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Report on Technical Visit to Europe on Electronic Guidance Technologies

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- Rouen Regional Government (Agglomération de Rouen)
- Connex
- Siemens/MATRA
- Samenwerkingsverband Regio Eindhoven (SRE) (Regional government for Eindhoven, Netherlands)
- Advanced Public Transport Systems (APTS)
- TNO Automotive
- EVAG - public transit agency for Essen, Germany
- Connexxion
- ANT Consultants

FROG Navigation Systems

Abstract

This report documents the information collected by an FTA-led delegation to several European organizations that have had experience in the development and operation of transit lane assist systems based on three different technologies, including (1) optical guidance in Rouen, France, (2) magnetic guidance in Eindhoven, Netherlands and (3) mechanical guidance in Essen, Germany. It includes summaries of the briefings prepared by the European hosts in response to questions from the delegation, the discussions the delegation had with their hosts and observations based on riding the systems in public service. This report is accompanied by a CD ROM that includes the presentations given by the various hosts during the visit and pictures taken by the members of the delegation.

Keywords: Vehicle Highway Automation, Lane assist, electronic guidance, Bus Rapid Transit

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Lane Assist Systems in Europe

Report on Technical Visit to Europe on Transit Lane Assist Technologies

A delegation from the U.S. spent one week visiting European organizations that have had experience in the development and operation of transit lane assist systems. We came with a list of questions designed to help identify the most important similarities and differences between the needs of European and American transit operators for use of such systems, and to help us gain the benefit of their prior operational experience. The locations that we visited were using three different technologies for lane referencing, providing important contrasts and points of comparison, and they also had significantly different periods of operational experience.

The U.S. delegation members represented FTA and FHWA, as well as four different transit properties, plus the project staff from the U.C. Berkeley PATH Program and Mitretek. The complete list of delegates is attached as Appendix B, while the agenda for the visit is attached as Appendix A and the list of questions that were asked at the visits is Appendix C. This report is accompanied by a CD ROM that includes presentations given by various hosts during the visit and pictures taken by the members of the delegation.

The primary information derived from these visits is summarized below, in the sequence in which they were scheduled.

1. French DOT's Perspectives and Support on Electronic Guided Bus Rapid Transit

French Ministry of Equipment, Transportation, Housing, Tourism and the Sea (French DOT) has been a champion of the development and deployment transit guidance system. The delegation first met with the French DOT in Paris to learn the national perspective on application of electronic guidance technologies to Bus Rapid Transit.

1.1 Background

The French Ministry of Equipment, Transportation, Housing, Tourism and the Sea (French DOT) has the primary responsibility for development of new transportation technologies. Under a large research program Prédit, the French DOT committed to investigate innovative ideas for improvements of land transportation systems. The program focuses on both technologies and the organizational issues involved in the deployment and operation of advanced technologies. Prédit 1, which studied new technology solutions to transportation issues, was carried out between 1990-1994. The research included subjects related to high speed rail (TGV), automated subways, safe cars, and environmentally friendly vehicles. Prédit 2 (1996-2000) investigated technologies for goods movement and a wide range of technologies for urban transport options, including guidance, automated transport, car sharing, and micro-cars.

The Prédit 3 program (2002-2006) investigates new approaches to mobility behaviors, financing transport systems in light of recent national funding cutbacks, and provision of multi-modal information. This program has a budget of €305 million contributed by various public partners involved in Prédit. The projects are grouped into the following eleven areas:

- Mobility, Territories
  - Group 1 – Mobility, territories and sustained development
  - Group 2 – Services and mobility
- Security and Safety
  - Group 3 – New knowledge for security
  - Group 4 – Security oriented technologies
- Goods Transportation
  - Group 5 – Logistics and transport of goods
  - Group 6 – Technologies for goods transportation
- Energy, Environment
  - Group 7 – Energy and environmental impacts
  - Group 8 – Clean and energy-saving vehicles
- Technology Integration
  - Group 9 – Integration of information and communication systems
  - Group 10 – Vehicles and infrastructures: integrated developments
- Integrating Policies
  - Group 11 – Transportation Policy

Prédit 3 is organized to provide a nationwide perspective on the policies associated with the development and deployment of new public transportation systems and technologies.

1.2 Bus Rapid Transit (BRT) in France

Increasing the mode shift to public transportation is difficult, even in France, because in many cases public transport does not meet the needs of the people in the same manner as the personal vehicle. This can be especially so with bus transportation due to circuitous routing, resulting in indirect trips to an individual's destination. Bus Rapid Transit systems are seen as a means of overcoming this problem by providing a more economical mode than Light Rail Transit (LRT). Even including the incremental cost of the technology for guidance and exclusive lanes, the guided BRT system still costs much less than an LRT system.

