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BENJAMIN EDELMAN

Personal Rapid Transport at Vectus, Ltd.

At a test track in Uppsala, Sweden, Vectus chief technology officer Jörgen Gustafsson watched as three driverless vehicle "pods" maneuvered through a test track. Proceeding at a rate of up to 30 miles per hour, the vehicles merged and diverged on a pair of concentric guideways, all under full computer control. Gustafsson envisioned these vehicles carrying passengers around a web of stations at airports, corporate or academic campuses, or even in cities. Waiting for a shuttle bus could become a thing of the past—and so, too, could the huge costs of installing traditional subways and light rail. Even better, the vehicles would transport each passenger directly from origin to destination, bypassing all other stations and eliminating waits for others to get on or off. This was personal rapid transport (PRT), and Gustafsson's Vectus, Ltd. aimed to make it a reality.

Meanwhile, Advanced Transport Systems Ltd. (ATS) of Bristol, United Kingdom, was nearing completion of a similar system at London's Heathrow airport. A lightweight, concrete guideway, little thicker than an elevated bicycle path, connected Heathrow's new Terminal 5 to the business car park a mile away. In five minutes, a passenger could proceed from T5 to the parking lot—without waiting for a shuttle to arrive or for other passengers to board. If the system expanded to cover more of the Heathrow property, it could whisk passengers to car rental providers and nearby hotels and even between terminals. (See **Exhibit 1**.)

Despite Gustafsson's grand aspirations, the next steps were challenging. ATS had won the Heathrow contract, but so far Vectus had only achieved the installation at its Uppsala test track. Numerous planners had evaluated PRT, but they inevitably rejected the PRT approach as unproven. As Gustafsson drove to work each morning, he saw opportunities for PRT at every turn—connecting a local mall to the train station across the highway, linking communities separated by a nature preserve, replacing slow buses that brought passengers to subway stations, and offering a safer alternative to bicyclists during rain or snow. Vectus had a solution to offer, but to whom and how?

The PRT Concept

Some called PRT vehicles "driverless taxis." In fact, PRT sought to combine the best characteristics of cars, taxis, and trains, while adding features unavailable in any existing transportation system. Like cars and taxis, PRT vehicles carried small groups, or often just a single passenger, with no need to wait for a shared vehicle to arrive or for others to board. Like train systems, PRT used an exclusive right of way, avoiding delays from other traffic. Most PRT plans called for an elevated track, although in principle PRT could be installed at or below ground level. Whatever its height, a PRT guideway provided guidance, support and power to vehicles, while keeping vehicles separate from pedestrians, cars, and others.

PRT sought to improve on rail by offering greater flexibility. Most train systems offered one or a few linear tracks making a series of stops, with all trains stopping at all stations on a given line. As a result, on traditional train systems, passengers had to change vehicles to switch from one line to another. In contrast, PRT vehicles could steer themselves from one track segment to another to suit each passenger's request. Furthermore, when stations were close together, train efficiency was limited by the time required for passengers to board at each stop. But a PRT vehicle stopped only when its passengers wanted to get off—eliminating unnecessary stops and reducing travel time. **Exhibit 2** presents a sample urban PRT system layout, as envisioned for an installation at an eco-development in Masdar City, United Arab Emirates.

By using small, lightweight vehicles, PRT systems sought to reduce cost as well as visual intrusiveness. Thanks to low vehicle weight, a PRT track or guideway could be correspondingly small—just 12 inches tall in the Vectus design. Support columns were also smaller than most supports for other elevated transit systems: PRT vendors proposed support columns with diameters of 16 to 24 inches, whereas ordinary monorails and elevated light rail systems required support columns measuring 30 to 60 inches. **Exhibit 3** shows cross-sectional profiles of PRT and other transport systems. Thanks to the light weight of PRT systems, PRT guideways could be prefabricated and installed on site with far less delay and expense than the poured concrete installations of elevated train and monorail tracks.

Small PRT vehicles also allowed for compact stations. In traditional rail systems, each station must be as long as the longest train. But with one-to-four-person PRT vehicles, stations could be both smaller and cheaper. In addition, stations could be built on the edges of existing buildings and could use those buildings' existing elevator, escalator, and climate control systems, thus further reducing costs and improving convenience. **Exhibit 4** presents possible station designs.

PRT systems used computer control to coordinate vehicle location and routing. By monitoring vehicle positions and knowing each passenger's desired destination, a control program could choose optimal routes to reduce travel time and avoid congestion. Control systems also managed empty vehicles, sending them to stations where statistical models suggested customer requests were likely.

PRT could significantly reduce total travel time by eliminating unnecessary stops and line changes and by departing as soon as a passenger was ready. **Exhibit 5** compares journey travel time of various transport systems. Projections suggested that PRT could transport passengers in as little as half the time required by other transit systems, and that the savings could be especially dramatic when passengers needed to transfer from one transit line or system to another. If small stations could be installed closer to passengers' intended destinations, PRT's time savings could be even greater.

