

Innovative Transit Systems

Survey of current developments

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ABSTRACT (aim, method, results):

This report is a knowledge survey of innovative transit systems. The improvements that have been made to transit so far have not been successful in breaking the trend of increasing car traffic and decreasing transit trip-making. This report aims at highlighting ideas and solutions offering many of the advantages of private cars while avoiding its drawbacks.

This report gives an inventory of small-scale transit systems offering direct trips without waiting, transferring or unnecessary stopping en-route. Some representatives for various principle solutions are highlighted without claims on being exhaustive. The perspective is that of the traveler and planner rather than that of an engineer. The various systems are compared and evaluated and we finally discuss where each system is the most suitable.

Seven guide-way systems are deemed as particularly relevant. With the proposed solutions it is estimated that up to 25 % of today's car travelers would voluntarily leave the car to go by transit. There are several suitable application areas for the new systems in Scandinavia. The development of innovative transit systems is well suited for Swedish know-how and Swedish industry.



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by

Dr. Ingmar Andréasson

LogistikCentrum

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Foreword

The current report is a continuation of the research within the thematic program “Advanced Transit Systems” at Chalmers University during the years 1994-97. In that program we were focussing Personal Rapid Transit systems (PRT). In this report we widen the perspective to include also other types of small-scale transit systems such as driverless minibuses, cable-propelled systems and Dual-mode.

This report is based on direct contacts with the developers of the systems described. My participation in planning for the latest Automated People Mover (APM) conferences since 1996 has helped me keep up-to-date with development.

This report is a translation of a Swedish report KFB 2000:69. The English version includes currency conversions, some updated costs, added information on two pending applications and one new reference. Swedish references have been replaced by English versions where possible.

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Molndal January 30, 2001

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Summary

The current report is an overview of innovative systems for public transport. The efforts made to improve public transport so far have not been able to break the trend of growing car traffic and declining transit ridership. This report highlights ideas and solutions offering many of the advantages of private cars without causing its negative effects.

This report gives an (incomplete) inventory of small-scale systems, offering direct, non-stop trips on demand. Some typical representatives of various principal solutions are described. The perspective is that of a traveler and a planner rather than that of an engineer. Various systems are compared and assessed and finally we discuss where the various systems are appropriate.

Seven guide-way systems are pointed out as being of particular interest. With the suggested solutions it is estimated that up to 25 % of car travelers would voluntarily leave the car to travel by transit.

There are several suitable application areas for the new systems in Scandinavia. The development of innovative transit systems is well suited for Swedish know-how and industry.

The conclusions are:

- Present transit is not competitive
- Innovative systems offer many of the qualities of private cars
- ITS in car traffic can be applied to transit
- Direct non-stop trips on demand cut transit trip times to half
- Small-scale systems may replace buses and trams
- Several developments are ready for implementation
- The new guideway systems cost less than trams
- There are several suitable applications in Sweden
- Opportunities for development by Swedish industry

1. The need for new solutions

1.1. Transit is the last choice of travelers

Over 80 % of all motorized trips in Sweden are made by car. Car traffic in cities continues to grow at a rate of about 2 % annually. Road networks in large cities are congested already. Transit ridership is declining at about the same rate - 2 % annually.

The efforts made so far on the improvement of public transport have been inadequate. Most of those travelling by transit today have no other alternative. They lack a driving license or access to a car.

In order to balance capacity and demand for car trips in Stockholm one would have to build new roads and also introduce car tolls (according to the State Institute for Communication Analysis). It would not even be enough to re-allocate the whole Swedish budget for road construction to the city of Stockholm. The thing that would make more people go with the present public transport would be a major economic crisis.

What does it take then to make people voluntarily leave the car at home and ride transit? It probably takes some of the values offered by private cars, viz.:

- + Freedom to travel at any time
- + No stopping or transferring en route
- + Travelling alone or with company of choice
- + Privacy and comfort
- + Music of own choice.

Deep interviews with commuters in Gothenburg confirm that habitual drivers have a strong urge for privacy and individuality in their trip making (ref. 1).

Price was not determining for those who chose to go by car. They can afford and are willing to pay for high-class service. An attractive transportation system may cost more than present transit - high price may even be an advantage since it brings status.

Cars are not good at everything. They also have negative sides, which even the most devoted car drivers would like to avoid:

- Congestion and accidents
- Unpredictable travels times
- Noise and pollution
- Accident risks.

This study aims at highlighting alternative transportation systems offering the advantages of private cars while avoiding its negative sides.

1.2. Becoming the traveler's first choice

We wish to offer the highest possible level-of-service in order to attract the maximum number of passengers. The service requirement leads to demand-responsive systems and direct trips. Trips must be individual and then vehicles can be kept small.

Small-scale systems improve accessibility by better coverage, shorter walking distances, more services and fewer transfers. Traffic can be more similar to taxis than to route buses and trams.

For this study I have chosen to focus small-scale public systems with intelligent control. Cable-propelled systems are included because they may be developed into being demand-responsive and offering direct trips.

I do not cover driverless metros, guided buses, cars with alternative fuels, taxis and minibuses with various degrees of ride-sharing. Yngve Westerlund treats the latter systems in another KFB-financed project at LogistikCentrum (ref. 2).

In what follows I describe some, in my judgement, interesting principle solutions illustrated by systems ready for implementation. This report is not a complete inventory nor does it offer detailed descriptions of technical design and performance. The perspective is that of a planner and a traveler rather than that of an engineer. The focus is on ideas and what they offer to travelers and neighborhoods.

The systems described offer direct trips on demand; i.e. traffic is adapted to the passengers instead of passengers having to adapt to routes and time-tables.

If trips are to be on demand you cannot expect many passengers in the same vehicle. Large vehicles require waiting passengers in order for their capacity to be utilized.

Small vehicles must run at short headway requiring automated control. For a fast and safe system of high capacity we cannot trust in driver attention and driver reaction.

Small vehicles bring other advantages too. The infrastructure they use (track, guide-way, suspended beam etc) can be made slimmer, lighter and cheaper. The cost of drivers is the motive for the large vehicles used in transit today. With automated control there is no reason and no defense for keeping passengers waiting to fill up large vehicles.

1.3. Four starting points - one solution

I intend to show how different starting points lead to the same solution with small demand-responsive and driverless vehicles.

Maximum level-of-service

The first starting-point is to offer the maximum level-of-service, i.e.

- Freedom from time-tables
- No waiting or insignificant waiting-time
- Direct non-stop trip without transfer.

Departures and choice of route must be according to individual demand. The operational principle is more like taxi than like bus. A vehicle normally waits for a (group of) passenger and departs as soon as he or she is ready. With this principle large vehicles are not needed since only rarely many persons wish to make the same trip together. The expected load corresponds to private cars or taxis, i.e. 1.2 - 1.5 passengers. In order to achieve higher loads one would have to keep passengers waiting.

During peak demand and with ride-sharing from transfer stations from route services the average load can exceed 2 passengers without anyone having to wait more than 3 minutes (ref. 3).

Handling capacity with small vehicles requires many of them and short headway. For reasonable economy the vehicles have to be driverless.

Slim guideways

Guideway dimensions are determined by the maximum load that they have to carry. How often it is subjected to this load is of little significance for the dimensioning. The lowest possible load is obtained by dividing the weight and spreading it out. Hence one vehicle with 2 passengers every 2 seconds offers the same capacity as a train with 1800 passengers every half hour. The load of a train is in the order of 1000 times higher.

So for a slim guideway we need small vehicles. Then we need many of them at short headway. Economy and safety requirements lead to automated control.

Many small stations

Short walking distances requires many stations.

Level-of-service requires trips to be non-stop. Other vehicles stopping for deboarding and boarding may not hinder trips. Hence stations must be off-line on sidetracks.

Off-line stations lead to quicker trips so that fewer vehicles are needed.

With frequent departures and many stations there will be only few passengers waiting at any time and stations can be kept small. Small stations are easier to integrate into the city environment. Fewer passengers at a station reduce the risk for assaults. Nobody gets into the station without a validated ticket from a machine at the entrance.

Economy

In a typical automated system based on small vehicles, guideway and stations account for about 75 % of the total investment (ref. 3). Costs are determined by guideway dimensions which according to the above is determined by maximum vehicle weight. The lighter the vehicle the less costly is the guideway.

Small vehicles lead to frequent departures, few waiting passengers and small stations, which are also less costly.

For a given capacity it takes more vehicles the smaller they are. Will many small vehicles not be more expensive than fewer and larger? According to statistics collected by Anderson (ref. 4) vehicle costs per seat are about the same for large and small vehicles. Large vehicles need strong engines, heavy brakes, more expensive suspension, deformation zones and much material. One would get one thousand 4-passenger vehicles at about the same cost as 100 vehicles for 40 passengers. Many small vehicles are also necessary for individual and direct trips on demand.

1.4. Which trips can the new systems accommodate?

Small scale does not necessarily imply lower capacity. Dense traffic with small vehicles in a network can offer the same capacity as sparse traffic with large vehicles in a corridor.

Think about the development of ski-lifts. In the early days of alpine skiing they built large cabins for shuttle service. Such cabins offer sparse departures causing long queues and they are hardly built nowadays. Many small cabins or chairs attached to one cable offer higher capacity and shorter waiting-times.

Small vehicles with frequent departures can in fact offer the same capacity as route buses and trams. In a PRT study for Gothenburg with 500,000 inhabitants (ref. 5) we have proven by simulation that PRT can replace all public transportation in Gothenburg with suburbs plus take care of 60 % of all car trips. With ride-sharing in 4-passenger vehicles it was possible in extreme cases to carry 5000 passengers per hour on the most loaded link.

In a mode-split analysis for central Gothenburg (ref. 6) we estimated that 32 % of car commuters and 19 % of other car travelers would prefer PRT for trips within the area served by PRT.

2. Some current developments

What follows is a description of some research and development areas relevant to the development of intelligent transit systems.

