MISTER and Other New-Generation Personal Rapid Transit Technologies

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ABSTRACT

This paper introduces MISTER (Metropolitan Individual System of Transportation on an Elevated Rail), and compares it with other leading personal rapid transit (PRT) designs that are currently under development. MISTER would be a high-capacity PRT, to be used initially for city transportation of passengers and goods. Like other PRT designs, it would be fully automated, driven by demand and individual travel requirements. MISTER would be more economically, energy and space efficient than private cars, buses, tramways (streetcars), metros and other rail transit systems. While most PRT concepts would feature supported vehicles, MISTER's cabins would travel suspended below an elevated guideway infrastructure. The vehicles would be propelled by electric motors powered by an external cable or rail. This configuration would enable the implementation of parallel parking bays, the negotiation of steep grades, and contactless, stationary frogs (rail switching or shunting equivalent) at intersections. In a later phase, MISTER's vehicles could be transferred from their suspended propulsion caddies, used for travel on the rail network, onto battery-driven and automated wheeled platforms, akin to golf-cart bases, for automated door-to-door delivery of MISTER cabins over city streets. A further extension would enable intercity travel (under, say 400 km) on the same elevated rail network, but at speeds of up to 150 km/h. The entire system would be fully controlled and automated by an autonomous yet adaptable, integrated computer network. Interest in MISTER has been expressed by the Polish cities of Zakopane, Krynica-Zdroj, Szczyrk, and Warsaw. MISTER is competitive with other PRT concepts, with an exciting potential for dual-mode operation.

INTRODUCTION

The Advanced Transit Association defined personal rapid transit (PRT) as an automated guideway transit system in which all stations are on bypasses, the vehicles are designed for a single individual or small group traveling together by choice on a network of guideways, and the trip is non-stop with no transfers (*1*). The PRT concept was germinated several decades ago, and several prototypes have been tested, but none have succeeded commercially. One source of delay to PRT implementation is a tendency to preserve existing, proven transit systems. Also, many policy and decision-makers have been influenced by bad publicity regarding PRT. Admittedly, the lack of inexpensive computer control and sensor-automation systems has also played a major role.

Despite these challenges, progress has been made in the development of PRT. Several systems, representing a "new generation" of PRT technologies, have emerged. These include EcoTaxi APGM, MicroRail, MonicPRT, RUF, SkyCab, Skyweb Express, ULTra, Unimodal and Vectus, and others, as well as MISTER, which is discussed in detail in this paper. EcoTaxi APGM (Automated People and Goods Mover), developed in Finland, would feature vehicles operating above-ground in clear tubes (*2*). MicroRail is a lightweight PRT concept under development in the U.S. Four- to six-passenger vehicles would travel 50-105 km/h; "NanoRail" would feature two-passenger vehicles (*3*). MonicPRT, under development in Singapore, is a two- to six-passenger vehicle concept (*4*). RUF, or "Rapid Urban Flexible," is a dual-mode concept in which specially-built cars and buses would operate on triangle-shaped monorails (*5*). SkyCab, under development in Sweden, would feature four-passenger vehicles running 4 to 5 m above ground. Stations would be located offline, immediately *below* the mainline track. Implementation feasibility studies have been completed in Linkoping, Malmo, the Sigtuna-Arlanda airport (*6*), and Stockholm. The Taxi2000 Corporation completed a prototype Skyweb Express vehicle in 2003, and has been generating interest in the PRT concept and vehicle (*7*). The company was established in the 1980s, and secured an eventually terminated contract (resulting from cost overruns) to build a PRT system in Rosemont, Illinois in the 1990s. The British Airports Authority, in October 2005, announced that it had invested in the ULTra PRT system for possible development at London's Heathrow Airport (*8*). Various aspects of ULTra, developed and demonstrated in Cardiff, Wales, have been documented (*9, 10*). Unimodal, also known as SkyTran and "PeoplePod," is a two-person, suspended vehicles concept (*11*). Vectus, based in Korea but with several European Union partners, would feature lightweight, low-energy, short-headway provisions similar to those of several other PRT concepts (*12*). Many of the "old generation" PRT systems from the early 1970s, such as Cabintaxi, CVS and Romag, were abandoned because of insurmountable technical problems, financial obstacles, or both (*13*).

