

# Personal Rapid Transit: Innovation Lasting

Robbert Lohmann, *2getthere*, the Netherlands

**Abstract—** Most break-through innovations have been technology-push developments. Market research with regard to customer wants and needs are of no use when customers don't know what they want or what they need. (Local) authorities, city planners and other decision makers tend to think along the lines of existing systems – to avoid the risk of doing something new (and different), but also because of a human inability to think outside the box.

Automated People Movers (APM) have arrived and are no longer an uncommon sight. Personal Rapid Transit (PRT) is in the position APM were years ago: being pushed to the market, trying to create awareness of the possibilities of the new technology.

*2getthere* is a subsidiary of Frog Navigation Systems – a company with a long history of bringing innovations to the market. Frog Navigation Systems was one of the pioneers with 'free ranging' automated guided vehicles in industrial applications using the patented FROG-navigation technology. The company also realized supplied the navigation system for the first automated container terminal (Port of Rotterdam) and realized the first electronically guided people mover system (ParkShuttle system). Now *2getthere* and Frog are actively developing Personal Rapid Transit.

Personal Rapid Transit (PRT) is 'a transport method that offers personal, on-demand non-stop transportation between any two points on a network of specially built guide-ways'. Personal Rapid Transit is all about (network and vehicle) controls. *2getthere's* ability to provide a PRT system is based on the well-proven (20+ years) FROG network and vehicle controls, fully customized for Automated People Mover requirements.

With the technology available, *2getthere* came from a different perspective than most companies active in this market. *2getthere* had to develop the concept of PRT with the technology available. Focusing on the wants and needs of the customer and the passenger, *2getthere's* vision on PRT was formed. The system is configurable as 'true' PRT – providing direct connections, on-demand operations and personal transportation – but alternatively 'ride sharing' (single origin, multiple destinations) and scheduled operations (to optimize capacity) can also be implemented (a PRT-like application).

The paper addresses the development and the vision of *2getthere* with regard to PRT and the fit of the PRT concept with Chain Mobility.

## I. INTRODUCTION

Automated Guided Vehicles (AGVs) are driverless industrial trucks, usually powered by electric motors and batteries. Applications of AGV-systems, with loads ranging from

(cardboard) boxes to pallets and (steel) coils, can typically be found in and between production- and storage environments.

Automated Guided Vehicles (or Automatic Guided Vehicles) have been moving material and product over 50 years. The first AGV system, a modified towing tractor with trailer following an overhead wire, was built and introduced in 1953 in a grocery warehouse. By the late 50's and early 60's towing AGVs were in operation in many types of factories and warehouses. This type of AGV, a tugger, is still applied today. In 2003 Frog Navigation Systems supplied four automated 7tons Tuggers for a chassis marriage process within an automotive factory.

Wire guidance was the principal AGV guidance technology in the 1970's. An electronic frequency is induced in a wire that is buried in the floor. A device called a 'floor controller' turned the frequency on the wires on and off and directed the AGV through its intended route. The AGVs were equipped with an antenna that would seek out the frequency and guide the vehicle based on the strength of the signal. For decision points and intersections, multiple (costly) wires need to be installed. The system would energize the wire that would correspond to the intended direction of travel. As the intelligence of the system was in the floor controllers, these systems were typified as 'smart floors, dumb vehicles'.

During the 1980s, non-wire guided AGV systems were introduced. Frog Navigation Systems developed a free ranging system based on grid-reference points. The patented Free Ranging On Grid (FROG) technology was developed and first implemented for an application at Apple Singapore. The system features 'smart vehicles, dumb floors'.

Throughout the years the system has developed further. With the technology as a basis, Frog is continuously looking for new markets where the technology can be applied. The 'black-box' allows any type of vehicle to be automated by the FROG-technology, creating new market opportunities.

## II. FROM OUTDOOR TO APM APPLICATIONS

Although there are multiple technologies that allow for free ranging movement in indoor environments, the FROG concept proved to be applicable outdoors as well. Banking on 25-year Sealand contract, ECT (Europe Combined Terminal) decided in 1988 to automate their Delta Terminal in their quest to reduce costs. Based on simulations and thorough technical and operational evaluations, ECT opted for a combination of Automated Stacking Cranes and Automated Guided Vehicles.

The ECT container terminal has been operational well over 10 years now and features over 240 automated container carriers. Currently a 2<sup>nd</sup> automated container terminal (Euromax) is being built in the harbor of Rotterdam, also automated based on the FROG-technology. It is the ECT application that leads to the development of the electronically guided APM concept ParkShuttle.