2.1. Driverless metros and trams

There are almost 100 automated systems carrying passengers today (ref. 7) most of which are driverless metros or trams. The reasons for automation have been to

- Decrease wage costs
- Offer frequent services even at low demand
- Increase safety

Experience from automation shows that the technology works and is safe. Traffic is still route-bound but departures are so frequent that timetables are not needed. Waiting-times are short but passengers still have to cope with stops en route and transfers between routes.

2.2. Intelligent Vehicle-Highway Systems (IVHS)

A substantial federal research program in the US aimed at increasing capacity and accessibility in the highway system. Similar developments are made in European car industry. The driver is still around but he is also a traveler and he is not paid. This automation does not save costs but frees the driver from distance-keeping and steering tasks. Headway can be reduced without sacrificing safety so that the highway can accommodate more traffic.

2.3. Adaptive Cruise Control (ACC)

Cruise controls for cars have been refined from simple speed-keeping to include regard to speed limits, distance to the car in front and relative speed. On some models it is possible to set the minimum time gap to the car in front:

- 1.0 seconds for aggressive driving
- 1.5 seconds for normal driving
- 2.0 seconds for careful driving

Interestingly this is below the safety requirements made on driverless systems. A common requirement is for the time gap to be large enough so that a vehicle is able stop without hitting the one in front even if that vehicle would stop abruptly.

Cars in normal traffic do not meet the above safety demands and at the same time they depend on the driver's ability to react and maneuver. Even though driverless systems are safer than manual ones they have to meet higher safety demands. A probable reason has to do with liability and indemnification toward the system operator in case of an accident.

2.4. Electric cars

Electric cars help solve the environmental problems with noise and emissions while they do nothing to alleviate congestion and accidents. The success of electric cars hinges heavily on the successful development of battery technology with respect to capacity, charge time and life.

Car manufacturer Honda develops a system called ICVS (Intelligent Community Vehicle System) based on electric cars. The name goes back to CVS, which was the first PRT system in the world, running in the seventies. Honda ICVS steers and switch following magnets in the road surface and use radar to keep distances to other vehicles and obstacles. While these cars go slowly in mixed traffic they drive fast in lanes reserved for ICVS. It is planned to add reserved lanes to form a connected network. Lanes can be narrower than ordinary lanes since no room is needed for reeling. Cars can be grouped into platoons to increase road capacity. ICVS would be collectively owned and be rented on a per trip basis.

Other developments of electric cars are exemplified by French PRAXITELE, SERPENTINE, CYCAB and Japanese VALSE by Yamaha.

2.5. Cable-propelled systems

Traction by cable is an old and proven technology. San Francisco cable-cars have been in service since 1878. Four cables are driven at constant speed from one engine central. The car driver (called the *ÔgripperÔ*) holds the cable with one handle and breaks with another handle. Switching is by rail switch, always placed downhill with free rolling.

In modern times cable technology has been developed for ski-lifts with small cabins leaving the cable at stations. While hanging cabins are appropriate for ski-lifts now there are cable-propelled vehicles on (mostly elevated) guideways for urban traffic. Vehicles may either be fixed to the cable with all vehicles stopping at the same time or detaching from the cable at stations.

Vehicles may roll on wheels of steel, rubber or plastics or else hover on air cushions or magnetic fields. Turntables are used at end terminals. Manual switches are used to take vehicles on and off the system.

Advantages of cable-propelled systems are simple, proven design and high safety. Vehicles need no propulsion and distance-keeping is trivial.

There are three leading suppliers of urban cable-propelled systems - Doppelmayr, Leitner and POMA. The main owner of Leitner recently acquired the latter. These systems are described later.

2.6. Personal Rapid Transit

Personal Rapid Transit (PRT) is characterized by

- Small driverless vehicles (3-5 seats)
- Off-line stations
- Vehicle waiting for passengers
- Departure when a passenger is ready
- Direct non-stop trips
- Quickest route to destination

Vehicles normally run on a guideway or are suspended from under a beam. For high capacity it is necessary that vehicles can run at short headway (1-3 seconds).

PRT share many qualities of private cars for trips between PRT stations. Stations can be closely spaced without delaying trips since vehicles may pass freely. System capacity is comparable to that of bus or tram.

PRT vehicles run on electricity from power rails or from batteries, charged during standstill.

A common safety requirement is so called “brick-wall safety”, i.e. if one vehicle would come to a sudden standstill the following vehicle must be able to stop, avoiding a serious collision.

Experience has shown that demands on control system, speed, headway and safety can be met in practical operation.

One Japanese system, CVS was in operation with passengers already in 1972 in a suburb of Tokyo. CVS carried 800,000 passengers during a 7 month exhibition with 60 vehicles running at 1 second headway. There were no incidents and availability was 98.2 %.

A PRT-like system with larger vehicles (Group Rapid Transit) has been and still is in service since 25 years in Morgantown, USA. The system has 73 vehicles and 5 stations, all off-line. The vehicles accommodate 8 seated and 12 standing passengers but choose their routes individually like PRT. The primitive control system is dimensioned for 7.5 seconds headway. About 50 million passengers have used the system so far. Operational experience is very good with 99.8 % availability and no accident.

A multi-disciplinary research program “Advanced Transit Systems” was conducted at Chalmers University during 1994 - 97. We analyzed PRT from the perspectives of user acceptance, city planning, travel standard, demand and social economy. Some of the conclusions (ref. 8) from the research on PRT were:

- PRT technology is available now
- PRT has capacity to replace buses and trams
- Travelers accept PRT
- PRT may halve trip times by transit
- PRT can attract 20-25 % of car travelers
- PRT can be socially profitable
- Visual intrusion is the main obstacle for acceptance.

One limitation of PRT is the fact that direct trips can be offered only within the PRT network. Travelers have to get to and from stations in other ways. Yet PRT typically offers half the travel times of conventional transit (ref. 5).

Examples of PRT systems are described later.

2.7. Dual-mode

Dual-mode vehicles can be driven automatically on dedicated guideway but also manually on ordinary roads and streets. Stations (entry- and exit ramps) need not be closely spaced since the street network is available too. Dual-mode can be attractive already with few links on congested arterials.

It is natural for the vehicles to be electrically driven with batteries charging on the guideway and while parked. Privately owned vehicles can be brought home to the private garage. They would be less efficiently used over the day and take up parking space as normal cars but on the other hand society does not have to make the investment. There can also be publicly owned vehicles to be picked up and left at the nearest station.

Safety on the guideway requires that all vehicles meet common specifications and that this can be verified before entering the guideway. Debiting a high price for charge may finance the guideway.

Electric cars (such as e.g. Honda ICVS) with automatic steering are also dual-mode. Roadway with magnets can be used by ordinary cars and by cars with automated control so that no new infrastructure is needed. On roads with mixed traffic speeds must be kept lower for safety reasons. Therefore it is planned to dedicate certain roads or lanes exclusively to automated cars. Capacity is increased only with automated control and platooning.

New dedicated guideways are necessary to increase capacity. With the guideway elevated it does not occupy much land. The capacity of a guideway corresponds to three motorway lanes and costs only a small fraction of that motorway.



Figure 2.1. Three-lane motorway at capacity (copyright Carter-Burgess, USA).



Figure 2.2. Travelers in figure 2.1 in automated vehicles on a guideway (copyright Carter-Burgess, USA).

Examples of Dual-mode developments are presented later.

2.8. Experience from current developments

From driverless metros and trams we can pick up solutions for automation, reliable components and redundancy (doubling of critical components).

From the development of IVHS we can pick up technique for measuring and maintaining short distances with retained safety. Cars in the USA have been driven in automatic mode at 100 kph with 0.5 seconds headway.

From the development of electric cars we can pick up battery technology to replace power rails along the guideway and allow charging during ordinary stops at stations. The batteries (metal hydride) in the new hybrid car of Toyota are claimed to last through the lifetime of the car.

From cable-propelled systems we can pick up simple, reliable and safe technology for propulsion of vehicles at short distances. Switching methods need to be developed.

Personal Rapid Transit can gain experience and solutions from the other systems where more development resources have been invested.

Dual-mode ties together the developments from automated guideway systems, electric cars and IVHS.

3. Some representative transit systems

In what follows we describe some typical representatives of various categories of systems. The selection is not exhaustive and descriptions are not complete. We have chosen to include systems meeting one or more of the following criteria:

- Typical of their category
- The most advanced in their development
- Possibilities for Swedish industry

Following descriptions of the various systems, in the next chapter is a compilation of system parameters, distinctive features and comparative assessments. Further systems are presented in reference 9.

3.1. FROG Park Shuttle

FROG Navigation System (Free Ranging On Grid) of the Netherlands have developed a technique for navigation based on wheel rotations and wheel angles supplemented by regularly spaced passive transponders in the road surface. The technique has been proven for automated trucks in warehouses and for moving containers in ports. A later application is the navigation of driverless minibuses (Parking Hopper and Park Shuttle).

Since December of 1997 four driverless minibuses operate in one of the long term parking areas at Schiphol airport near Amsterdam. Two loops are operated, each 1 kilometer with three stops. Traffic signals and barriers control conflicts with manual cars.



Figure 3.1. Parking Hopper at Schiphol



Figure 3.2. Traffic control by signals and barriers

In Rivium Business Park outside Rotterdam three vehicles operate over a distance of 1.3 kilometers between a metro station and a business park. In addition to the terminals there are three other stops en route. The public has been riding the system since February 1999. Before that an ordinary bus served the distance. Already after a few months operation ridership had

doubled (ref. 10).



Figure 3.3. Park Shuttle at stop



Figure 3.4. Dedicated bridge over motorway

Vehicles are battery powered accommodating 6 seated and 4 standing passengers. Navigation precision is 2-3 centimeters and speed is limited to 30 kph for safety reasons. The roadway is fenced off and vehicles have sensors detecting obstacles. The roadway is a 3 meter wide asphalt surface with embedded transponders. Each vehicle has its own navigation system and a stored map of route alignment and stops. Vehicles determine their own path based on passenger destinations as entered into an on-board unit.