MISTER: DESCRIPTION AND COMPARISON TO OTHER PRT CONCEPTS

The purpose of this paper is to introduce MISTER (Metropolitan Individual System of Transportation on an Elevated Rail) and compare it with other PRT systems. MISTER features a combination of simple and common sense solutions, plus some innovative concepts and design features. A summary of system comparisons is presented in Table 1. The ensuing discussion elaborates on these comparisons in terms of configuration, operation, movement and control, and provides some details on MISTER's technology.

TABLE 1 Comparison of MISTER and Other PRT Concepts

MISTER	Other PRT Systems
Overhead rail (suspended vehicles)	Very few (e.g., Unimodal)
Asymmetric rail structure	None?
Physical rail separation between main and side rails	None?
Two level rail structure on major trunk lines	None?
Rail switching within vehicle caddy	Some (Unimodal, Taxi2000, SkyCab, Vectus)
No batteries in vehicles (external power)	Some (Unimodal, Taxi2000, Ecotaxi)
Parallel parking bays at stations	Some (MonicPRT, ULTra)
Station buffer areas for arriving and empty vehicles	Very few (e.g., Taxi2000)
Strategic "vertical cage" garages	None?
Stops at street level or any other level	Some (ULTra, Skycab)
10-15 m above-ground operation	Some (Unimodal, Taxi2000)
Only right turns at intersections	None?
High capacity – 1 sec headway at 40 km/h	Some (RUF)
2 simple rules for vehicle diverge/merge decisions and control	lack of information
All movement and turn decisions within vehicles	None?
Possibility of "door-to-door" travel	Some (e.g., MicroRail, RUF)
Possibility of intercity travel	Some (e.g., Unimodal)

CONFIGURATION

Configuration concerns include the person-carrying capacity of vehicles, speed, propulsion, the vehicle-rail interface, vehicle weight, guideway height, and guideway support spans. MISTER's vehicles would carry a maximum of four persons and, in its first phase, travel at modest speeds of some 40-50 km/h. All of the other PRT concepts would feature two- to six-person vehicles; one, RUF, would also operate a 10-person "Maxxi-RUF" bus, while MicroRail would couple vehicles to form human-operated trains. MISTER's speed would be at the low end of current PRT concepts; some are proposing a speed as high as 200 km/h (e.g., RUF). In truth, speeds would vary, as recognized by Taxi2000, according to operation along a mainline or junction. Notably, MISTER's vehicles would not require any developing technologies, such as induction MAGLEV, complex steering controls, or battery power.

MISTER would operate on overhead rails having an asymmetric truss structure, with suspended vehicles. Only one other PRT concept – Unimodal – would feature suspended vehicles. Rails would be at a height of about 10 m (such as for north-south orientations) and 15 m for the perpendicular routes, to ensure that there is no interference between the two of them or with any existing road infrastructure such as traffic lights (see Figure 1). It can be argued that it is easier to "hang" from a rail than to "stand" on it. Vehicle movement, wind dynamics, climb angles, friction/energy efficiency and snow protection are better in suspended-vehicle than in supported-vehicle configurations. With suspended vehicles, gravity counteracts lateral forces, such as from the wind, whereas with supported vehicles, gravity compounds such forces. Vehicles can also be light (tare weight of 200-300 kg) which would translate into lightness of the rail infrastructure and supporting columns (spaced every 20-30 m). In comparison, the tare weight of a supported vehicle can be at least double that of a suspended vehicle. The column spacing in MicroRail, for example, would be just 15 m. Also, with the guideways of some other systems being quite wide and bi-directional, such as in the Vectus proposal, there are major weight and cost factors, and a need to have complex directional driving control.