History of Personal Rapid Transport

PRT had been discussed since the mid-1950s; since 1964, more than 200 PRT-related writings had been published.[1] PRT concepts were first proposed in 1953 by city planner Donn Fichterg, who called for the smallest possible vehicles and the smallest and cheapest possible guideways in order to fit within existing cities. With the 1964 Urban Mass Transportation Act came increased interest in PRT, including studies by the Urban Mass Transportation Administration (UMTA), the Housing and Urban Development Administration (HUD), and others.

In 1970, the U.S. Department of Transportation decided to install a PRT system at the University of West Virginia, Morgantown, connecting three campuses spread across a congested city. NASA Jet Propulsion Laboratory served as the system manager, and Boeing built the system's vehicles. The Morgantown installation preserved many key PRT concepts, including offline stations and nonstop service. But its vehicles held as many as 21 passengers, requiring larger guideways and stations. System costs ballooned to $126 million (about $319 million at 2009 levels, adjusting for inflation), four times the initial projections, tempering interest in PRT. Nonetheless, the Morgantown system became operational in 1972, carrying more than 63 million passengers through 2009 and dramatically reducing the school's need for traditional shuttle bus service.[2]

For nearly two decades, PRT stalled, even as the idea sparked Web-based fan groups, occasional conferences, and an 8,000-word Wikipedia article. Still, little progress was made toward further installations.

By the late 1990s, technological advance and growing urban congestion brought renewed interest in PRT. Declaring that "present mass transit technologies have not fully met suburban transportation demand," Chicago Regional Transportation Authority (RTA) chairman Gayle Franzen endorsed the PRT concept. After considering 12 PRT proposals, in 1993 the RTA selected a system designed by Taxi 2000 (profiled below) and defense and aerospace systems supplier Raytheon Corporation. The RTA's PRT system would connect the O'Hare airport and its subway station with nearby hotels, a convention center, and office buildings. But by 2000, new RTA leadership canceled the project because of concerns about system cost and low anticipated revenues. A subsequent Booz Allen analysis criticized the decision to use an enlarged chassis with a 72-inch-wide guideway rather than the 39-inch guideway initially proposed—a change that dramatically increased the cost of guideway construction.[3]

From 2001 to 2005, the European Commission Directorate-General Research allocated $3.5 million toward the study of PRT. In a series of studies termed "Evaluation and Demonstration of Innovative City Transport" (EDICT), planners considered PRT in several contexts: at a docklands redevelopment area in Cardiff, Wales; as a way to connect the Ciampino, Italy, airport to its city center; to connect the Technical University of Eindhoven (in the Netherlands) to its rail and bus station; and to reduce automobile congestion at a shopping center in Huddinge, Sweden, by encouraging passengers to use rail and bus. Although PRT was evaluated favorably, as of July 2009, none of these systems had been built.

From 1997 to 2009, studies in the U.S. considered Seattle's SeaTac airport (to connect the airport with car rental, hotels, and other facilities), Cincinnati (for downtown transportation), and New Jersey (for a variety of applications). Each study reported that PRT would offer substantial benefits, but the idea was nonetheless rejected for lack of proven installations. The Seattle report concluded: "The PRT system would provide the best overall access and circulation [but] a concern exists whether the system could successfully meet potential demand."[4] A New Jersey study carefully analyzed PRT in a 100-page report, but concluded that "there has yet to be a full scale deployment of this technology" and recommended that the state await "additional development and demonstration" by others.[5]

PRT Providers

Several companies developed technology for PRT systems.

Advanced Transport Systems and PRT at London Heathrow

As of August 2009, Advanced Transport Systems had made the greatest progress toward full implementation of PRT: ATS had finished a 2.4-mile, 3-station, 21-vehicle installation at London Heathrow Terminal 5. After intensive testing, the system was scheduled to begin trials with airport staff in early 2010 and to open to the public in spring 2010.

The ATS ULTra system featured rubber-wheeled, battery-powered vehicles that used laser sensors to follow a narrow guideway. Vehicles charged their batteries as passengers alighted and departed, and in charging bays that held vacant vehicles. The initial ATS guideway consisted of concrete slabs on steel mounts, resembling an elevated bicycle path, though ATS also demonstrated guideways with a grid that let sunlight pass. ATS projected that its guideway would cost £4 million to £6 million per mile. COO Phil Smith explained the rationale for ATS's design: "By keeping the guideway simple, we reduce costs and improve reliability."

ATS began in 1995 in association with the University of Bristol. Founder Martin Lowson headed a team of 50 engineers working on rocket design for the U.S. Apollo space program, then returned to the U.K. to become professor of aerospace engineering at the University of Bristol. Beginning in 1996, Lowson's publications evaluated the energy requirements, safety, and overall design of PRT, and ATS developed from these efforts. ATS was spun off from the University of Bristol, and by 2001 it had received grants from the U.K. Department of Trade and Industry to build a test track and prototype vehicles. With approval from Her Majesty's Rail Inspectorate, ATS first carried passengers on its Cardiff test track in 2003.

ATS's first installation came from BAA, formerly British Airports Authority, which owned London Heathrow Airport as well as two other London airports and additional airports in Scotland and Southampton. As the result of a 2006 acquisition, BAA in turn was owned by Ferrovial, a Spanish construction company that had diversified into toll roads, parking lots, and airports.