The idea for the ParkShuttle was quite simple: if we can transport goods outdoor with our technology, why wouldn't we be able to transport people? Based on this notion some initial designs were made for what a vehicle should look like. Also the market was approached to see what interest there would be for such a transport system. As the concept generated a lot of interest, the development proceeded steadily.

The city of Capelle aan den IJssel (near Rotterdam) had a business park to be developed that was weakly linked to public transportation. In line with the national regulations, the business park could only be developed if public transportation to the site would be facilitated. The ParkShuttle concept fit the requirements and would allow for the development of the envisioned business park. Because of the time pressure construction of the first vehicles had already commenced, when the decision to order was postponed.

Fortunately, Amsterdam Airport Schiphol had interest as well. Being a 'private' entity, Schiphol was able to make a decision quicker, resulting in implementation of 4 ParkShuttles, each accommodating 10 passengers, in December 1997. In the mean time, the city of Capelle aan den IJssel had also decided to proceed and 3 ParkShuttles were installed in February 1999.

At Schiphol the system operated on long term parking lot P3 (accommodating 10.000 cars). The track consisted of two (single directions) loops of 1km, each with 3 stations. Each loop had several crossings for automobile traffic (equipped with barriers and traffic lights) and pedestrians (audible alarms). To ensure maximum flexibility in the operations the vehicles are able to access both loops. The system operates on demand, carrying passengers from the shuttle stops near their cars to the main passenger lounge. From here buses provide transportation towards the passenger terminals. The service is available 24/7 and free of charge to users of the parking lot.

The main purpose of the pilot project was to acquire knowledge about passenger acceptance, ease of use, traffic management, comfort and safety of the ParkShuttle. In a next phase the track could have been extended to the passengers terminals. Although surveys showed great passenger satisfaction over the 7 years of operations of the pilot system, they were (temporarily) ceased in 2004. Installation of the 2<sup>nd</sup> generation ParkShuttle was seriously considered, but based on the uncertainty in the airline-industry the decision has been postponed. *2getthere* remains in contact with Schiphol Airport with regard to the operations of automated people mover systems.

The initial decision to implement the ParkShuttle transportation system between subway station Kralingse Zoom and business park Rivium (city of Capelle aan den IJssel) was taken in 1995. The goal of the pilot was to prove that at the same expense, a better service and higher frequency could be achieved – making (public) transportation a more attractive alternative for car drivers. From February 1999 to November 2001, three ParkShuttle vehicles

operated on the 1300-meter single lane trajectory. Bi-directional travel was enabled by means of three passing locations. The success of the system prompted the decision in December 2001 to upgrade the system from its' pilot status.

In phase II, the trajectory has been extended and the number of stations increased to 5 – significantly reducing walking distances for employees and making the system more attractive to use. The 1800-meter track has three stops within business park Rivium. A new stop has been created to service business park Brainpark III and the residential suburb Fascinatio. The dedicated infrastructure, installed at grade, is now dual lane (with exception of the forementioned tunnel and bridge). Several at grade crossings with pedestrian and car traffic are realized. In Phase II both the number of vehicles (6) and the capacity of the vehicles (20 passengers) doubled – at the request of operating company ConneXXion. During peak-hours all vehicles are operational, on-schedule, based on a 2.5 minute interval. The scheduled service ensures the capacity is optimally used, while the on-demand operations in off-peak hours ensure the passenger service is maximized.

### III. MAKING THE LEAP TO PRT

The ParkShuttle has been developed based on market demand, with limited knowledge within the company about public transportation and the APM-market. Market intelligence was quickly gathered through research, but the fact remains that Frog is a technology oriented company that pushes new innovations to market. Most break-through innovations are realized through technology push, instead of market demand as customers (almost) always think along the lines of existing systems and technologies.

For Personal Rapid Transit this is also the case. Whether coming from a theoretical or technical perspective, the companies now offering PRT systems are pushing their system (technology) to market. Potential customers are unaware of the existence and/or possibilities of PRT systems and need to be educated. Not only about the possibilities, but also about the management of the risk associated with newly developed transport systems such as these. The perceived risk is often large, while the actual risk in practice is very manageable.

For the last couple of year PRT has mainly been a topic of discussion on the internet and at conferences. Slowly it is starting to develop with the topic being embraced in more discussions and larger conferences. The market education is working and more potential customers are being informed about PRT and its characteristics – either by suppliers or by a growing number of consultants with PRT-expertise. However, this is still just the 'tip' of the iceberg, as the first true PRT application still needs to be realized.