A central control system (SuperFROG) takes care of planning and traffic control based on signals and barrier gates. The PC-based control system assigns tasks to vehicles and dispatches them via radio. Only start- and end-points are communicated. Vehicle computers determine the shortest path and monitors safety distances.

It is not clear to me how closely vehicles can be spaced considering they navigate independently. The FROG system is suitable for short distances (up to 5 kilometers) with low travel demand. One distinctive advantage is the fact that no special guideway is needed. Park Shuttle crosses the motorway on a dedicated bridge. The speed is limited by the risk for conflicts with other vehicles and/or pedestrians.

Costs for the system in Rivium Park are stated to be about 3 million USD including 3 vehicles, stations and 1.2 kilometers of roadway.

The FROG navigation system is also used by ULTra PRT to which we come back later.

3.2. Taxi 2000

A multi-disciplinary research team at the University of Minnesota developed the Taxi 2000 PRT system. Professor J. Edward Anderson is today the world leading expert on PRT systems. The university has licensed the rights to Taxi 2000 Corporation lead by Anderson. Taxi 2000 had in turn licensed the rights to Raytheon Corporation who changed the specifications and named their version PRT2000. Raytheon invested about 50 million USD and demonstrated on their test track technology, control and safety with 3 vehicles running at 48 kph with 2.5 seconds headway.

Vehicles and guideway in Raytheon's version were large, heavy and expensive. When the customer (and financing partner) Chicago RTA delayed their order Raytheon chose to discontinue the development. All rights have been returned to Taxi 2000 who have recruited a development team and are negotiating with new financiers.



Figure 3.5. Scale model of Taxi 2000



Figure 3.6. Cutaway of guideway

Taxi 2000 vehicles seat 3 adult passengers (side by side) or alternatively 4-5 children or one wheel-chair or baby-carriage with attendant. Vehicles run on smooth rubber tires in a U-shaped trough measuring 0.9 x 0.9 meters. Propulsion is electric with linear induction motor (LIM) and direct current from a power rail. Switching is mechanic with a switch arm in the vehicle following guide rails in the guideway. Speed is 32-80 kph. Initial testing is in 65 kph with 3 seconds headway (ref. 11).

With the linear induction acceleration and braking perform independently of friction (Minnesota gets lots of snow in the winter). Therefore it is possible to design for safe headways down to 0.5 seconds (violating the brick-wall regulation).

Investment cost is estimated to about 3.5 million USD per km (single) guideway including vehicles, stations and control system.



Figure 3.7. The guideway can be attached to facades



Figure 3.8. Model of station

Taxi 2000 has raised wide enthusiasm in the USA where citizen groups have been formed in several states to convince authorities to pursue competitive alternatives to private cars. Citizens for PRT have been established in Minneapolis (www.cpirt.org), Santa Cruz (www.umunum.org) and Austin (www.acpirt.org).



Figure 3.9. Vision by the citizen group for Minneapolis

Taxi 2000 has been selected by the SkyLoop Committee of Cincinnati Ohio among 50 guideway systems as the most suitable and economic means to solve the traffic problems of that city. A simulation model of the proposed system is available on the organization's website www.skyloop.org.

3.3. ULTra



Figure 3.10. ULTra prototype vehicle

ULTra (Urban Light Traffic) is a PRT system developed by researchers under the leadership of Professor Martin M. Lowson at the University of Bristol, UK. Battery powered vehicles run on rubber tires in trough-shaped concrete guideways elevated or at grade between curbs. Instead of being guided and switched mechanically against the guideway, vehicles navigate using on-board maps, wheel rotations, wheel angles and guideway transponders (FROG system). Steering is by the wheels and guideway sides act as safety barriers. Batteries are charged during standstill at stations or in the depot.



Figure 3.11. Concrete guideway



Figure 3.12. Cardiff scenery

Thanks to battery operation the guideway can be made simple and less costly without power rails. Battery operation is also a prerequisite for navigation without mechanical guidance. A further advantage is the fact that emergency evacuation can be arranged without risk of touching hot power rails.



Figure 3.13. Crossing road



Figure 3.14. Running at grade

Where PRT can run at grade construction costs will be much lower. Case studies indicate that over 50 % of the network can be placed at grade. It would be possible to operate vehicles on open surfaces at reduced speed (as FROG Park Shuttle).

ULTra has been dimensioned for 4 seated passengers, 40 kph and 3 second headways. Headways are eventually to be reduced to 1 second. Guideway grade can be 10 % and typical spacing between supports is 18 meters. Curve radius can be down to 5 meters, which is excellent and facilitates integration in narrow street spaces (ref. 12).

Open guideway profile with wheel propulsion and -braking requires snow removal and some form of de-icing. The advantage with the open profile is that the guideway later can be used by other electric cars having automated control on the guideway (Dual-mode). A conventional electric car needs to be equipped for navigation, communication and distance-keeping. These functions are becoming available now for cars.

Investment for a complete system (vehicles, guideway, stations and control) is calculated at about 5 million USD per kilometer. If the guideway would be all elevated total costs may be around 7 million USD per kilometer.

A prototype vehicle has been built and a government research grant of 5 million GBP has been awarded for development and test of a prototype system. On top of that the city of Cardiff in Wales is financing studies for the selection of area and planning for the first commercial installation.

The prototype system is estimated to be in service early 2001. Commercial operation with passengers is planned for 2003.

3.4. Austrans



Figure 3.15. Austrans prototype vehicle

Austrans is based on larger vehicles than pure PRT systems and is classified as Group Rapid Transit (GRT). Austrans vehicles accommodate 9 passengers, all seated. Austrans will be operated as individual PRT except in peak hours when ride-sharing is applied and vehicles make intermediate stops. All stations are off-line so that stopping vehicles do not block the main line.

Austrans wheels are gripping around special Z-shaped rails permitting steep grades and safe braking. Wheel arrangements allow sharp turns down to 8 meters (at 18 kph). The small turning helps fitting Austrans into city streets with tight corners. Rails are flexible (!) so that they can switch fast (1 second). Safety distance before the rail switch requires a minimum headway of 3 seconds.

Another unique feature of Austrans is lateral movement of rail segments at stations. Loading and unloading of vehicles can then be made independently, thus increasing station capacity.

Financing of 15 million USD is secured for developing vehicles and test track. Vehicle

chassis and cabin were completed in December 2000. The test track is under construction outside of Sydney and is expected to be fully operable by May 2001. The Bishops Group developing Austrans is large and well renowned as designers and suppliers of wheel suspension/steering for cars.



Figure 3.16. Austrans over street

The performance of Austrans positions that system above PRT both with respect to speed (up to 120 kph) and capacity (up to 9000 pph). The larger vehicles compensate for the longer headway imposed by the rail switch.

Austrans have been invited to offer a system in Singapore and to make feasibility studies in Canberra as well as cities in South America and California. Austrans is expected to be fully commercial by 2003.

System cost is stated to be 15 million USD per km elevated guideway and 12 million USD at ground level.



Figure 3.17. Austrans test track outside Sydney

3.5. SkyCab

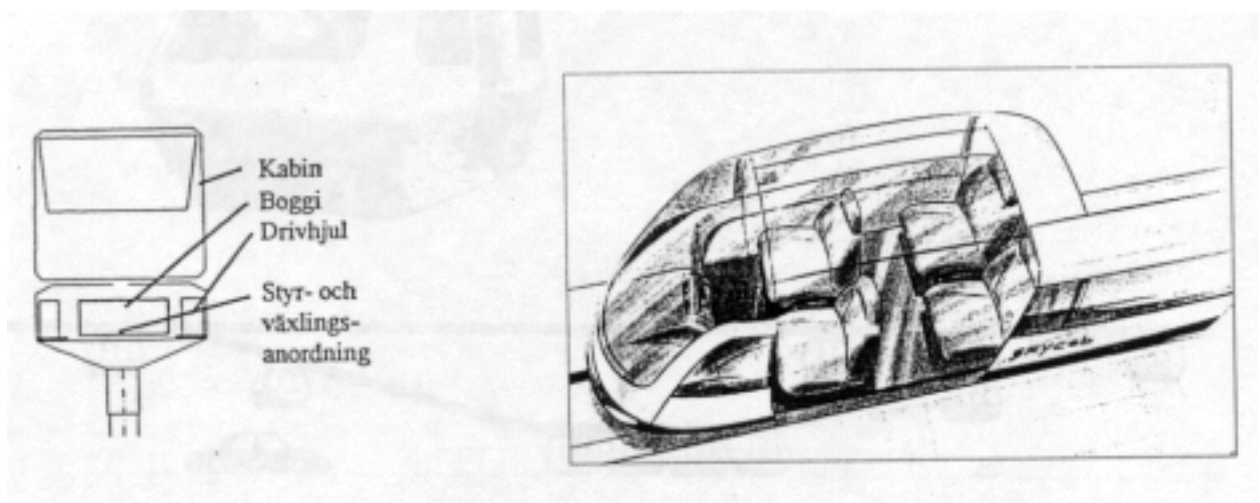


Figure 3.18. SkyCab vehicle and guideway profile

Figure 3.19. Sketch of vehicle

Swedish SkyCab is a PRT system based on electric vehicles with rubber wheels running on a covered guideway. With components from electric cars and modern battery technology power supply can be limited to charging at standstill. Vehicles steer with the front wheels and switch following inductive loops.

The guideway is covered leaving a narrow slot up and drainage downwards. Material can be

either steel or concrete. The span between supports can be 12-30 meters and curve radius down to 20 meters at full speed. Speed is normally 36 kph with 1.6 second headway.

SkyCab like other PRT systems would normally run on elevated guideways but may also run at grade or in tunnels. Inductive guidance and battery operation gives large freedom in guideway design.