As air traffic at London Heathrow Airport increased, the airport faced a corresponding growth in ground transportation—passengers and staff moving to and from parking lots, car rental providers, hotels, and office parks, as well as between terminals. A few destinations were located within walking distance of terminals: for example, in 1977 Heathrow opened a Piccadilly Underground station within walking distance of Terminals 1, 2, and 3—the first subway station line in the world to reach an airport. But most passengers relied on shuttle buses to move around Heathrow. Buses faced congestion arising from limited roadway, limited room to install new roadway, and passengers' slow movements, particularly when traveling with luggage and in unfamiliar locations. Heathrow's ground transportation problems were the subject of intensive study by BAA's planning department. Ground transportation could also be controversial, as in BAA's earlier decision to prohibit nearby hotels from operating their own shuttle buses to and from Heathrow terminals; instead, hotels passengers used a shared "Hotel Hoppa" service intended to reduce road congestion by pooling trips to multiple hotels.

ATS first approached BAA in 2003. "They came along, saw our staff, got our feedback, and kept coming back," recalled David Holdcroft, the BAA project manager who ultimately became PRT manager.

Initial BAA plans called for a five-station PRT trial system to connect Heathrow Terminal 1 with parking lots approximately two miles away. (See **Exhibit 6**.) But simulations and trials revealed that automobile congestion would sometimes result if PRT took over a one-lane tunnel currently used by automobile traffic. Instead, in 2006, BAA decided to begin by using PRT to connect Heathrow Terminal 5 with the 1,500-space Terminal 5 business car park.

Terminal 5 opened in March 2008. Until the start of PRT service, the Terminal 5 business car park offered a dedicated shuttle bus service operating every 8 to 10 minutes, 24 hours a day, with a transit time of 4 to 8 minutes to and from the terminal. Passengers choosing the business car park paid BAA £21 ($34) per day. Further afield, BAA's long-stay Terminal 5 car park offered shuttle service every 10 minutes, at a reduced fee of £15.60 ($25) per day. Those wanting direct access to Terminal 5 could choose Terminal 5 valet parking, which offered walking-distance convenience at £59.50 ($97) per day.

BAA's statements about PRT emphasized cross-cutting benefits. For one, PRT would improve passenger service by leaving as soon as passengers were ready, eliminating the wait associated with shuttle buses. BAA also touted its continued leadership in airport technology, noting the automated baggage screening that it had pioneered in 1996, which was ultimately copied by most top airports worldwide. In addition, BAA emphasized PRT's environmental advances, including zero local emissions and a 70% reduction in energy consumption compared with shuttle buses. Environmental improvements were particularly welcome after controversy arising over Heathrow's third runway, which had attracted opposition from neighboring households that would face additional noise and from those concerned about air pollution.

Following up on Heathrow's interest in having a PRT system, in 2005 BAA invested £7.5 million (approximately U.S. $13 million) in ATS and ultimately received 37% ownership of the company, including two seats on the ATS board of directors. The Heathrow installation used ATS vehicles and an ATS control system; contractor Laing O'Rourke built the guideway and stations. With its experience in passenger handling, BAA specified the appearance and branding for all passenger-facing elements in the system.

The Heathrow PRT project broke ground in November 2006. By the time Terminal 5 opened in March 2008, the guideway was structurally complete and station construction was underway. Because guideway sections were partially prefabricated off-site, construction crews found they could install as many as five 18-meter sections in a single overnight shift (relying on foundations and footers installed in advance). Reviewing the installation process, BAA's Holdcroft found that PRT imposed little intrusion: "The installation of PRT at Heathrow proves one aspect of claimed PRT benefits in that it has been overlaid on a busy airport infrastructure without any disruption or displacement of existing facilities, adding a whole extra layer of transportation."

ATS estimated that capital construction costs, including vehicles, would reach $30 million for the initial installation. ATS estimated that on a larger system, operating costs would total $1.17 per passenger trip, 40% less than the existing bus service.[6]

While ATS's trial installation at Heathrow would initially only connect Terminal 5 to the business car park, the Heathrow property invited further expansion. If the trial were successful, the initial Heathrow guideway could be extended along a perimeter road to reach additional parking lots, car rental facilities, hotels, and office buildings, as well as other Heathrow terminals. (See the Heathrow Airport map in **Exhibit 7**.) In this larger installation, Holdcroft suggested that PRT could offer a further benefit: "Rather than knowing where you want to go, the PRT system could focus on what you want to do—automatic way-finding to get you where you need to be, without you knowing where that is. Way-finding has always been difficult at airports, but with PRT, you could ask for flight BA 231, and the system will take you to the right place."

ATS continued to solicit business elsewhere. Business development managers in California, Abu Dhabi, and the U.K. pitched design, building, operations, and maintenance services, as well as preliminary consulting services to help prospective installations plan their requirements.

Both BAA and ATS looked forward to the ultimate availability of PRT. BAA's Holdcroft noted that PRT was a popular subject for inquiries to Heathrow's public relations office, second only to Heathrow's new runway. ATS's Smith added: "Building the working reference site is absolutely key. Everyone else is watching and waiting."

Vectus, Ltd.