Frog Navigation Systems came into contact with PRT in 2000, co-operating with a golf-cart manufacturer to research whether it was possible to automate these vehicles using the FROG-technology. Automation of the golf-cart proved possible, but a field trial of the golf-cart system (the horticultural exhibition Floriade 2002) proved that the golf-cart basis is not suited for a public transit system with the requirement for a large yearly mileage. Redevelopment of the chassis would be required to guarantee a longer technical life-span and enable the system to run 100.000km a year.

The Floriade 2002 was not a true PRT application as it only featured two, on-line stations. However, it was a PRT-like application that introduced 2getthere (the then founded subsidiary of Frog Navigation Systems, specifically concentrating on APM-systems) to the concept. However, at this point in time there had been no strategic decision to develop the complete concept of PRT further, as it remained to be determined first whether the market would be interested in such a concept.

In the subsequent year (2003) research was conducted to establish the market demand for PRT. As there were various indications that PRT was drawing attention from potential customers, the conceptual development of PRT was commenced in 2003. To date the conceptual development has been largely completed, but continuous refinements to detailed areas, incorporating new developments, are still being made.

#### IV. PRT 2GETTHERE STYLE

Personal Rapid Transit (PRT) is 'a transport method that offers personal, on-demand non-stop transportation between any two points on a network of specially built guide-ways'. A PRT system consists of a number of small automated vehicles (seating 2 to 6 passengers) combining the desirable aspects of the private car (private travel at any desired time) with the social advantages of public transport (no congestion and parking issues).

*2getthere's* Personal Rapid Transit system features of a number of automated taxi's (CyberCabs) and a supervisory control system. The guide way can be constructed at grade, but also elevated, embedded in buildings or underground. The system in configurable as 'true' PRT – providing direct connections, on-demand operations and personal transportation – but alternatively 'ride sharing' (single origin, multiple destinations) and scheduled operations (to optimize capacity) can also be implemented.

Personal Rapid Transit is all about (network and vehicle) controls. *2getthere's* ability to provide a PRT system is based on the well-proven (20+ years) FROG network and vehicle controls, fully customized for Automated People Mover requirements.

PRT-like systems have been installed (e.g. at the Floriade 2002 by *2getthere*), but to date no 'true' PRT system has been realized. The first applications are imminent, however, as increased market interest indicates. A PRT system can be installed as feeder system to a public transportation node or (central) parking facility and as a local transit system. Possible applications range from airports to business and industrial parks, theme parks and resorts, city centers and residential areas.

#### V. PRT APPLICATIONS

For any application it is important that the PRT system fits within the environment. In an existing environment, the system will be optimized in light of the restrictions its surroundings pose, optimizing the value to both passengers and local residents. Where and how (at grade or elevated) the system is constructed should be carefully evaluated with regard to visual intrusion, noise and other effects on the surroundings. In a Greenfield development system optimization within the site development requires an integrated approach.

*2getthere* takes a flexible approach in its' system configuration allowing the system to be designed as true-PRT or as a PRT-like system. A PRT-like system will feature an aspect that contradicts

the definition of PRT. A PRT-like system might feature scheduled operations (for specific periods) and/or 'ride sharing' functionality. Scheduled operations can be considered to reduce the empty vehicle movement, while ride sharing functionality is intended to increase the average occupancy of the vehicles – both resulting in a higher hourly capacity or a lower required fleet size to achieve the same hourly capacity.

*2getthere's* system operates according to operational scenarios. The scenarios can become active automatically based on time-settings or can be activated by the operator (allowing him to act immediately on changing transport patterns). This allows scheduled and on-demand operations to be combined in the same application – using the scheduled service in rush hours to reduce the required fleet size (and the capital cost of the project). Or it allows to combine ride-sharing and personal, non-stop transportation in a single application. Scenarios provide the flexibility to customize the system to the required operations for every (occasionally repeating) transport pattern.

*2getthere* works based on the requirements and develops the system based on the characteristics of the application, the spatial planning and the customer preferences. A transportation system should be customized for each application, taking into account all specifics to ensure the passenger service is optimized and the capital and operating costs are minimized.