Figure 3.20. Design study of SkyCab for Linköping (copyright Bernhardt Arkitekter)

Preparations for test tracks and extensive studies have been made in several Swedish cities (ref. 13) and for the Arlanda airport.

A vehicle mockup is claimed to exist and a consortium of industries including ABB and NCC are ready to finance and develop SkyCab. The control system is a development of control systems for Automated Guided Vehicles (AGV) for warehouses.

Investment for SkyCab is estimated at about 4 million USD per system kilometer.

3.6. FlyWay

The FlyWay system from SwedeTrack consists of vehicles of different sizes suspended under beams. Here we describe the PRT version with small (5 passenger) vehicles suspended under a square beam 0.7 x 0.9 meters.



Figure 3.21. Flyway suspended system



Figure 3.22. Cabin for 5 passengers

The cabin is connected through a slot to a drive engine running inside the beam. Running surfaces inside the beam are effectively protected from snow, leaves and vandalism.

The cabin suspension and inertia produce natural banking to reduce forces on passengers in curves and during acceleration and braking. Beams need not be super-elevated in curves thereby reducing cost.

A unique feature for FlyWay is the ability to lower the cabin from the beam at stations. Stations can be placed at grade and travelers need not go up and down to enter and exit. At grade-stations cost less and visual intrusion is reduced. At the same time this feature offers a natural escape in case of obstacles en route.

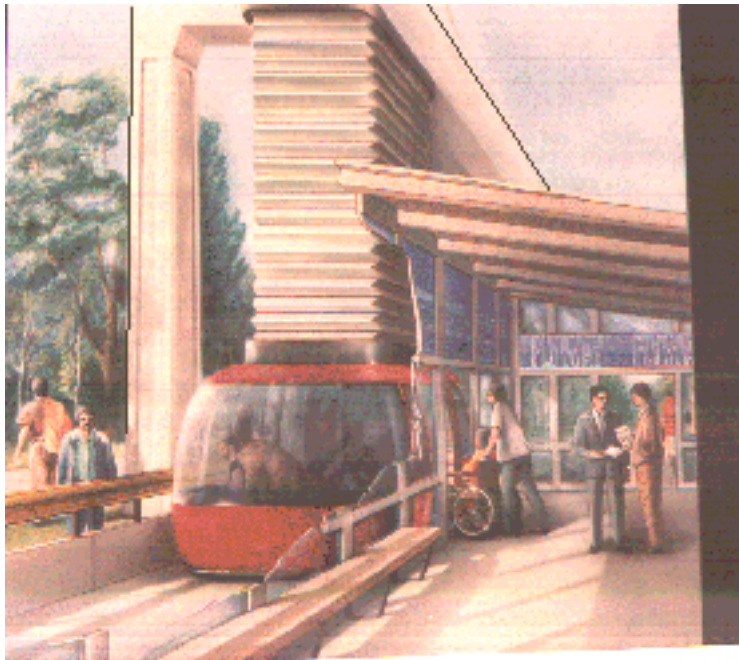


Figure 3.23. FlyWay cabins can be lowered to ground level at stations

The FlyWay concept also includes larger cabins and beams for higher capacity but then we abandon the concept of individual direct trips on demand. Another foreseen possibility is platforms for the transport of cars suspended under the beam, i.e. a kind of Dual-mode.

Certain co-operation has been established with Siemens with large suspended cabins (SIPEM) in operation.

The FlyWay system has raised international interest with serious inquiries from the Far East.

The FlyWay design is well worked out with several patents (including switching) and has been described thoroughly on their webpage at www.swedetrack.com.

3.7. Leitner

Leitner have been building cable-suspended ski-lifts for more than 100 years. The cable technology can also be used to pull vehicles on rails. The Leitner guideway is a spaceframe design carrying the rails and guide-wheels for the cable.



Figure 3.24. Turn-table for cable guideway



Figure 3.25. Leitner vehicle for 30 passengers

In the simplest variant vehicles are fixed to the cable and they all stop for boarding and alighting. This solution is suitable for shuttle operation with two vehicles or two groups of 2-3 vehicles. With more stations these have to be equally spaced so that all vehicles stop at stations. Vehicles come in several sizes for 30-140 passengers.

One cable may be up to 6 km round trip length. Hard wheels run on tube rails much like modern roller coasters. Speaking of roller coasters the guideway may ramp up to 20 %. That allows guideways to go down to ground level stations with short ramps. Speed is 36-50 kph. One important limitation is the curve radius - as large as 60 meters - making integration in existing cities difficult.

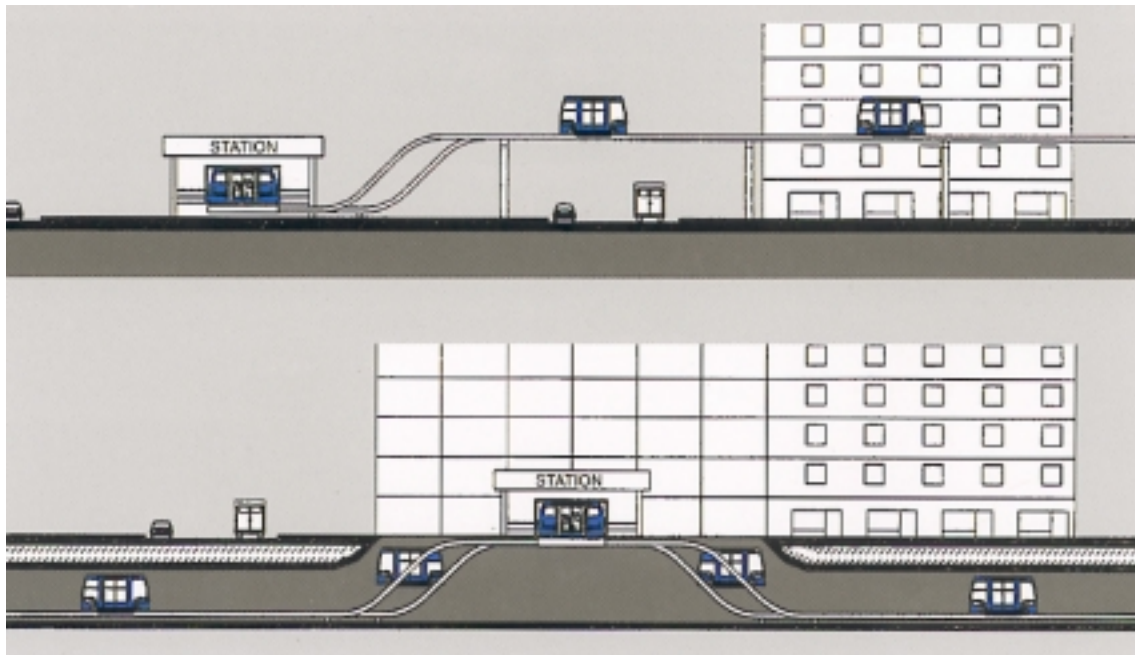


Figure 3.26. With steep ramps stations can be placed on ground

In a more advanced variant, called MiniMetro, the cable is driven at constant speed while vehicles detach at stations. Vehicles decelerate by rubber wheels of different speed mounted on the guideway. During boarding and alighting vehicles advance at creep speed. The stations can be located anywhere along the line.

There are neither switches nor off-line stations. That imposes a limit (30 seconds) to how closely vehicles can run without blocking each other at stations. MiniMetro vehicles can accommodate up to 50 passengers and speeds up to 30 kph. MiniMetro can negotiate curves down to 30 meter radius (which is still much) but not as steep ramps (15 %).

Vehicles may transfer between cable sections at standstill and switch on a turn-table.

Leitner has a test track for MiniMetro in Vipiteno, Italy since 1988 and are building a city transit system in Italian Perugia. The Perugia system is 3 kilometers - partly elevated, partly at grade and partly in tunnel. Public operation is planned for June 2002 with 7 stations and 25 vehicles, each taking 50 passengers.

3.8. Doppelmayr

Doppelmayr offer similar solutions as Leitner. Doppelmayr installations include a cable-propelled metro in Austrian ski resort Serfaus with vehicles hovering on air cushions. A shuttle train on rails was recently inaugurated in Las Vegas.

The smallest system of Doppelmayr is called CableLiner. 30-passenger vehicles depart at 24 second headway on a guideway up to 4 kilometers long. In addition to the two terminals the guideway may have 1 or 2 stations en route. Vehicles detach from the cable and slow down to

creep speed at stations allowing passengers, baby-carriages and wheel-chairs to get on and off. Turn-tables turn vehicles at the terminals. There can be no switches and all stations are on-line. Speed is 29 kph. Doppelmayr has a test installation in Wolfurt, Austria.



Figure 3.27. Doppelmayr CableLiner

3.9. Cable system with switches

I have described cable system even though they are route-bound without intelligent control. The justification for including them is the fact that cable links may be combined into networks with stations off-line. Then direct trips on demand would be a possibility.

It should be possible to switch a cable vehicle without stopping. Each vehicle would have two grips catching either of two overlapping cables in a switch. Guide-wheels would steer the vehicle through switches. Stations can be off-line where propulsion is by rubber wheels mounted on the guideway. Distance control is trivial when vehicles on the same link are fixed to the same cable. Merge conflicts can be avoided with synchronous control so that vehicles do not depart until there are free “slots” on all cables to the destination.

In previous research (ref. 14) we have proven that synchronous control may work even in large networks and at high demand. The weakness of synchronous control is the risk that a vehicle fails to maintain its planned speed. This risk is minimal in a cable system with vehicles pulled by a cable.

With switches and off-line stations one could build a true PRT system propelled by cables. Why is nobody doing that? Maybe it is difficult to change cable grips at speed. Cable

propulsion also seems to be difficult in narrow curves. In such curves propulsion would have to be by guideway mounted rubber wheels. There are systems (Mitchell Transit System) where all propulsion is by guideway wheels pushing vehicles along.

Cable propulsion ought to be cheaper than individual propulsion and control. Yet in known cases it is not. Leitner's price indication 6-7 million USD per kilometer is in the high end among PRT prices. My guess is that the higher cost is due to the larger vehicles leading to heavy and more expensive guideways.