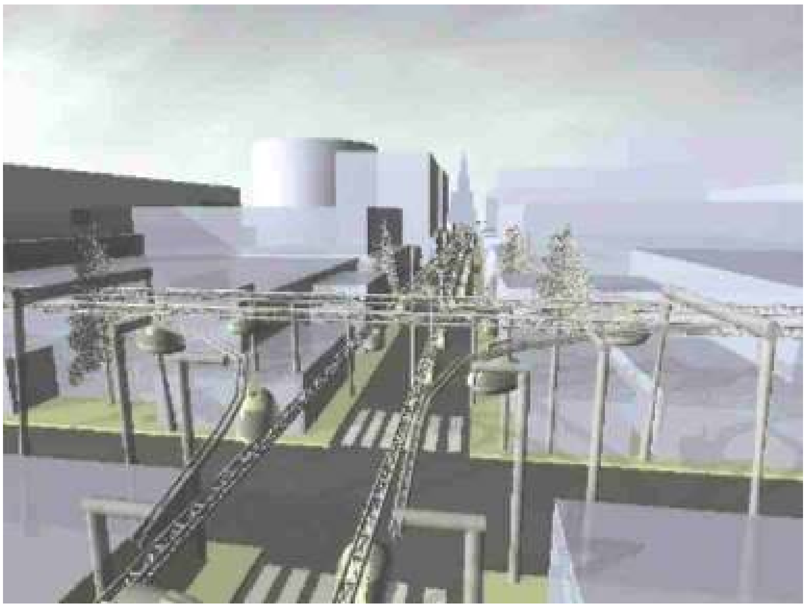


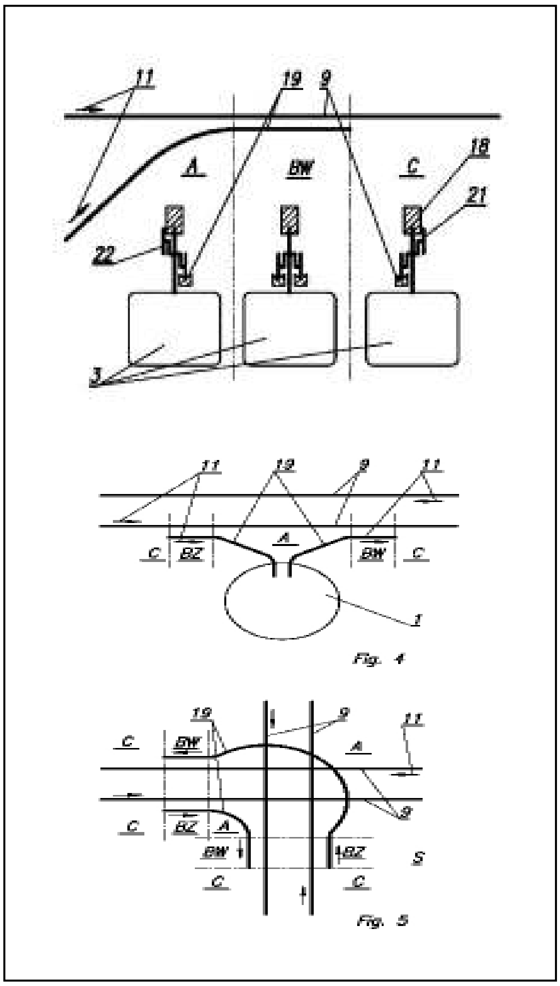
FIGURE 1 Hypothetical MISTER Operating Scenario (courtesy: Michal Golinski)

OPERATION

Operational issues include junctions, power needs, headways and capacity. MISTER's asymmetric truss rail arrangement would allow the use of special frogs (stationary) at crossovers. Rails would not be joined or move at junctions; rather, the gondola's suspension-propulsion caddy would switch from one rail onto a parallel one (Figure 2). The caddy has left- and right-hand sets of wheels, and would travel on the left set when on main lines, and on the right set when on diverging/merging rails. This would provide for non-wearing mechanisms in diverging and merging. The Taxi2000 vehicle would also feature an in-car switch. Track elements would be stationary at junctions in RUF, as well, with switching done by magnetic fields; but, the junction infrastructure would consume a substantial area.

The vehicle's centre of gravity would be offset in relation to the rails, and thus would be used for horizontal stabilization against the lower rail of the truss structure. In the example, in Figure 3, the vehicle is travelling on the right set of wheels (21, 21-b), over a rail structure (19). It is suspended on the top right wheels (21), generating momentum (M) due to the vehicle's gravity centre being offset against the contact point of the wheels (21). This momentum is countered by force (F) exerted by the wheels (21-b) against the lower part of the rail (19). A hypothetical intersection, showing the rail infrastructure, vehicles and the stationary frog, is illustrated in Figure 4. MISTER would have intersections connecting both rail levels (10 m and 15 m) in right turns only, alternating at 90 or 270 degrees at every second intersection. This would alleviate the need to create "spaghetti-type" junctions with more than two levels of intersecting lines, as used in many road intersections. The extent to which right-turn only intersections is used by other PRT concepts is unknown.