#### VI. SOME COMMON MISTAKES

Personal Rapid Transit is all about network (and vehicle) controls. *2getthere's* supervisory control system is based on the well proven SuperFROG system for industrial applications. A development history of 22+ years, demanding applications in multiple environments and experiences with APM-systems ensures *2getthere* is technologically ahead. The controls and experience are a significant competitive edge and the basis of several key advantages: proven reliability and availability, flexibility in configuration and operations, speed of implementation and minimum capital and operational costs.

The system allows for synchronous control of operations on the basis of Frog's time synchronization patent. Merging and docking procedures at stations (with independent berths) are accurately timed to allow for smooth operations. The system operates according to the parameters set in a scenario. The scenarios contain parameters with regard to work scheduling, traffic control, communication and job generation and assignment. The number of scenarios that can be programmed is virtually unlimited, allowing the operations to be optimized for each hour of each day.

Work scheduling, the assignment of transport requests to vehicles, is based on a customized set of rules (framework of conditions). The rules incorporate elements such as vehicle availability, distances, lay-out and transport requirements. Generation of transport requests is typically done by push-buttons at the stations of the system or generated automatically based on logged patterns of transportation requests and/or synchronization with the arrival/departure of other modes of transportation. The supervisory system is also in control of fleet management. This entails a.o. ensuring timely recharging of the batteries and keeping log files of all system events, alerts and transportation requests. The log files can be retrieved for statistical processing at any time.

The necessary communication to and from vehicles is done via a Radio Frequency (RF) wireless link. The system is easily expandable in terms of the fleet size and has standardized interfaces for communication with other systems (traffic lights, beams, etc.). The system was developed and tested in-house and operates on a Linux-platform.

## VII. PRT VEHICLE

Often the PRT vehicle draws the most attention as it is the most visible aspect of a PRT system (along with the elevated infrastructure). However, with all the automotive technology available in a competitive market, the development and fabrication of the vehicle is no longer the most difficult aspect. It requires the proper attention, but the expertise and technology is readily available.

The CyberCab PRT vehicle can be compared to an automated taxi. It offers direct connections between origin and destination (via the shortest route in the network) and offers personal transportation (charging passengers per vehicle, while allowing for group travel). The CyberCab vehicle is developed in close co-operation with expert 3<sup>rd</sup> parties with automotive experience. The CyberCab accommodates a 6-person family (4 adults, 2 children) and additionally has space available for either a wheelchair or luggage. The vehicle features an automated sliding door, optionally a second door can be installed allowing (dis)embarking on both sides of the vehicle.

The cabin is spacious and well illuminated at night. Large windows provide excellent all round vision and add to the personal safety (feeling) of the passengers. Seating is comfortable with all measurements exceeding normal (public) transportation standards (standing passengers are not facilitated). Information is conveyed to the passengers by means of the user console, display and voice module. The camera system allows the operator to display images of each vehicle interior real-time.

Each vehicle is equipped with advanced safety systems, a.o. for short- and long range obstacle detection. The sensors create a sensory shield, serving as a virtual bumper enabling the vehicle to make a controlled stop prior to contact with obstacles. In the control logic this is an integrated aspect of the normal operations and not an exception handling procedure – ensuring a more comfortable ride experience.

The vehicle is a mere 1450mm wide, resulting in a narrow track. The maximum speed of the CyberCab is 40 km/h (25 mph).

## VIII. PRT INFRASTRUCTURE

*2getthere's* CyberCab system operates on its' own dedicated guide way, enabling it to provide direct connections unhindered by the congestion of other traffic. No physical guidance (rail) of guiding infrastructure elements (kerbs and/or walls) are required for the operations, making the system less vulnerable (more reliable) and ensuring reduced capital and maintenance costs.

The integration of the infrastructure within the (existing) environment is key. In (historic) city centers, build-up and residential areas, applications are faced with a dilemma: installation at grade would require reconfiguration of the spatial planning, but an elevated guide way is usually not acceptable because of the visual intrusion (even when minimized). The system will need to be

optimized in light of the restrictions its surroundings pose, optimizing the value to both passengers and local residents.

All stations are typically created off-line. Each individual station would be designed to the requirements, its' surroundings (spatial planning and space available), user friendliness and capital and maintenance costs. When required a station can feature multiple (independent) berths – allowing for multiple vehicles being boarded at the same time, ensuring a higher throughput, eliminating single-point-of-failure vulnerability and thus increasing system availability.

As the system uses a simple, completely flat infrastructure, it is possible to create at-grade crossings with other traffic. An at-grade crossing will only be possible if the intensity of both traffic flows is low enough to allow for it. In case of (multiple) intensive traffic flows, either grade separated crossings are required or the entire track should be constructed elevated.