3.10. RUF

The "RUF" acronym stands for Rapid Urban flexible and is the name of a Danish Dual-mode system. Its inventor Palle Jensen has been praised in several television programs and has received several awards.



Figure 3.28. RUF electric car for road and guideway



Figure 3.29. MaxiRUF for 10 passengers

The RUFs are battery operated cars designed to be able to run driverless in platoons on a monorail. RUF cars can be privately owned or rental and there will also be public vehicles for 10 passengers and wheelchairs.

The guideway is assembled from 20 meter sections of steel or fiber concrete. The cross section is triangular measuring about 0.9 x 1.2 meters.

RUF batteries are charged in ordinary power outlets and from power rails on the guideway. The off guideway range is 50 kilometers.

Switching takes place on flat surfaces where vehicles follow inductive loops. Speed is limited to 30 kph during switching, entering and exiting the guideway.

Maximum speed is 80 kph on roads and 200 kph on guideways. Capacity is up to 7200 vehicles per hour in platoons, corresponding to three highway lanes.



Figure 3.30. RUF guideway over street

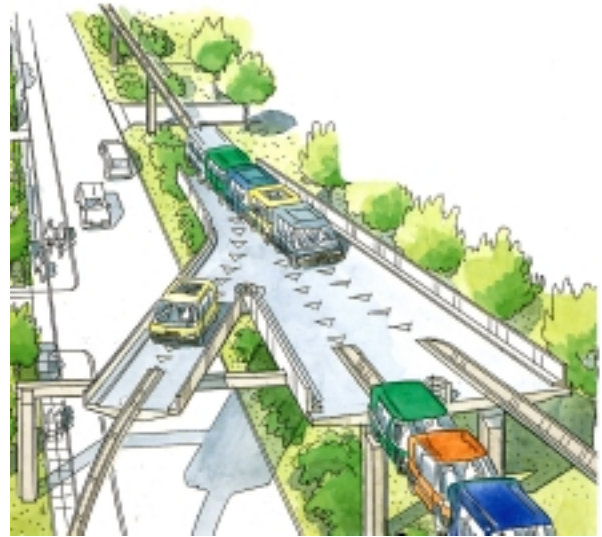


Figure 3.31. RUF switch and exit ramp

The RUF guideway is very slim except in switches where the monorail is widened into normal runway width. A course network does not need many switches. In my judgement switches could very well be placed at grade where they can be combined with possibilities for entry and exit.

The cost of a RUF guideway is estimated to be around 3 million USD per kilometer double track. Vehicles would cost about the same as ordinary electric cars.

A prototype vehicle and a test track have been built at the Danish Institute of Technology. A Danish consortium – RUF International – run the project supported by the Danish Ministry of Energy and the Environment. The RUF system has been well received by traffic authorities in Denmark. The CalMode consortium in Southern California endorse the RUF project. One of the cities looking at implementing RUF is Los Angeles (ref. 15).

4. Comparisons

4.1. System parameters

Important parameter are summarized in table 4.1 and commented on below.

System	Guideway	Switching	Propulsion	Pass. cap.	GW dim WxH m	dim LxWxH m	h.way secs	Time Theor cap. pph	Curve Speed kph	radius m	Grade %	Supp. spacing m	System cost MUSD
FROG	asphalt surfaces	steered wheels navigation	el. motor battery	10					30				2
Taxi2000	steel frames covered U-shape	mechanic on guide rail	LIM power rail	3	0.9x0.9	2.6x1.4x1.5	0,5-3	5400	32-80		12	18	3.5
ULTra	concrete U-shape or curb	steered wheels navigation	el. motor battery	4	2.1x0.5	3.4x1.5x1.6	1-3	7200	40	5	10	20	5-7
Austrans	steel rails for grip wheels	flexible rails	el. motor power rail	9	01.09	5.4x1.9x2.3	3	9000	18-120	8	20	20	12-15
SkyCab	steel/concrete covered U-shape	steered wheels induct. loops	el. motor battery	4	1.5x0.6	3.5x1.5x1.5	1,6	7200	36	20	10	12-30	4
FlyWay	steel beam suspended	guide-wheel in beam	el. motor power rail	5	0.7x0.9	3.3x1.7x	2	9000		8	10	38	7
Leitner/D-mayr	rails on steel frames	turn-table	el. motor cable	30 50		5.5x2x	24-30	4500 6000	22-30	30	15	10-30	7
RUF	monorail road/street	steered wheels induct. loops	el. motor rail/battery	4-10	0.9x1.2	3.5x1.7x1.6	0,5	8600	30-200	26	20	20	3 double track

Table 4.1. System parameters

Guideway

All systems have vehicles rolling on a runway except FlyWay with cabins suspended from under a beam and FROG running on asphalt. Guideway material is steel except for ULTra that has a concrete guideway. SkyCab can use either steel or concrete guideways. Austrans rails need a concrete bed for support. Taxi 2000 and SkyCab have their guideways covered with a narrow upward slot while the Ultra guideway is open. All guideways have openings for drainage of rain and snow.

Switching

The normal solution is for vehicles to switch and the guideway to be fixed. Austrans has a rail switch needing a longer time headway, which is compensated by larger vehicles and ride-sharing. FROG, ULTra and SkyCab have no switching mechanism and steer through switches by navigation or inductive loops respectively.

Propulsion

Most of the systems are propelled by electric rotation motors with energy from power rails or batteries. Taxi 2000 uses linear induction motors (LIM) without moving parts and independent of friction against the guideway. Leitner and Doppelmayr cabins are drawn by cables propelled by electric motors.

Passenger capacity

Some systems (FlyWay and Leitner) use more than one vehicle size. We have given the size most appropriate for demand-responsive operation. Vehicle capacities over 4 passengers are seldom filled when operated on demand.

Time headway

The smallest safe headway between vehicles is determined by speed, reaction time, braking power and comfort requirements. A common requirement is so called “brickwall safety” imposing that if one vehicle would somehow come to a sudden stop then the following vehicle must be able to stop in time to avoid a serious collision. In most cases the limitation on comfortable emergency braking is the one parameter determining the time headway. Therefore the time headway is essentially determined by speed and is independent of system solution. Safety belt or airbag would allow shorter time headways.

The time headway for Austrans is limited by the time to throw the rail switch.

Theoretic capacity

Theoretic link capacity is calculated from time headway and vehicle capacity. Practical capacity is considerably lower (about 25 % of theoretic capacity) due to empty vehicles (about 30 %) and average load. We assumed 2 seconds headway for Taxi 2000 and ULTra. They plan to use 3 seconds initially and then trim to headways below 2 seconds.

Speed

In most systems guideways can be designed for various speeds. Higher speeds require larger curves but they also mean shorter trip times and smaller fleet size. High speeds require longer headways and hence reduce link capacity.

Note that effective travel speed equals line speed when vehicles do not stop en route.

Curve radius

We have stated the minimum possible curve radius, often requiring reduced speed. Most of the systems can or could slow down in curves. All of the systems can or could bank in curves (more expensive guideway) allowing higher speeds with the same level of comfort. Suspended cabins bank naturally in curves without banking the beam.

Grade

All systems can handle 10 % grade. This is steeper than normal roads, which in turn can handle steeper grades than light rail systems. Taxi 2000 and Leitner MiniMetro can handle 15 % grade thanks to LIM and cables respectively. Austrans and RUF can handle as much as 20 % grade.

Spacing of supports

Often several values are given for the spacing between supports. The longer spacing requires reinforcements on the guideway increasing cost. The FlyWay beam was designed for longer spacing than the other systems. One practical limitation is the permitted length of vehicles for the transport of guideway sections to the assembly site.

System cost

System cost is presented as the total cost per system kilometer of single guideway, including stations, vehicles and control system in a typical mix. FROG runs on asphalt with simple stop shelters. The low cost for ULTra refers to a system with half of the guideway at grade while the high cost refers to a completely elevated system. Austrans costs are given for a system at grade or completely elevated respectively. The RUF cost is per kilometer double guideway but excluding vehicles.

Austrans vehicles are twice as big as most other vehicles and their guideway is about twice as expensive too. This is in line with the rule of thumb saying that guideway cost is proportional to vehicle weight.

For comparison a tramway line in Swedish Kungens Kurva was estimated to cost about 18 million USD per kilometer double track (ref. 16).

Analyses of social economy indicate that PRT systems can be socially profitable investments considering savings in travel times, congestion, pollution and accidents (ref. 17, 18 and 19).

4.2. Distinguishing features

Off-line stations

In order to compete with private cars it is necessary for transit trips to be on demand, along the quickest path with no stopping en route. Then stations must be off-line. With on-line stations trips would take longer and link capacity would also be dramatically reduced. Only terminal stations without through traffic can be on-line.

All the systems except the cable-propelled ones use off-line stations.

Passenger capacity

With trips on demand there will not be many passengers in each vehicle – only those who wish to travel together. Without ride-sharing we expect the same load as in a private car or a taxi – typically 1.2 passengers. With ride-sharing (ref. 3) in small systems it is possible to reach an average load of 2.4 passengers excluding empties. It is important for vehicles to be lightweight since that allows for slim and inexpensive guideways.

All *seated* passengers is a prerequisite for performance and safety during acceleration and braking. With *standees* emergency braking would have to be limited, time headways be increased, reducing link capacity.

Most of the systems have small vehicles for seated passengers (3-5 persons) and they can all accommodate a *wheelchair* or a *baby carriage*.

The larger vehicles of Austrans presuppose ride-sharing and some stopping en route (during peak hours) in order to be reasonably filled. Leitner and Doppelmayr cars must be large since they cannot run closer than 24-30 seconds.

Switching

With small vehicles it takes many of them running at short headways. Short headways are only possible with the switch in the vehicle and a fixed guideway. Then successive vehicles can switch in different directions without delay. A rail switch takes time to throw and approaching vehicles must be able to stop before the switch if for some reason it should be in the wrong position. Guideway switches mean longer headways reducing capacity.