MISTER's gondolas would travel independently of each other, powered by small electric motors (requiring 20 KW for acceleration and 1-2 KW for cruising). The energy requirement would be similar to that of ULTra; an estimate of MISTER's energy consumption *rate* was being developed as of press time. A modest but constant speed, together with a minimum headway of approximately 1 sec (10 m), would enable a high utilization of the system's throughput and capacity. The headways of other PRT systems would range from a high of 2.5 sec (Vectus) down to, effectively, 0 sec, in which the vehicles would couple (RUF). MISTER would be capable of moving 4,000 passengers in each direction with one person per vehicle, on a single rail, and up to some 32,000 passengers on a two-level line (Figure 5) with four passengers per vehicle. Assuming an average of 1.5 passengers per vehicle, and up to 2.5 after some ticketing incentives to share rides with others, a realistic capacity range of 6,000 to 10,000 passengers per hour per direction on a single line could be achieved, with double that on a two-level line. The capacity projection for a single line would be comparable to that of Taxi2000 and RUF, and greater than that of Vectus. In comparing PRT with rapid rail transit, it should be noted that PRT systems can distribute their passenger load over a network, with numerous stations and a relatively fine grid "mesh," such that more people can be delivered than in systems that are limited to linear corridors.



Rail junction operation for stations and intersections:

On-ramp (merging into main traffic A-BW-C):

- Motion on right wheels (#19) of engine caddy in merging area A
- Motion on all wheels (#9, 19) of engine caddy in merging and main rail area BW
- Motion on left wheels (#9) of engine caddy in main rail area C

Off-ramp (C-BZ-A):

- Reversal of the sequenc above, using BZ area

Rail lines intersection:

- Joining of the off-on ramp sequences in the intersection area of LITI (C-BZ-A-BW-C)

FIGURE 2 Rail Switch Operation Schematic

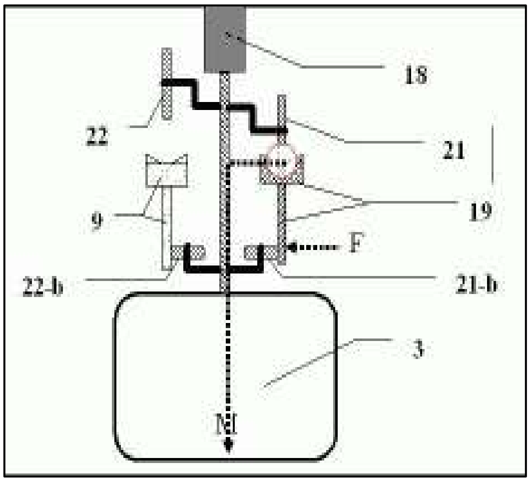


FIGURE 3 Vehicle-Rail Interaction Example

FIGURE 4 Intersection Illustration (M. Golinski)

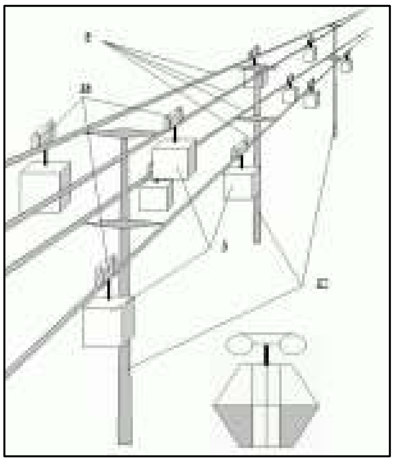


FIGURE 5 Bilevel Operation

There would be a mechanical energy recovery unit in each gondola (simpler and less expensive than gyro or electric units), as well as additional safety measures such as air bags. Electric motors would run on external power, so no battery charging or swapping would be needed. The latter are major problems for systems using battery power, especially with high capacity traffic requirements, cold climates and hilly terrain. Batteries also add weight to the vehicles, thus reducing their energy effectiveness. RUF and ULTra would use battery-powered motors; nearly all other PRT proposals would run on electricity (Vectus would use linear induction motors).

Off-line stops would have parallel gondola parking bays (Figure 6) instead of the sequential ones used in most other systems. This would solve the potentially major problem of blocking upstream vehicles in case of failure, or slow exit/entry of passengers in downstream vehicles. Overhead rails would greatly simplify the need for ground infrastructure at stops, thereby reducing costs and problems with their location, while allowing easy wheelchair access. There would be no at-grade rail crossings, nor a need for large station platforms. Unimodal and Skycab have also proposed efficient (small) station designs; Unimodal's concept, because it involves a suspended vehicle, is similar to that of MISTER. Differing stop sizes and multilevel arrangements, in addition to parallel parking bays, would further enhance overall system flexibility and the ability to deliver people and goods to where they want.