The communication network is an important element of the infrastructure. Base-stations, connected to the glass fiber backbone, are used for the wireless LAN communications with the vehicles. Additionally the intercom and CCTV modules at stations (and crossings) are also connected to the backbone. All connect to the control room, preferably located near the maintenance depot.

## IX. CONCEPT APPLICABILITY

Personal Rapid Transit sounds and is presented by some as the holy grail of transportation. It supposedly could solve all of today's transit problems and has no disadvantages that seem unacceptable. End the dream: no system is the holy grail of transportation. Each system has its' own niche.

The characteristics of an application determine which transportation concept is most suited. There is no ranking among the characteristics, but as a whole they determine whether the most suited concept is manual or automated, has dedicated guide ways or mixes with regular traffic, is mass, group or personal transportation, will (need to) be installed at grade, underground or elevated, operates on-demand or on-schedule, etc.

The basis of any application should be an analysis of the transportation demand and flow. Each application has its' own specifics and the most appropriate transportation system will need to be determined based on these. *2getthere* analyses applications on nine specific elements:

1. Function (local transit, feeder system, internal transit, etc.)
2. Intensity of transportation (capacity required)
3. Spreading in time
4. Spreading in space (origins – destinations)
5. Spatial planning (space available)
6. Customer requirements / preferences
7. Application surrounding environment characteristics (a.o. visual intrusion)
8. Application Specific Issues (e.g. political influences)
9. Costs of Ownership

There is no prioritization among these elements and all are analyzed simultaneously. It is possible that multiple types of systems are suited for the same application – however usually a customer preference or the costs of ownership associated with the system will tip the balance.

Based on these characteristics (requirements and customer preferences) *2getthere* advises customers if and which one of the concepts could be suited. The characteristics also determine the optimum configuration of the suitable concept (e.g. indicate a scheduled service is a preferred option).

Personal Rapid Transit (PRT) and Group Rapid Transit (GRT) systems are ideally suited as feeder systems or as local transit systems. A local transit system connects facilities within a certain location (e.g. within a business district). These systems have a high level of sophistication, allowing both line and network configurations and being able to operate a short headways.

Main reasons to consider these type of automated systems is the reduced operational and life cycle costs. Electronically guided people movers minimize the capital costs of the infrastructure in comparison to rail-guided systems. The automated system provides an improved service to the passengers: 24hr transportation, on-demand or at a high frequency. Cities benefit from reduction of car traffic, congestion and the environmentally friendly character of the transportation system. To (real estate) developers and resorts the system presents the possibility to reduce space wasted for non-value added activities (such as parking) by connecting locations and optimizing land use.

## X. FIT WITH CHAIN MOBILITY

As feeder system the PRT concept fits well within the thought of chain mobility. Chain Mobility means gearing transport systems to each other in such a way that virtually no time is lost in changing from one to the next. This requires a flexible and better manageable transport system that is profitable in time and kind to operator and passenger alike. Automated people movers by design would fit well in a chain mobility approach. There are over a hundred applications, however relatively few in public transport.

If Chain Mobility is the solution to make public transportation more attractive and a more valid alternative to the personal car, the integration of the different links of the chain is key. This integration between the different links is most easily achieved by automation. A human will never be as accurate as a computer – both in driving as in timing. Integration between different automated systems is possible, but integration using the same technology in different concepts is rather easy in comparison.

By using three concepts (Personal Rapid Transit, Group Rapid Transit and Bus Rapid Transit) all based on the same technology, seamless mode transfer is facilitated. In comparison to other automated transportation concepts, the FROG-technology used as basis ensures the three system are distinctively different for several reasons:

- The concepts are electronically controlled, not guided by rail or other infrastructure elements.
- The concepts are complementary to each other – each specifically suited for a different link of the chain.
- The concepts use the same vehicle software and can be controlled by the same supervisory control system.
- The supervisory control system can communicate with any other information system to import/export data 'real-time'.