All systems except Austrans have fixed guideways. ULTra, SkyCab and RUF have no switching mechanism at all.

Suspension beam or supporting guideway

Although PRT can run at grade (fenced in) and in tunnels, elevated guideways will be the

most common execution. Only FlyWay is suspended from a beam.

Beam suspension needs more sideway space since there must be swaying room against supports and other vehicles. Figure 4.1 in the next section compares the space requirements of systems.

The ride feeling hanging under a beam is different from that riding on top of a runway. Suspended cabins will bank naturally in curves and during acceleration and braking. That reduces forces on passengers but some people may perceive it as uncomfortable.

Stations at grade

FlyWay offers the possibility of lowering cabins at stations eliminating the need for elevators, escalators and expensive stations. Austrans can descend to ground level on short 20 % ramps. Leitner with fixed cable can manage the same grade, but not with detachable cable.

Curve radius

Curve radii larger than 20 meters are difficult to fit into existing street intersections. Road intersections have a minimum radius around 12 meters on the inner edge. Cars can turn on an outer radius around 5 meters.

The curve radius is normally limited by speed and comfort demands. All systems have the possibility to slow down and bank in curves.

Guideway-bound or Dual-Mode

In all systems except RUF vehicles are bound to their guideway. The ULTra guideway is designed to allow electric cars equipped for navigation and distance control. FlyWay foresees the possibility of carrying ordinary cars on hanging platforms.

Propulsion by cable or in vehicles

All systems except Leitner and Doppelmayr use vehicles with on-board propulsion.

Power rail or battery

ULTra and SkyCab are planned for battery operation with charging during standstill. The other electric vehicles use power rails in the guideway, often backed up by battery on board.

4.3. Comparative assessment of guideway systems

I have made a subjective assessment of relative strengths and weaknesses of each system. The results are summarized in table 4.2 and commented on thereafter.

	Switching networks	Travel standard	Weather resistance	Stations at grade	Curve radius	Visual impact	developm. resources	Swedish industry
Taxi2000			+			+		
ULTra			-		+		+	
FlyWay			+	+	+		-	
SkyCab							+	+
Austrans		-		+	+	-	+	
Cables	-	-	+		-		+	
RUF	-	+	+					

Table 4.2. Subjective assessment of strengths and weaknesses

Switching in networks

Leitner and Doppelmayr lack the possibility of switching at speed and so far are not suitable for operation in a network. RUF switching is made at low speed and the switches are bulky when elevated. You can choose to have fewer switches, placed at grade and combined with entries and exits. Since RUF vehicles can use ordinary streets the guideway network does not need to be fine-meshed.

Level of service

Austrans and the cable systems make intermediate stops. RUF is the only system offering direct trips door-to-door (for privately owned RUF vehicles).

Weather resistance

Taxi 2000 is independent of road friction thanks to magnetic propulsion and braking. FlyWay offers excellent protection inside the beam. The cable grips of Leitner and Doppelmayr are safe in all weathers (compare ski-lifts).

The open profile of ULTra requires snowplows on vehicles and/or guideway heating (very energy-consuming).

The SkyCab guideway has a narrow upward slot and a wide downward opening. Friction heat from dense traffic (running empty vehicles if necessary) may be enough to keep the guideway free from ice. During extreme weather conditions, operation may have to be closed off. It should be possible to arrange some mechanical emergency braking against guideway sidings.

RUF vehicles have a pinch brake around the guideway tearing off possible ice.

Stations at grade

Austrans can negotiate 20 % grade reducing barrier effects when the guideway is brought down at stations.

The FlyWay solution lowering cabins is the most elegant one, taking no extra space on the ground apart from the station itself. The up and down motions take time reducing station capacity. FlyWay can compensate the extra time with more loading births on sidings, costing space and money.

Curve radius

ULTra, Austrans and FlyWay can negotiate the tightest curves simplifying the integration in city environments. SkyCab too should be able to negotiate tight curves at reduced speed. In contrast cable systems are very poor at turning.

Visual intrusion

One important difference between suspension beam and supporting guideway is the elevation. A suspension beam has to be situated at least 2.5 meters higher than a supporting guideway with the same ground clearance. It can be argued which alternative causes the least visual intrusion. Figure 4.1 shows the visual intrusion of the various systems to the same scale.

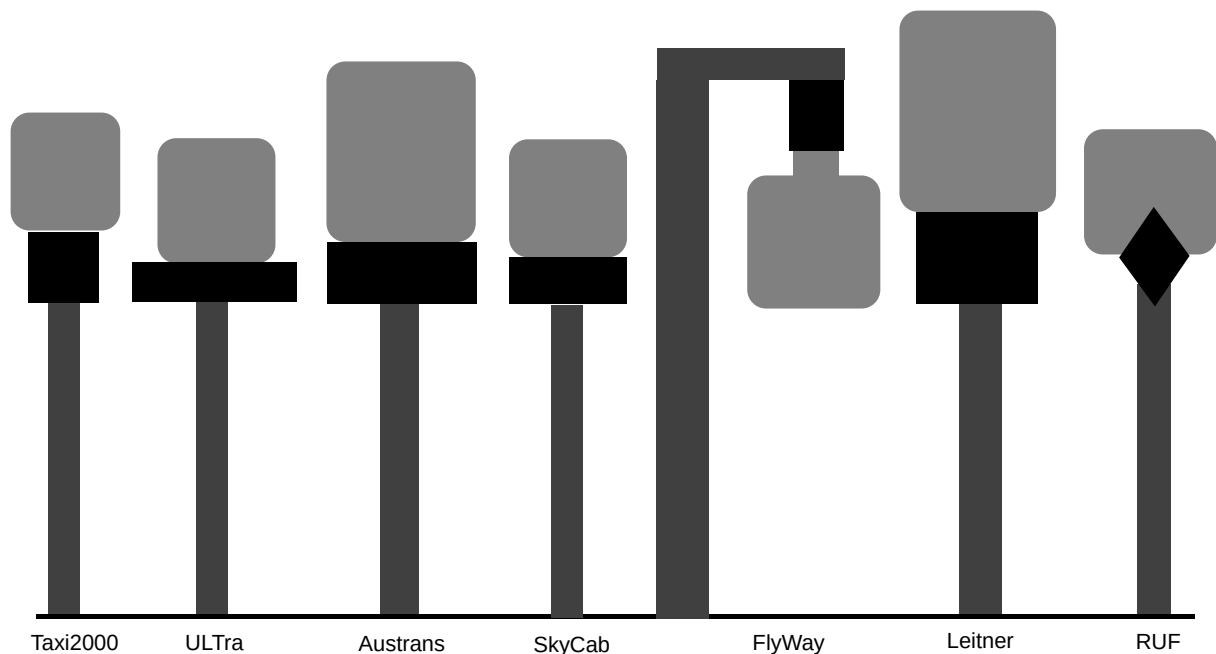


Figure 4.1. Profile of vehicles, guideway and supports

FlyWay, Taxi 2000 and RUF have the slimmest guideways. RUF switches (not shown) on the other hand are bulky when elevated. FlyWay supports are higher and thicker than the others.

The Austrans guideway is like a narrow-gage railway on a viaduct. Cable systems make the most intrusion with present cabin sizes.

Development resources

Cable systems are the most developed and proven in operation, except so far they lack switches.

Austrans has recently built a test track outside Sydney. RUF has a piece of guideway and an operable vehicle prototype.

ULTra has secured financing of a test track to be constructed during 2001. SkyCab has an industry consortium with sufficient resources once they decide to go ahead. Taxi 2000 is negotiating with financiers. Flyway is working with minimal resources awaiting a customer project.

Swedish industry

For us in Sweden it is interesting that FlyWay and SkyCab are Swedish products. SkyCab have gone furthest in committing Swedish industry.

4.4. Where do the solutions fit in?

Cable systems are suitable for shuttle operation over short distances. The cable technology is proven but cannot be extended into networks. One possible application would be the connection of building blocks within a hospital area.

PRT can be the only public transportation system in cities up to the size of Malmö, Sweden (population 250,000). Most bus and tramway lines can be replaced by PRT. As an example 2 seconds headway, 2 passengers per vehicle and 30 % empty vehicles give a link capacity of 2500 passengers per hour on a single guideway. There are hardly any bus or tram lines with higher passenger flows. With PRT, trips can be distributed over several links, increasing capacity and accessibility as well.

PRT can also supplement line haul services connecting between transit corridors or feeding to commuter trains and subway. In that way PRT may increase patronage on other transit inducing more people to leave their cars at home. A PRT network in central Gothenburg was estimated to increase transit ridership by 19 % within the area served. At the same time transit ridership in the surrounding region would increase by 10 % since some drivers would prefer to leave the car in favor of a combination of bus, tram and PRT (ref. 6).



Figure 4.2. PRT network for central Gothenburg

Another suitable application for PRT is local traffic in and around an airport between terminals, parking lots, hotels and offices.

Major business and entertainment centers can be made more attractive with pedestrian connections between different shops and parking lots. With parking off-side land is more

efficiently used and the area can be much more pedestrian friendly.

Dual-mode is suitable for corridors with capacity problems such as arterials leading into large cities. In Stockholm this would be true for all the major arterials, E4 from the north and south, E18 from the west and north-east, Nynasvagen, Varmdovagen and Drottningholmsvagen. Double tracks for RUF over the motorway divider would increase capacity with as much as three additional motorway lanes in each direction. The RUF guideway can be used only by RUF vehicles but it would be attractive even without a connected network.

ULTra guideways are built for PRT operation (network covering local areas) but may later accept other electric cars (equipped with precision navigation and distance control) and be extended into larger connected networks.

5. Continuation

5.1. Some pending applications

SkyCab together with Bernhardt Arkitekter have designed and analyzed a PRT system for **Linköping**, connecting the city center with the university campus (ref. 13). The first phase would include 21 kilometers of guideway, 25 stations and 100-115 vehicles.