Vectus was created through the auspices of POSCO, the world's second-largest steelmaker (in terms of market value). POSCO's Dr. Jeon-Young Lee, senior vice president for New Business Development, had been charged with finding opportunities for the company to expand beyond steel. Dr. Lee explained: "We need multibillion dollar businesses. Fortunately, we have a 10-year horizon. We can afford to wait." Under Dr. Lee's supervision, POSCO began to develop businesses in the areas of fuel cells, magnesium sheets, and underwater electric turbines.

Dr. Lee first learned about PRT when serving as dean of research at Korea's POSTECH University. After being approached by a Korean entrepreneur who was excited about PRT, Dr. Lee built a 20-meter test track to demonstrate the potential of small vehicles and inspire further interest. By 2005, POSCO had created the subsidiary Vectus, Ltd. to develop and market PRT for commercial use.

After considering building a full test track in the U.K., POSCO chose Sweden as the center for PRT operations because of its winter weather, its national interest in environmentally friendly systems and alternatives to automobiles, and its history of safety innovations (such as Volvo automobiles). Dr. Lee explained the choice of location: "We must sell to the international market, not just to Korea. By building Vectus in Sweden, we show that this system is for worldwide use."

The Vectus design featured polyurethane-wheeled vehicles running on steel tracks. (See **Exhibit 8**.) Linear induction motors were placed approximately every 10 feet along the guideway to provide propulsion. At the same time, a dynamo on each vehicle converted a portion of the forward motion into electricity to power vehicle systems. To switch tracks, vehicles relied on on-board actuators that grabbed guide rails leading in the desired direction—eliminating the need for moving parts on the track. (See **Exhibit 9**.) During testing in harsh winter conditions, Vectus vehicles were able to clear the track of accumulated snow and ice, as shown in **Exhibit 8**. Vectus projected that its track and track-mounted systems would cost $15 million per mile.

In 2007, Vectus completed a 1,300-foot test track in Uppsala, Sweden, including obtaining safety approval from the Swedish Rail Agency. By 2009, Vectus had approximately one dozen employees recruited from rail and mass transit. For example, chief technology officer Jörgen Gustafsson had worked at ABB and Adtranz (later acquired by Bombardier) on rolling stock for subway applications before joining Vectus in 2008. Approximately 50 others were involved as consultants and suppliers.

2getthere

Founded in 2001 in Utrecht, Netherlands, 2getthere provided both group and personal transport systems. 2getthere's group transport systems included automated transit systems carrying up to 30 passengers. At the Rivium business park in the Netherlands, 2getthere offered a ParkShuttle driverless bus with eight stops on a 0.8 mile roadway connecting offices to a subway station. To detect intruders on a right of way, the buses employed both long-range (laser) and short-range (ultrasonic) detection systems that let the bus slow or stop when an obstacle was detected. 2getthere had another installation at Amsterdam's Schiphol airport, where automated vehicles followed two 2getthere guideways to transport passengers within a large parking lot.

2getthere's PRT system called for a rubber-wheeled, battery-powered vehicle guided by magnets embedded under a roadway surface. As a pilot project, 2getthere operated small, driverless vehicles at a horticultural show in the Netherlands in 2002, charging €2.50 per passenger for transport to a hilltop observation point. Vehicles operated with close headways, every 25 seconds, for 12 hours per day, albeit with just two stations rather than the network contemplated for the PRT system.

2getthere faced two public relations setbacks. In December 2005, two ParkShuttle buses collided during system start-up in circumstances ultimately attributed to operator error. In February 2006, a fire in the ParkShuttle garage destroyed one vehicle and seriously damaged another. All vehicles were unoccupied during these incidents, and no passengers were injured.

In 2008, 2getthere received a contract to install below-grade PRT for the Masdar City development in Abu Dhabi, United Arab Emirates. According to the master plan for Masdar City, the system would eventually encompass 83 stations providing nearby access to almost every point in the city. (**Exhibit 2** shows a planned system map.) Plans called for a first installation at the Masdar Institute of Science and Technology. As of April 2009, Masdar's initial section of PRT was scheduled to open in September 2009, connecting a new university campus using a network of 13 vehicles.

Cabintaxi

Cabintaxi of Detroit, Michigan, envisioned PRT based on technologies derived from German research conducted several decades earlier.

From 1969 to 1978, the German Ministry of Research and Technology funded development of Cabintaxi systems, both for use within Germany and for export. During this period, Cabintaxi built 1.1 miles of guideway on a test track near Hagen, Germany; the system included two bypasses and 24 vehicles. Cabintaxi logged more than 400,000 miles of vehicle testing, including more than 10,000 continuous vehicle hours in 1978, with vehicle separations as low as three seconds. The city of Hagen prepared a full study of Cabintaxi implementation in 1971–72, but budget cuts from the German Ministry of Research and Technology prevented implementation. All told, the ministry provided more than $200 million (in 2009 dollars) of funding to Cabintaxi before halting the project. As of 2009, the sole surviving installation was a 2-station, 0.3-mile system at the Schwalmstadt-Ziegenhain hospital in Germany, installed in 1975.

Cabintaxi's design called for vehicles running both above and below a guideway, allowing bidirectional traffic on a track the width of a single vehicle.

