincinnati Area Metropolitan Planning Organization had leaned strongly in favor of a conventional surface-level rail system (called "Light" Rail), and had sufficient political strength to postpone any serious consideration of PRT of any type.

State Fair. Interest from Cincinnati was sufficient to enable Taxi 2000 Corporation, when I was its CEO, to raise about $800,000 to design, build and demonstrate one automated, linear-induction-motor propelled, three-passenger vehicle that operated on a 60-ft length of guideway. It ran flawlessly for thousands of rides during the 2003 Minnesota State Fair. Citizens for PRT assisted in more ways than I know by providing displays and people to manage the crowds and answer questions. A reporter asked me: "What was the most surprising thing about it?" After a moment of thought, knowing that it worked technically exactly as designed, I said that the most surprising thing to me was the thrill people got out of riding only 40 feet. I could only imagine the reaction to riding around the loop of the first pilot system and subsequent applications. Seeing a comprehensive display of what it would be like to live in a city served by PRT and appreciating the way concerns about PRT would be treated produced an overwhelmingly positive reaction.

Figure 14. Taxi 2000 at State Fair.

What happened to us after that, though, was awful. A clash of interests caused three board members including me to resign from Taxi 2000 Corporation in January 2005 and to go on to form PRT International, LLC. I had the satisfaction, at least, that the Chicago RTA project, made possible by work at the University of Minnesota, was the catalyst for a great deal of activity around the world today. PRT now seems unstoppable!

Today

As a result of publicity from the Chicago PRT project, operational PRT systems are under test at Heathrow International Airport and in the Masdar project in Abu Dhabi, and a test PRT system is in operation in Uppsala, Sweden. In September 2009 plans to install PRT systems were announced for four Swedish cities: Stockholm, Södertälje, Umeå, and Uppsala; and in the South Korean city Suncheon. New conferences on PRT or Pod Cars as well as the APM Conferences have been held and more are planned. Clearly, PRT is coming of age. I have been invited to give a paper entitled "Overcoming Headway Limitations in PRT Systems" at the forthcoming Pod Car Conference in Malmö, Sweden, 9-10 December 2009, www.podcar.org/cop15 and look forward very much to that event.

Figure 15. ULTra at Heathrow.

On August 31, 2009 the City of San Jose, California, released a request for proposals to Federally Funded Research and Development Centers to find a Center qualified and willing to work with them to identify which of the 25 PRT systems currently on their list they should plan for and deploy. The selection is to be made in December. This is the most significant action by any American city related to PRT since the Chicago RTA initiative of 1990. I am very hopeful that the Federal Center will do a thorough and objective job. May the truly best PRT system win! On October 4, 2009 the *Boston Sunday Globe* published an article by Rebecca Tuhus-Dubrow entitled "Invasion of the Pod Car: The dream of personal rapid transit picks up speed."[2] This is the first article on PRT by a writer and published by a major American newspaper in more than a decade. New information is coming so rapidly now that I can only refer the reader for the latest news to http://kinetic.seattle.wa.us/prt/, the best independent webpage on PRT.

With concern about too much CO_2 released into the atmosphere as well as other atmospheric pollutants, increasing prices of oil, ever increasing congestion, retiring baby boomers, and economic hard times there is today far more evidence than in 1974 that these new systems are needed, should be developed, and can be developed. Designs that meet the requirements of low cost, acceptable visual impact, and adequate all-weather safety and reliability appear to have a bright future. These are only a few of the requirements. In my basic non-technical paper [24], which I update from time to time, I list some 37 design requirements and 18 design criteria.

What have we Learned?

During over 50 years of experience in PRT development and planning, some things have been learned that should be of benefit to future PRT designers. PRT development is a challenging in-

[2] http://www.boston.com/bostonglobe/ideas/articles/2009/10/04/invasion_of_the_pod_car?

terdisciplinary task that cannot be taken casually. It should not be undertaken without deep understanding of the interrelated features of the system, the urban environment in which it would be deployed, and the institutional factors that enter. Inadequate designs have provided fodder for PRT critics, and if such designs represented all that is possible, I would agree with them; however, these critics have never come up with a single valid reason that optimized high-capacity PRT should not be developed. I recommend that the engineers and managers in any new PRT program follow a rigorous set of rules of design such as I have outlined [20]. I hope other experienced designers will add to them.