SkyCab also designed a PRT network for **Arlanda** airport, connecting terminals, parking, hotels and offices around the airport to nearby Märsta center (ref. 21). The first stage network would include 44 kilometers of single guideway, 51 stations and 600 vehicles.

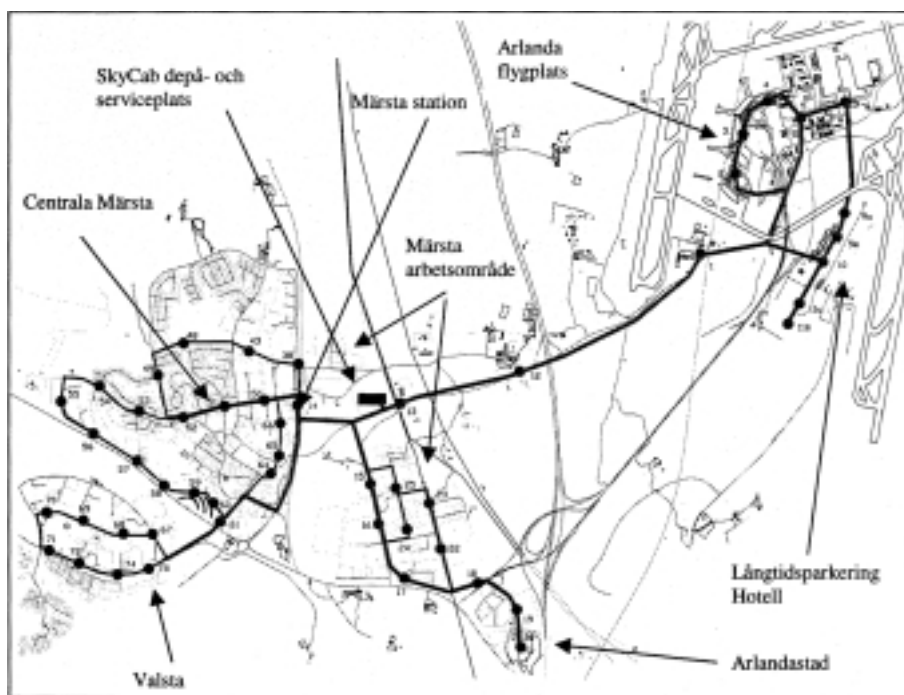


Figure 5.1. First stage PRT network for Arlanda-Märsta (copyright SkyCab AB)

On behalf of Huddinge Municipality, Transek analyzed alternative transit systems for **Kungens Kurva** outside Stockholm. A tramway line, one GRT loop or two PRT loops would feed to a nearby subway station (ref. 16).

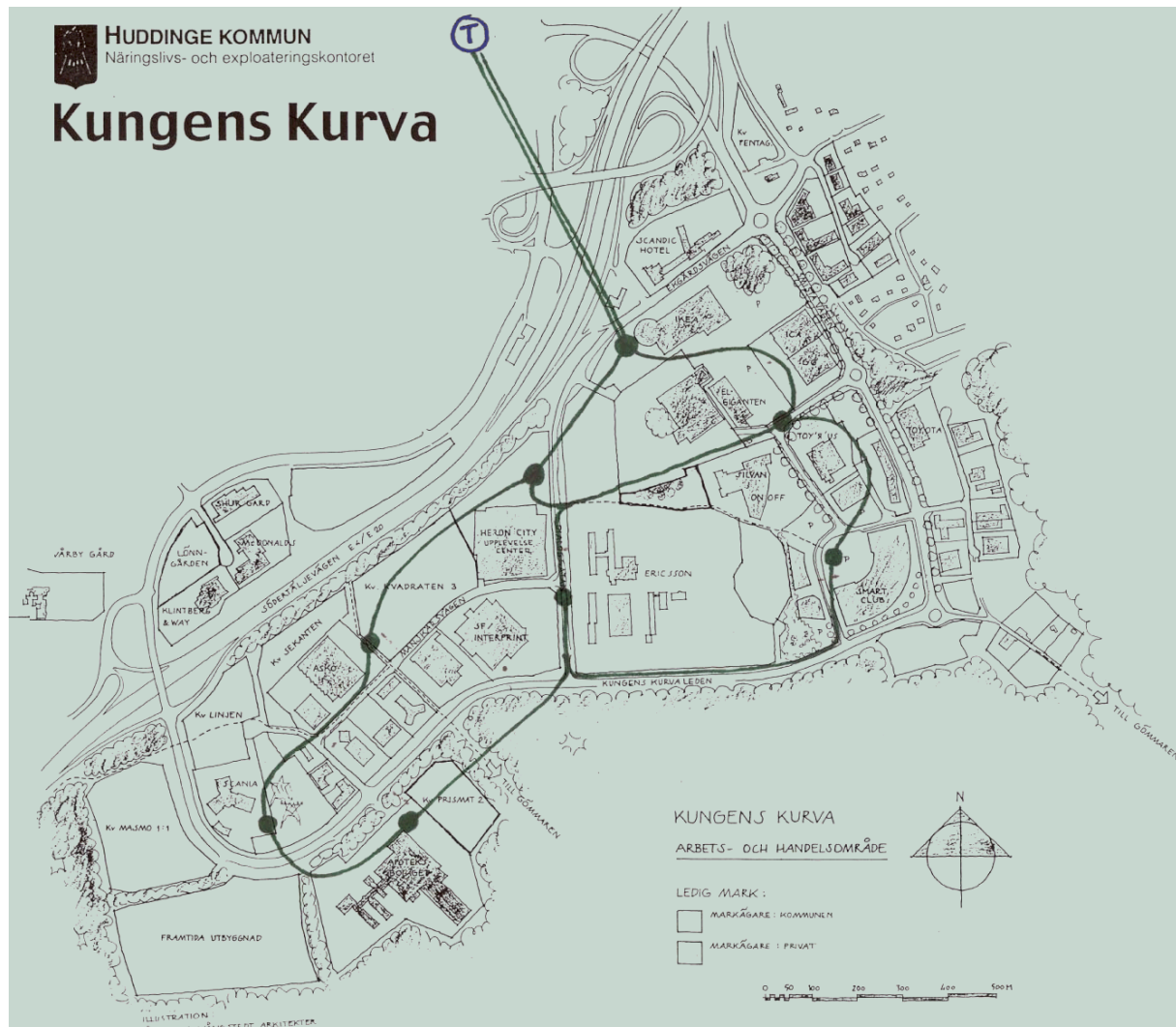


Figure 5.2. Proposed PRT network for Kungens Kurva (copyright Transek AB)

The former airport **Fornebu**, Oslo is being developed with high-tech industry, offices and housing. PRT has been suggested for internal communication and connection to Lysaker railway station.

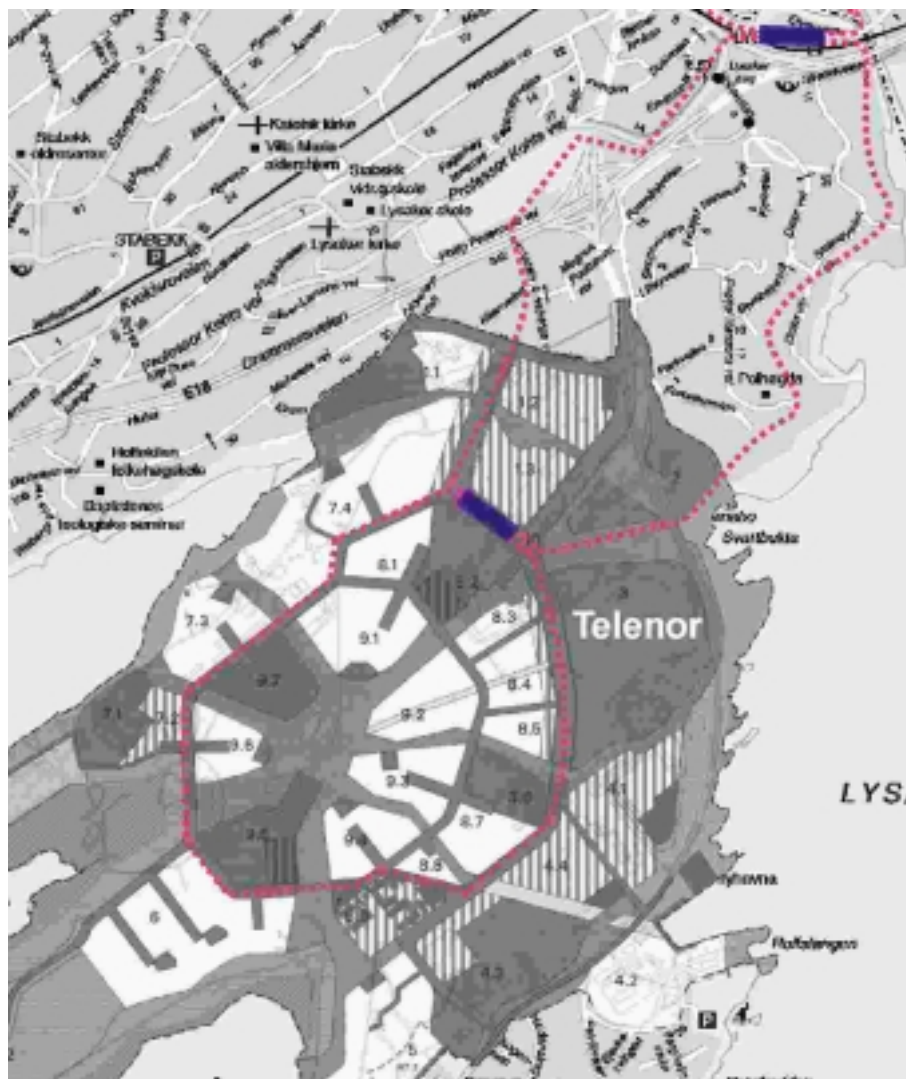


Figure 5.3. Proposed PRT network for Fornebu (copyright Arno Mong Daastol)

The RUF system has strong government support in Denmark and would be suitable for the congested arterials leading into **Copenhagen**.