As of 2009, Cabintaxi's management sought investment funding and industrial partners to update Cabintaxi's design to use newer technology and to support manufacturing and construction.

Taxi 2000

Taxi 2000 of Fridley, Minnesota, designed a "Skyweb Express" PRT with an enclosed guideway protecting the rail surface from accumulation of snow or ice. A vehicle bogie traveled within this guideway, while the vehicle chassis rode above the guideway, connected through a slot at the top of the guideway frame. (See **Exhibit 10**.) Within the guideway, additional rails provided guidance, switching, communication, and power transmission.

The Taxi 2000 model had served as the basis for the Chicago RTA/Raytheon design, including the construction of a test track in Marlborough, Massachusetts. Even after the Chicago installation was canceled, Taxi 2000 continued to seek installations. For example, Taxi 2000 received a detailed evaluation during 2000–2001 in the Ohio-Kentucky-Indiana Central Area Loop Study.

As of 2009, Taxi 2000 offered professional services for feasibility studies and projections as well as a design for PRT to be built in coordination with other vendors. In a feasibility report for an unnamed city, Taxi 2000 described itself as a "technology provider," suggesting that "the next step in the design/build process is to 'partner with' a company whose core business is leading large scale infrastructure projects."[7] That said, Taxi 2000 had also built systems to demonstrate its technology, including a 60-foot test track with a prototype vehicle. Taxi 2000 continued seeking capital to construct a full-scale test track with an offline station and multiple vehicles.[8]

Others

Numerous additional vendors sought to provide PRT systems. Their websites presented plans primarily in computer-generated images; they had not yet completed built prototypes or test tracks.

As of 2009, large rail vendors had not publicly discussed PRT or small vehicles. But with thousands of employees and substantial capital, rail providers such as Bombardier, Hitachi, and Siemens could accept a huge contract more readily than an upstart firm.

Possible Uses for PRT

PRT designers saw possible uses in a variety of installations.

Airports

Airports transported passengers in a variety of circumstances: from their arrival on the property (often at parking lots or at a single rail station serving an entire airport) to numerous check-in points, to security screenings, then to waiting areas and gates. These transportation tasks drew on several technologies: walkways, shuttle buses, moving sidewalks, and monorails. Airport transportation problems were particularly acute for passengers unfamiliar with an airport's layout, who often struggled to find their desired destinations.

Expansion requirements further complicated airport transportation. Expanding a terminal was often infeasible because of the large space required for aircraft, gates, and taxiways. Yet building an additional terminal required duplicating numerous passenger services, providing transportation systems to transfer passengers between terminals, and assuring that all terminals were adequately connected to parking lots, hotels, train stations, and other services.

Passengers' time sensitivity constrained airport design. For one, an airport's best customers were typically business travelers anxious to reach their destination—making ground transportation delays particularly unpalatable. And as an airport grew, passengers needed more time to make their way from one flight to another, lengthening required connection times and often making large airports less attractive for those changing planes.

As of 2005, 25 of the top 50 airports worldwide had installed automated people movers (APMs), most often to move passengers between terminals.[9] An APM typically cost between $80 million and $800 million and served two to eight stations. When installing APMs to serve existing terminals, airports typically sought to avoid disrupting existing systems, but large stations and guideways inevitably required closing access routes or imposing detours on both vehicles and passengers. Construction could last two years or longer, making for substantial disruptions.

Airports funded transportation systems through fees charged to airlines (often as rent for gate areas); as surcharges on parking, car rental, and other on-property services; and through "passenger facility charges" added to ticket prices.

A few airports had evaluated PRT. Besides the Heathrow installation discussed above, in 1991–1992 Seattle's Sea-Tac airport considered PRT to connect terminals, parking lots, car rentals, hotels, and other area businesses. Envisioning PRT stations within airport terminals, the study praised PRT's potential quality of service but raised doubts about system reliability and robustness.[10] Nine years after the completion of Denver International Airport (DIA), staff of that facility evaluated what PRT could have offered, relative to the moving sidewalks and automated people mover that the airport had ultimately installed. They found that an in-terminal PRT (including stations and track junctions) could have been as narrow as the moving sidewalks, and they estimated that the costs of an in-terminal PRT would have been comparable to those of the moving sidewalks, automated people mover, elevators, escalators, and associated systems that were actually installed. They identified additional benefits from PRT: centralization of waiting areas, which reduced duplicate passenger facilities and concessions.[11] That said, DIA's experience with PRT was less favorable: DIA's automated baggage-transfer system incorporated some elements of PRT design but did not operate reliably, delaying the airport's opening, imposing millions of dollars of unexpected costs, and sparking extended litigation.

Corporate, University, and Hospital Campuses

Institutional campuses brought a set of users together in a set of buildings owned by a common operator. Large corporate campuses fit this mold, as did many university campuses and the largest hospitals.