A successful PRT development program requires at least the following:

- Leadership that understands the engineering science behind PRT, its relationship to the transportation problem in quantitative detail, the various PRT development programs and their successes and failures, the concerns of citizens and planners, customer needs, and the institutional problems that have hindered development of PRT. This experience can be acquired through involvement in site-specific planning projects in which all of the practical considerations concerning the installation of such a system are considered. Currently there is a substantial body of literature on all of these aspects of PRT.

- A strong, disciplined, and continuous commitment to weight and cost control.

- Use of proven components when such components are available, but willingness to develop new components when necessary.

- Commercially realistic performance specifications.

- A commitment to careful system optimization of components.

- Willingness to consider unconventional guideway designs to obtain adequate stiffness with minimum guideway size and cost [29]. Almost every PRT program that has failed has failed due to lack of attention to guideway design requirements.

- Sufficient training at the beginning of the design process to enable engineers to avoid pitfalls by having thought about them in advance when errors can be easily corrected and before committing to specific hardware solutions.

PRT developers need to recognize that once PRT matures, it is "just" one more civil work, albeit a badly needed one. In the long run PRT technology will be similar to bridge technology, or the technology to build any other civil work. It will be taught in Universities and companies will win contracts to plan, build, and operate PRT systems based on their management and technical strength and skill. PRT development will proceed much more rapidly if those involved can learn to work cooperatively. Consider the Automobile Manufacturers Association.

Today cities all over the world have serious infrastructure problems coupled with declining budgets. Trying to solve these problems in old ways is an exercise in futility [22, 23]. Governments must learn to encourage innovation in the civil sector just as they have in the military. Our future depends on it!

On April 27, 2009 the Obama Administration issued a Funding Opportunity Announcement, the first paragraph of which says"

"This is the first solicitation for the Advanced Research Projects Agency – Energy (ARPA-E). ARPA-E is a new organization within the Department of Energy (DOE), created specifically to foster research and development (R&D) of *transformational* energy-related technologies. Transformational technologies are by definition technologies that *disrupt the status quo*. They are not merely better than current technologies, they are significantly better. Often, a technology is considered transformational when it so outperforms current approaches that it causes an industry to shift its technology base to the new technology. The Nation needs transformational energy-related technologies to overcome the threats posed by climate change and energy security, arising from its reliance on traditional uses of fossil fuels and the dominant use of oil in transportation." (Emphasis added.)

PRT is a *transformational* technology. It will indeed be *disruptive*, but in a very positive way. We watch to see if the Obama Administration can carry through its mandate for change.

For information about the author's work and PRT generally see the following web pages:

www.prtnz.com, www.prtinternational.com
www.advancedtransit.org, www.cprt.org, www.acprt.org
http://kinetic.seattle.wa.us/prt, http://faculty.washington.edu/jbs/itrans
http://gettherefast.org

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A full list of all of the people who in one way or another have led to the current state of development of PRT would be very long, and I am sure that representatives of each of the 25 companies on San Jose's list of PRT companies have their own stories about how they got involved in PRT and all of the people who helped them. Many of the exceptional people whose roles should not be forgotten are no longer among the living. Here is a list, sort of in chronological order, of people now deceased who in my experience should in particular be remembered: Dr. Eugene E. Lundquist, Edward O. Haltom, Lloyd Berggren, Minnesota State Senator Mel Hanson, Dr. Richard C. Jordan, Dr. John Borchert, Professor Fulton Koehler, Dr. Jack H. Irving, Dr. Lawrence A. Goldmuntz, Charles Broxmeyer, Morse Wade, Richard Doyle, Michael A. Powells, Jr., Dr. Arthur G. B. Metcalf, Will Rich, Tony Potami, Dr. Byron Johnson, A. Sheffer Lang, Roy Moore.

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Outside the United States more people than I know particularly in Sweden, South Korea, and England have in recent times enabled PRT to grow and flourish while we in the United States have watched with envy. In particular, I acknowledge and thank Will Wilson of Auckland, New Zealand, who found me on the web and created two websites that have enabled us to get our message out.

Evolution of this Paper

The first version of this paper was written in 1974, the second in 1982, the third in 1996 as a paper to be presented to the 1996 International Conference on PRT and Other Emerging Transportation Systems while I was CEO of Taxi 2000 Corporation, a fourth in 2008 and a fifth in 2009.

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