Vehicles would ascend and descend at very steep angles, thus further simplifying stop designs and enabling their location in any building or on street level. The maximum gradient proposed by the other PRT concepts is ULTra's (20%), although 10 to 15% is the norm. In addition to buffer areas at the stops for arriving and empty vehicles, there would be strategically located garage cages (Figure 7) for holding excess vehicles during low demand times, and in preparation for peak times. The system would send vehicles to garages in anticipation of predictable demands, such as for sporting events or morning rush hour. Most stations would have above-ground rail "buffer zones" to hold a number of arriving vehicles for which there is no parking bay available yet and also for empty vehicles, which are then quickly available, if unexpected influx of passengers appears. This would further system flexibility to cater to traffic demands and prevent congestion or lack of vehicles. The Taxi2000 concept would also feature a station buffer area for empties. The empty vehicle management concept is based, in part, on the findings of Andréasson's simulations (*14, 15*).

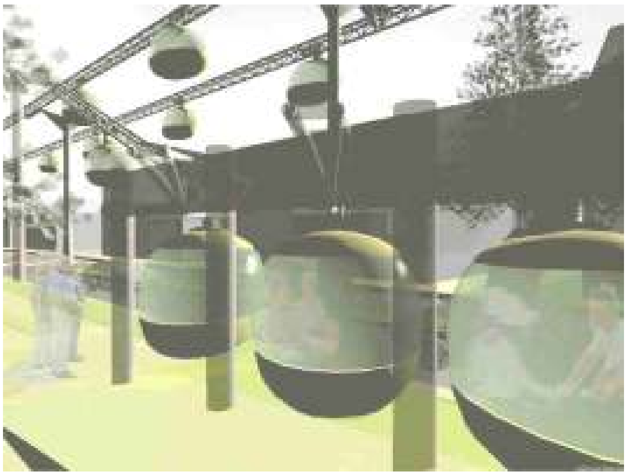


FIGURE 6 Ground Level Off-Line Station

MOVEMENT AND CONTROL

Vehicle movement control and decisions would be delegated to each individual vehicle. Vehicles would interact only with nearby system objects, such as other vehicles, stops and junctions, but would report their own position, trip route plans, and operating data to the central system. Feedback from the central system would enable each vehicle to adapt its planned trip and alternate route options (such as if the preferred path becomes congested or impassable), depending on the changing situation of the overall system. The information exchange with the central system would not need to be more frequent than at the start of each trip or at any time when the vehicle decides to alter its trip plan. And, the central system needs only to communicate expected loadings of the track sections and stations to “active” system objects, which would transfer the information to passing vehicles. With this communication plan, there would be no processing overload of any system components.

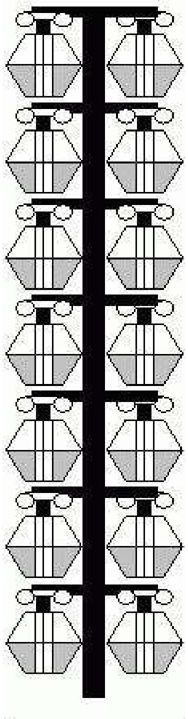


FIGURE 7
Garage Cages

For a comparison, MISTER’s control strategy is different from that described by Anderson (*16*). For example, MISTER’s central system does NOT control decisions, such as determining whether a given vehicle will be waved off by a station or intersection, and there are no zone controllers. All merge, diverge, accelerate and decelerate decisions would be made by the vehicles themselves after a dialogue with neighbouring vehicles or nearby control points (station or junction) that are on the vehicle’s path. The central system, apart from recording and storing data, accounting, and so forth, would only collect information about the intended travel paths of vehicles, and broadcasts aggregated information about the expected loadings of particular rail sections to all relevant stations. The central system may also “advise” stations to wave off a certain percentage of passing empty vehicles, as they are needed by downstream stations, where passengers might also be waiting. But, there would be no direct command of the individual actions of vehicles, stations or junctions. Even the decisions to request or send off empty vehicles from a station would be made locally, with the central system only providing strategic statistics to “interested” control points. These are very important differences from those described in (*16*) that simplify the entire system operation and thus further increase safety. It is difficult to compare and contrast MISTER’s control system with those of other PRT concepts, in part because of their technical detail and complexity.