Large technology companies sometimes operated private shuttle systems to transport their staff both on and off-campus. The best-known was Google's 32-vehicle fleet, which connected Google's 20-building campus with residential neighborhoods throughout the Bay Area. At peak times, on peak routes, shuttles could run as frequently as every 15 minutes, though most routes were served significantly less often. Similarly, Microsoft offered 14 "Connector" buses to and from residential neighborhoods, along with 41 "Shuttle Connect" hybrid cars that linked the campus's 60+ buildings and a nearby public bus station. But the Shuttle Connect service was notoriously unreliable—a reason often cited by employees who arrived late for meetings in faraway buildings. Meanwhile, as of 2007, 61% of Microsoft employees still drove to work in single-occupancy vehicles.[12] To date, neither company was served by rail transit: Google's campus was three miles from the nearest CalTrain stop, while light rail was not scheduled to reach Microsoft's Redmond campus until approximately 2020, with station locations not yet determined.

University campuses also offered shuttle service, for students as well as faculty, staff, and visitors. For example, Harvard University operated a fleet of five intra-campus shuttles as well as vans for handicapped passengers, on-request evening vans, and inter-campus buses. Service was often unreliable as a result of traffic and other delays, and many students favored walking or bicycling. For many universities, the lack of nearby rail connections was the main impetus for providing shuttle bus service. For example, American University and Tufts University campuses were 1 to 1.5 miles from the nearest subway stations in their respective cities.

Corporate and university campuses occasionally considered PRT. Ithaca, best known as the home of Cornell University, hosted a PRT conference in 2007, and the New York State Energy Research and Development Authority in 2009 funded a study of PRT for Ithaca. On the Microsoft campus, an online video presented a possible PRT installation in vivid animation.[13]

Urban Applications

Urban applications offered several possibilities for PRT. Some cities lacked adequate density or population to support the high fixed costs of traditional rail transit. (See **Exhibit 11**.) Meanwhile, bus service struggled to attract passengers more comfortable in their cars. Several cities considered developing PRT installations. For example, in 2001 the Cincinnati-Covington-Newport area examined PRT for a "Central Area Loop" to connect three downtown areas at the borders of Ohio, Kentucky, and Indiana. In October 2008, the Santa Cruz Public Works Department sought proposals to design, build, operate, and maintain a PRT system in the city of Santa Cruz with a connection to the University of Santa Cruz. Santa Cruz stood ready to offer a right of way to any company willing to build and finance a PRT installation. In Europe, urban evaluations included an EDICT study of PRT in Italy, the Netherlands, Sweden, and Wales. Promising discussions took place in Uppsala, Sweden, where PRT benefited from experience at the Vectus test track, university students largely without cars, and a congested downtown area already under redevelopment with a new central bus station.

PRT could also serve as a feeder to existing transit systems, much as buses transported passengers to and from subway and light rail stops. A single ticket could cover both PRT and subway or light rail, and PRT stops could even be placed within existing train stations to streamline transfers. Because PRT vehicles would await passenger requests, passengers transferring from train to PRT would not need to wait for PRT vehicles to arrive.

Next Steps for Vectus

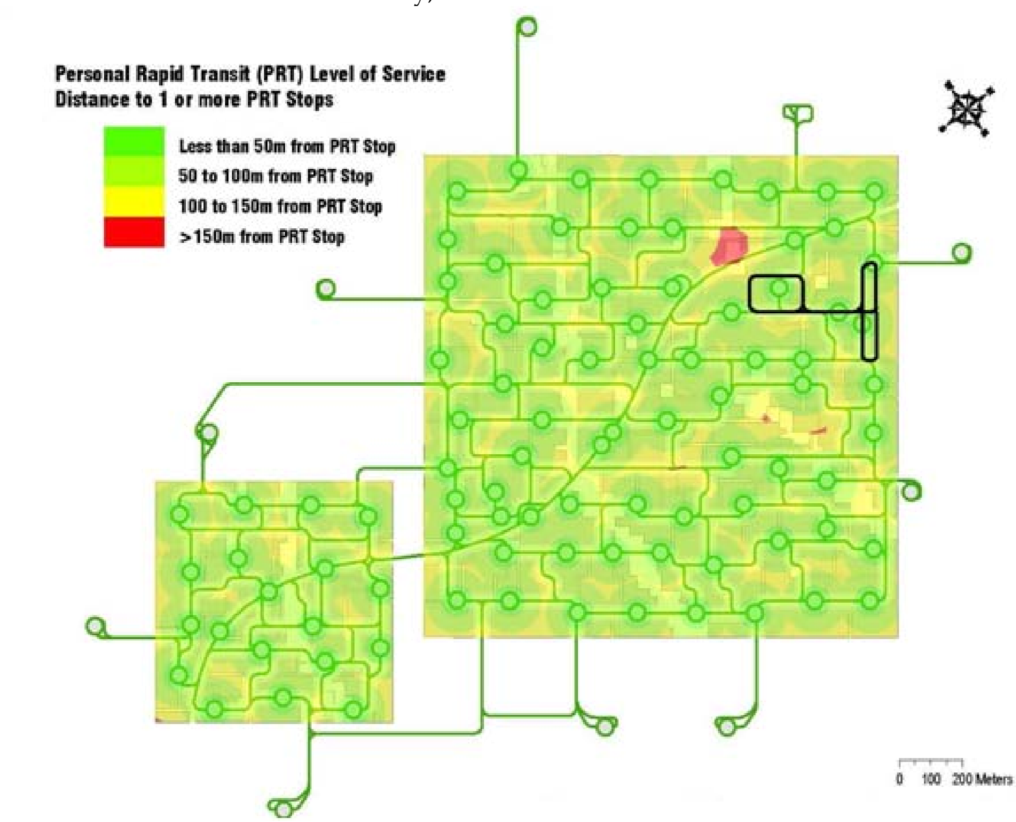
Ongoing installations at Heathrow and Masdar City prompted increased interest in PRT, and PRT industry conferences reflected a growing sense of opportunity. From Ithaca to Santa Cruz to tourist destinations in Korea, Vectus had identified numerous opportunities, each seemingly suitable for PRT. But Vectus had yet to sign a single contract.