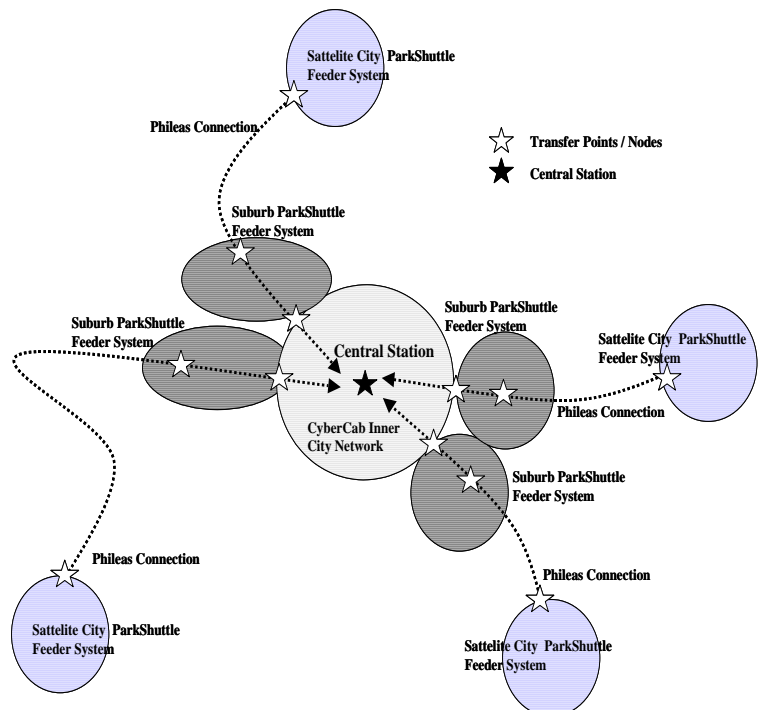
To improve the transportation chain it is important that the systems are interconnected, minimizing the waiting times at transfer points. If all systems operate using the same supervisory control system, synchronization is achieved more easily. A transportation network

connecting the whole city, synchronizing the services by public transportation and minimizing travel times. The service will be comparative, if not better than than provided by the car.

Within a public transportation network such as this, the Phileas would connect satellite cities, suburbs and other more remotely located areas with a relatively high activity density with the city centre. The ParkShuttle would serve in a network in those locations, satellite cities and suburbs, as a feeder towards the Phileas. Finally, the CyberCab operates in the inner city, directly connecting the most important locations – such as downtown business parks, financial districts, shopping and entertainment venues and public transportation nodes.

To optimize the transportation network, the average speed of the different modes should be a high as possible, while there should also be a dense network of stops. For this reason the feeder system, a ParkShuttle application, will be equipped with a dense network of stops, minimizing the distance to be covered towards the first stop (usually either covered on foot or by bike). The traveling distance with the ParkShuttle will be restricted to a maximum of 6 kilometers, as a longer journey would make public transportation less attractive. The ParkShuttle will dock at a station of the Phileas, synchronized with the Phileas services – allowing for an immediate transfer. Because of this the stops of the Phileas can be spaced further apart, allowing for a higher average speed. In the end, the improvement in the first link of the transportation chain thus improves the chain as a whole : it is as strong as its' weakest link.

The personal rapid transit system would be installed in inner cities, providing direct connections. The CyberCab will dock at Phileas stations at several points, allowing for transfers. In principle, however, it is not designed to allow transfers, but rather to establish direct connections. Where Phileas is used to connect satellite cities and suburbs to the city centre, e.g. the central station, the CyberCab connects the different facilities within the inner city (also with the central station).



## XI. CONCLUSION

Mobility growth requires a balanced approach by governments as it contributes substantially to the economy, but also has a negative impact on the environment through the traffic it generates. Increase in collective transport will reduce the traffic burden, without impeding on the freedom of mobility. To achieve this, public transport has to become more like the automobile and vice versa.

Trips per automobile normally require only short first-and-last-link sections. By taking a chain mobility approach to the transport system, these first-and-last-link sections will get the attention they deserve. Task for vehicle manufacturers is to provide tools and vehicles that allow for easy management and control, making it possible to reduce transfer time between travel modes.

Automated people movers can be fully controlled in their movements and hold good prospect for real time interaction with other transport modes. Automated people movers have proven their qualities in large and medium scale applications like metros and light-rail systems. Interesting developments are taking place for the smaller vehicles that allow influence by the passenger in destination and routing.

Personal Rapid Transit has been innovation lasting. Although the idea has been around for 50 years, the technology to realize the vision is only available today. The skepticism about the concept is logical in respect to the past (failed) developments and certain aspects of the concept that need careful consideration (visual intrusion, personal safety). However, it can be realized today (technically) and should be matched with right environment (such as airports and business parks) to proof itself first!

What comes after that will only become clear on the basis of the succes of the first application.

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