Vehicles would maintain their distance and communication by dual systems of laser and local radio links, to ensure the prevention of vehicle collisions. Two simple rules would be followed by each vehicle: first, mainline traffic would have priority over any launching vehicles. Second, exiting from the mainline cannot occur if there is no possibility of accommodating the vehicle at the destination facility (station, intersection, garage or service yard). This is different from some other concepts, in which the destination *and* path must be clear before vehicle launch. In MISTER, decisions would be made “on the fly” upon approach to the decision point. The first rule prevents the joining vehicle from causing problems on the mainline, such as forcing other vehicles to brake or to make space for the joining vehicle. The second rule prevents the vehicle from trying to stop at an overcrowded station, while also preventing the vehicle from trying to change lines if the switch point (diverge) capacity is exhausted. “Diverge capacity” refers to the length of rail connecting two lines, and the number of vehicles that it can accommodate.

In instances of inability to stop at a selected station, the vehicle would continue on the main line. The vehicle would either stop at the next station or make a “loop” and attempt to return to the selected station in a minute or two, with an increased priority, depending on passenger preferences. In some cases, a station may wave off an approaching vehicle, even if it has a free berth, so that an earlier vehicle that is returning would be able to stop. It is anticipated that “wave-off” situations would be rare, given proper planning of station locations and capacities.

OTHER DESIGN ISSUES

One problem that is common to rail structures is solar heat-related stress. In MISTER, this would be solved by the installation of heat shields. The heat shields could also serve as snow protection devices if placed above the rail. Further to the rail, it is envisioned that the truss structure would be less expensive to build than roll-formed steel rail, because less steel would be needed for the same length and strength of track. This assumption needs to be validated, however, through research and testing. Other design issues that need to be resolved, confirmed or optimized include icing of guideway rails, icing of power supply cables, and vehicle stability in high winds. Capital and operating costs also need to be estimated for various scenarios, similar to the efforts that other PRT system developers have made. Some financial figures should be among the outputs of the case studies of MISTER applications in Zakopane and other Polish cities. ULTra has prepared a useful analysis of the noise levels of its vehicles, at various speeds, while MicroRail has estimated system installation times. Similar analyses for MISTER, in addition to a continued discussion of the prospects for government support, would complete its proposal.

STATUS AND FUTURE PHASES

The concepts and assumptions of MISTER have been verified and confirmed as feasible (*17*) by a number of senior university researchers from transport and related faculties, and by representatives from suppliers and project bureaus. A case study of MISTER operation in the extreme climatic environment of the mountainous region of Zakopane, Poland was being developed as of press time.

MISTER's design allows for major extensions of the system and its future functionality. Some of the future possibilities are to:

1. Provide a true, fully automated door-to-door transportation service, without any need for inroad equipment implantation.
2. Provide high speed (up to 150 km/h) intercity travel for distances of up to 400 km.
3. Augment MISTER to fully automatic city driving. MISTER's vehicle weight, combined with low operating speeds, would ensure operational safety. Also, the response time of the electronic systems would be faster than human reaction times.

The extension of MISTER to intercity travel of up to 400 km would enable the replacement and complement of existing rail networks, at a cost much less than that of conventional rail systems. The speed would have to be increased to up to 150 km/h to make long-distance travel viable. One idea, similar to that proposed by EcoTaxi APGM, would be for low-atmosphere tubes to enclose the rails and vehicles, thereby substantially reducing wind resistance and providing major energy efficiency.

CONCLUSION

Continuing with the city driving, dual-mode concept, an overhead rail and a cabin suspended below its propulsion caddy allows for a transfer of the cabin onto a flatbed, battery powered, light platform, which could navigate driverless over existing street infrastructure. An overhead caddy unit would remain in storage at the transfer station (or move to another station on its own), so that the reverse process could take place. The passengers or cargo would not have to change vehicles, as the cabin could switch propulsion units and travel mode while occupied.

The scenario of driverless vehicles on city streets is no longer science fiction, as auto guidance and driving systems have been making rapid advances. For example, in the 2005 DARPA race over the Mojave Desert (*18*), several driverless vehicles covered over 200 km of difficult terrain at an average speed of close to 30 km/h. Also, Volkswagen was testing automated cars that can travel up to 130 km/h once they have "learned" a course. These advances and successes, along with those of the ParkShuttle vehicles, Cybercar (*19*) and others, suggest the feasibility of dual-mode operation.

In summary, MISTER combines some of the best ideas from other systems and adds its own innovations, of which the contactless, stationary frog at junctions, station buffering, "vertical cage" parking facilities, multilevel and parallel loading bays, dual-mode travel, and intercity travel are the most notable. The new generation of PRT technologies has elevated the viability of the concept, and an increasing number of agencies are expressing an interest. MISTER is a competitive candidate in this new generation, particularly given its potentially high levels of functionality, efficiency and expandability.

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