Looking at PRT's capabilities and limited adoption, the *Economist* concluded that "hesitant local authorities are the only significant obstacle."[14] Local authorities could definitely present a challenge, but Gustafsson suspected there was more to the problem. How exactly should he sell PRT—to whom, and for what purposes?

Exhibit 1 PRT at London Heathrow Terminal 5

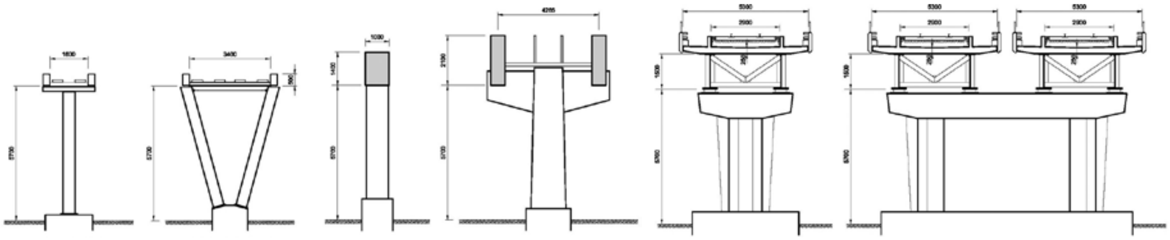
Source: Advanced Transport Systems Ltd.

Exhibit 2 PRT Plan at Masdar City, United Arab Emirates



Source: John Mogge, "The Technology of Personal Rapid Transit," January 2009, p. 9, http://faculty.washington.edu/jbs/itrans/moggeprtpaper.pdf.

Exhibit 3 Cross-Section of Various Transit Modes



Single PRT Dual PRT Single Monorail Dual Monorail Single Light Rail Dual Light Rail

Source: Advanced Transport Systems Ltd.

Exhibit 4 Possible Station Designs (Visualizations)

Source: Vectus, Ltd.

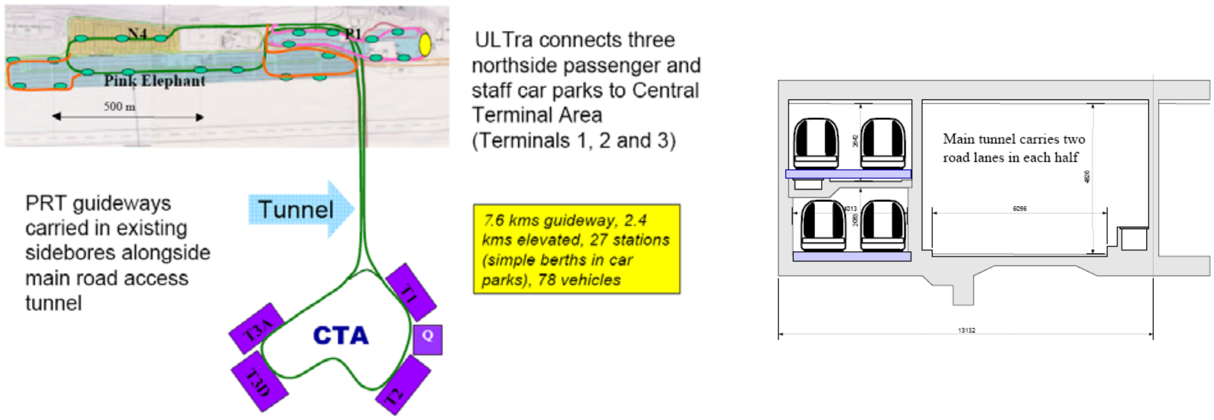
Exhibit 5 Journey Times in PRT and Traditional Transit

Mode	Headway (minutes)	Average wait time (minutes)	Average line speed (mph)	Total trip time (minutes)	Increase over PRT
Heavy rail	10	5	20	17.0	49%
Heavy rail	2	1	20	13.0	14%
Light rail	10	5	15	21.0	84%
Light rail	2	1	15	17.0	49%
Bus	10	5	14	22.1	94%
Bus	2	1	14	18.1	59%
PRT	0.05	1	23	11.4	-

Source: Jon Carnegie and Paul Hoffman, "Viability of Personal Rapid Transit in New Jersey," February 2007, pp. A3-4, http://faculty.washington.edu/jbs/itrans/big/PRTfinalreport.pdf.