Figure 5.4. RUF guideway for Copenhagen

The province government in Noord-Brabant, Netherlands developed an ambitious renewal program “Passenger transport for tomorrow” which was approved in February 1999. The stated goal is a PRT system for the capital ‘s-Hertogenbosch (ref. 22).

Cardiff City Council initiated a study to identify the most suitable area for an ULTra pilot system.



Figure 5.5. ULTra guideway for Cardiff

Singapore government commissioned Austrans and architects to design a transit system for the Buona Vista area.

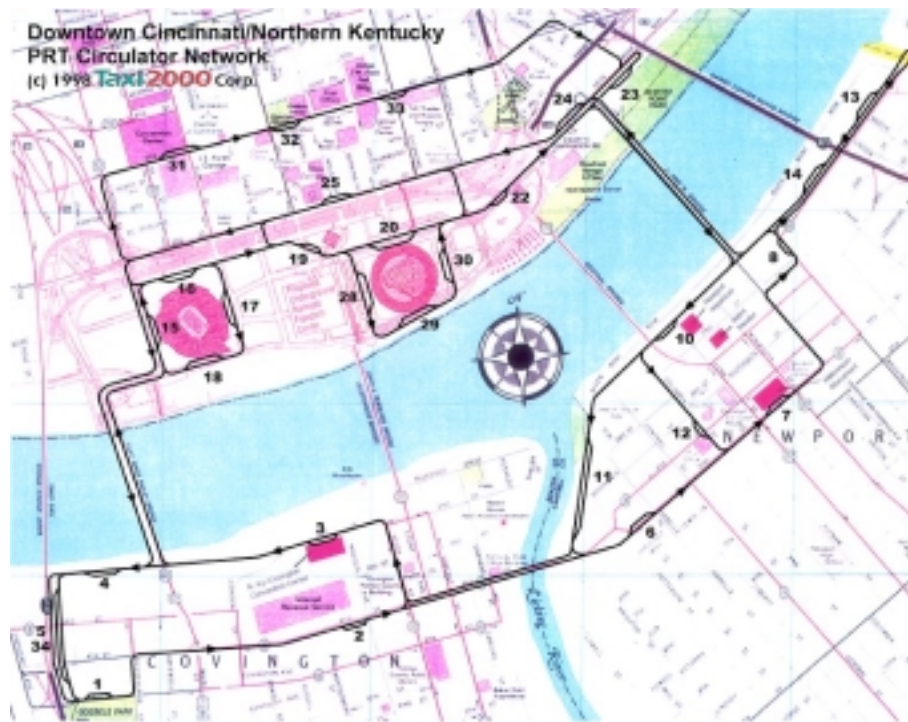


Figure 5.6. Guideway network for Taxi 2000 in Cincinnati

In **Cincinnati** Ohio the SkyLoop Committee selected Taxi 2000 as the most suitable guideway system for that city.

The professional organization Cities21.org (www.cities21.org) have developed a preliminary concept proposal “**Page Mill** Traveler Centered Transformation”. The Page Mill area is a part of Palo Alto in the Silicon valley owned by Stanford University. Some 23,000 employees work in major companies such as Hewlett Packard. Interest groups including employers, local government, transit operators and citizen groups would announce a design competition for a PRT system connecting the area internally and to a CalTrans commuter rail station. The first stage would include a 3 kilometer loop with 5 stations. The full system would be 8 kilometers with 18 stations and some 500 vehicles. A sample solution has been designed based on Taxi2000 technology. Potential suppliers would be invited to meet or improve the Taxi2000 solution. A request for proposals is planned for the spring of 2001.

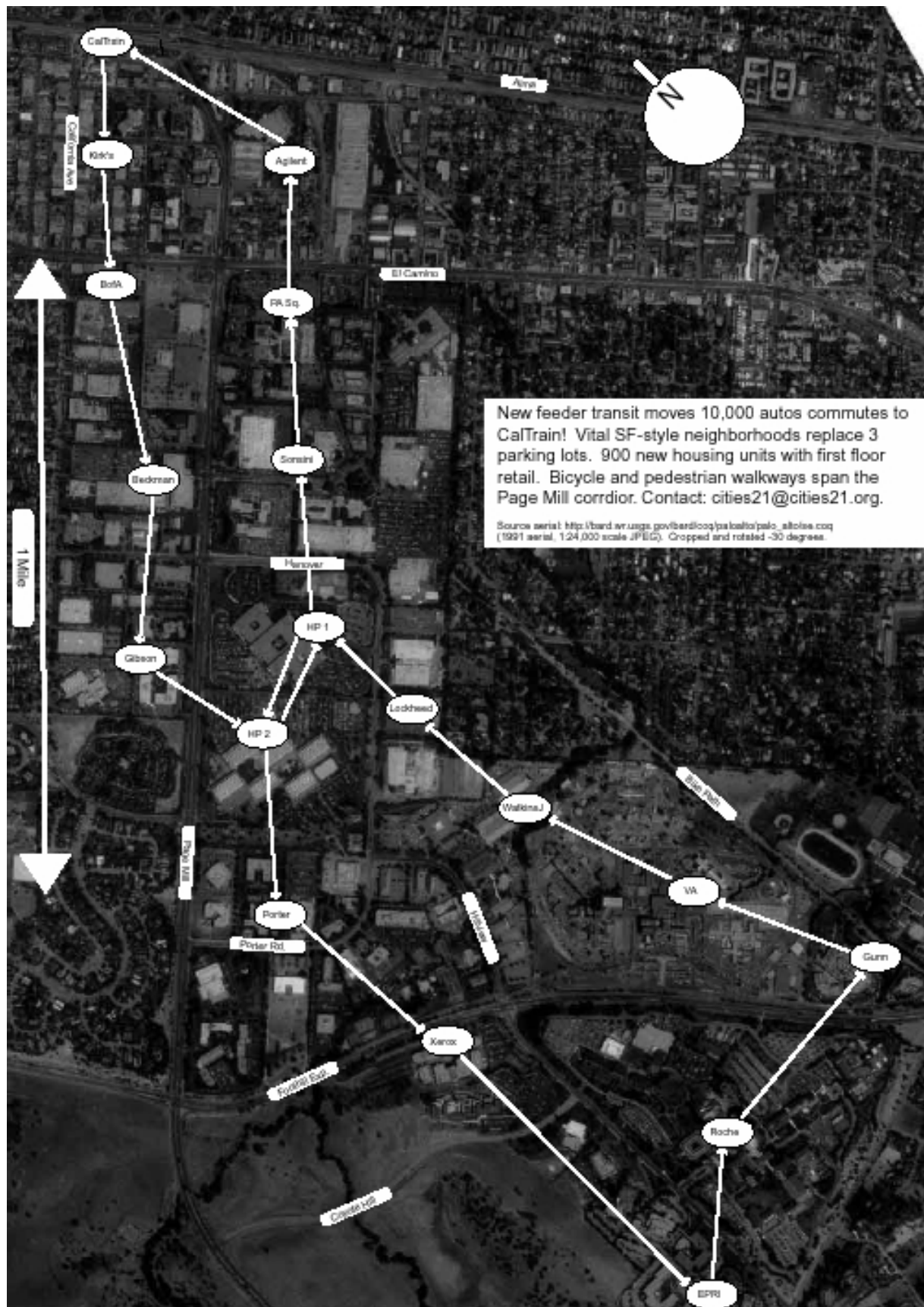


Figure 5.7. Proposed PRT network for the Page Mill area in Palo Alto (copyright cities21.org)

5.2. What next?

Each of the systems described in this report can be implemented to work successfully. Which of them will be the most successful may depend more on political decisions and financing than on technical merits and differences in performance. Regardless of who can first demonstrate a system in operation it will boost interest for the other systems too. Among PRT systems ULTra seems to be nearest implementation. Austrans with larger vehicles is also ready for commercialization. RUF is first on track (!) among Dual-mode systems. Cable systems have already been proven in shuttle operation.

Implementing any of the systems is a large investment even though they all cost less than a tramway system. With present restrictions on public spending it is important to identify other stakeholders benefiting from an attractive transit system.

Potential financiers may be owners of land to be developed and made attractive. With a superior transit system they can attract more tenants and/or charge higher rents. Other financiers may be business owners in a shopping area offering good communications to attract more customers. An airport authority can finance a transit system with landing fees and/or fares. No group of travelers puts higher value on time than airline passengers do.

Many cities follow these developments with a great interest but none before has taken the opportunity of being the pioneer. Most cities are waiting for someone else to first prove that the systems work in operation. Now that several developers are about to have test tracks and commercial operation, interest is expected to grow rapidly. At the same time uncertainty over technology, costs and benefits is reduced.

We are facing a development well suited for Swedish industry. Sweden is well equipped internationally within areas of competence relevant to innovative transit systems:

- + manufacturing of vehicles
- + tele- and mobile communication
- + automation and control
- + traffic analysis and –planning.

Unless we carry on development in Sweden we will be left to import systems developed in other countries. Good ideas cannot be stopped in the long run. The question is not if, but where and when the first innovative systems will be in operation. Then we will all wonder why nobody did it before.

6. Conclusions

The conclusions of this survey are the following:

- Present transit is not competitive
- Innovative systems offer many of the qualities of private cars
- ITS in car traffic can be applied to transit
- Direct non-stop trips on demand cut transit trip times to half
- Small-scale systems may replace buses and trams
- Several developments are ready for implementation
- The new guideway systems cost less than trams
- There are several suitable applications in Sweden
- Opportunities for development by Swedish industry

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Internet addresses

Systems developers

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www.aebishop.com/austrans
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Citizen groups

www.cprt.org
www.umunum.org
www.acprt.org
www.skyloop.org

Links to intelligent transportation systems

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