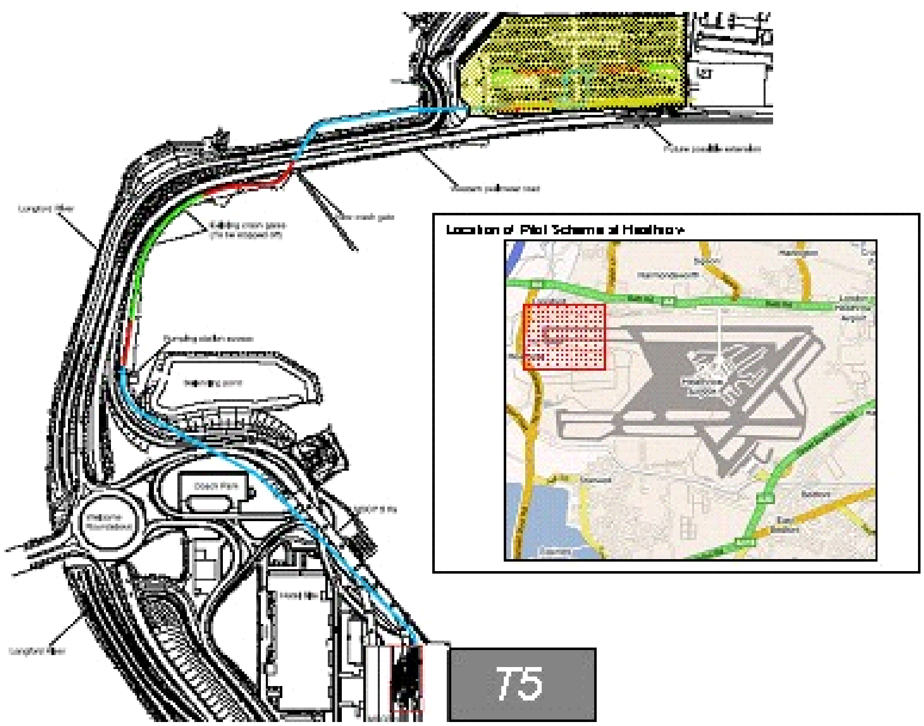
Note: Numbers refer to a four-mile trip along a single transit corridor.

Exhibit 6 Initial Plans for ATS PRT Installation at Heathrow Central Terminal Area



Source: BAA.

Exhibit 7 ATS PRT Installation at Heathrow Terminal 5

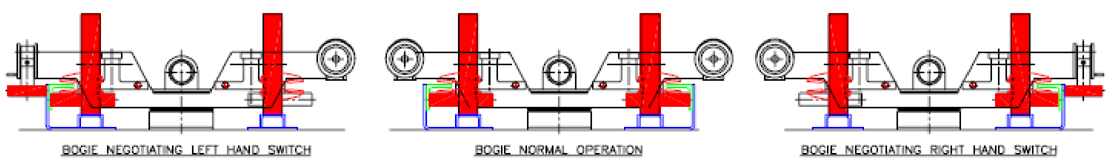


Source: BAA.

Exhibit 8 Vectus Vehicle in All-Weather Operation

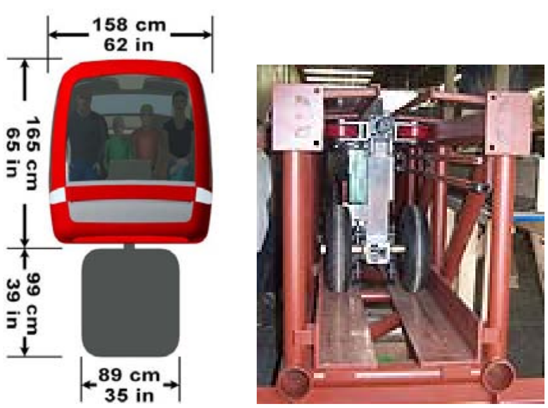
Source: Vectus, Ltd.

Exhibit 9 Vectus Vehicle's On-Board Switching Wheel (preliminary design)



Source: Vectus, Ltd.

Exhibit 10 Skyweb Guideway, Chassis Placement, and Bogie



Source: Jon Carnegie and Paul Hoffman, "Viability of Personal Rapid Transit in New Jersey," February 2007, pp. A1-5, http://faculty.washington.edu/jbs/itrans/big/PRTfinalreport.pdf.

Exhibit 11 Capital Costs of Traditional Transit Systems

Mode	Capital Cost Per Mile ($ millions)
Heavy Rail	
NY City 2nd Avenue Subway	$2,000
Los Angeles Red Line	$258
Dulles Metro Extension (Washington, DC)	$170
Light Rail	
Los Angeles Gold Line	$65
Minneapolis Hiawatha Line	$60
Houston Metro	$43
NJ Transit River Line LRT	$29
Automated Guideway	
JFK Airport Airtrain	$148
Seattle Monorail	$150
Indianapolis Clarian	$28
Busway	
Exclusive average (GAO)	$13.5
HOV average (GAO)	$9

Source: Jon Carnegie and Paul Hoffman, "Viability of Personal Rapid Transit in New Jersey," February 2007, pp. A3-9, http://faculty.washington.edu/jbs/itrans/big/PRTfinalreport.pdf. Data derived from respective transit agencies and the U.S. Government Accountability Office.

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