Prior to 2002, the French Government financed public transportation infrastructure, providing 25-30% of the capital costs for bus system lanes, shelters, bus stop pads, and other infrastructure. Rolling stock was the responsibility of the local agencies. A new government structure was introduced in 2002, with a move to de-centralization. This resulted in the elimination of national assistance and shifted the responsibility entirely to the local governments. National taxes were reduced due to the reduction in funding provided, but local taxes have risen to make up the difference. This funding shift has caused local authorities to become more focused on efficiently spending their limited resources on transit improvements.

BRT systems were proposed, based on assumptions that the vehicles would cost the same as traditional transit buses. Guidance is considered for precision docking and reduction of infrastructure costs, buses operate in exclusive lanes, and the level of service is comparable to LRT systems. Traditional bus systems cost two million euro per kilometer (€2 million/km) for a bus and the associated infrastructure improvements, so the goal was set for a BRT system to cost no more than seven million euro per kilometer (€7 million/km) including vehicles, stations, lanes, and guidance. BRT operations on highway shoulder lanes were also considered, but have not been deployed to date.

1.3 Government Support for the Development of Electronic Guidance System

Guided bus systems were developed under the Prédit 2 program. The main motivation for use of lane assist technology in France right now is a recent law requiring handicapped accessibility of buses within ten years, which in turn is generating demand for precision docking. Equally important, the government has set a goal of using bus lateral guidance to allow Bus Rapid Transit to provide LRT-like quality of service at lower cost ($7 M vs. $15 M per km for LRT). However, the Ministry representatives noted that LRT is currently “fashionable” in France despite higher costs, so buses are generally not supplanting LRT initiatives. This is particularly notable since funding for capital costs of transit systems is now completely decentralized in France, with no subsidies from the national government.

The selection of computer vision technology for bus guidance was based on the ability of a domestic supplier (MATRA, since acquired by Siemens) to provide it, without any formal evaluation relative to other alternatives. Snow was not considered to be a significant problem because it is quite rare in French cities (typically only a light snowfall a few times per year). The “worst case” tolerance at speed including turns was considered to be five centimeters (5 cm). A safety margin of forty to fifty centimeters (40-50 cm) is built into the systems to allow for system failure recovery.

Certification of automatic guidance systems in France requires satisfying the codes for both highway vehicles and for guided vehicles (such as automated people movers).

The increased cost-consciousness of local transit authorities will shift the focus of BRT guidance technology deployments from new vehicles to retrofits of existing fleets. Systems will need to move from focusing on “fashionable” new vehicles to continuing to use their current rolling stock. The government’s goal is to have guidance systems retrofitted on exiting rolling stock for three thousand Euros (€3 K) per bus, which is much less than the cost of customized new vehicles, but it is not clear whether that is a realistic or achievable goal. Research is also being conducted to add improvements to the currently available guidance system, so that it could potentially be extended beyond the current precision docking application in Rouen to use along the entire bus route by 2007.

The Ministry sees a serious need for outreach to local government officials, to educate them about the opportunity to use precision docking to improve accessibility of their buses. Additional benefits, such as reductions in stopped vehicle time, narrowing of lane widths, and driver assistance are considered above-and-beyond this accessibility goal.

Although only one current project in France is providing lane guidance on buses between stations (for a limited distance in Clermont-Ferrand), future projects are expected to extend capabilities in that direction.

1.4 "On Tires" Light Rails, Economic Point of View

Public transport investments in France have tended in the past toward modes that were considered "more fashionable" than other modes. This trend led to the shift from streetcar transport to bus transport, with the removal of much of the streetcar track and infrastructure, similar to what was seen in many United States cities. The trend then shifted from bus to light rail, with heavy investment in exclusive right-of-way, rails, stations, tunnels, and other related infrastructure. The rail transport systems are more expensive and do not provide greater benefits than buses, according to a Ministry representative, however they have been the mode of choice and have had greater public acceptance.

The TEOR service in Rouen, France is good example of a BRT system providing equivalent service to LRT but at a great reduction in cost. Both LRT and BRT systems have been deployed in Rouen, allowing a direct side-by-side comparison of capital investment and operating costs.

The LRT system was the first to be installed in 2001. Rouen sought to expand the system and accepted bids for this extension but found the cost to exceed available funding resources. The city then decided to construct the new lines using BRT.

The costs of right-of-way, construction of the guideway, stations, and ticket-vending facilities are the same for each mode. Rail, however, has added costs associated with rails, customized garage and maintenance facilities, energy distribution system, rolling stock, and engineering. Both systems were built under bids that included a complete reconstruction of the associated corridor including surrounding vehicle travel lanes, stations, signals, and vehicles, so specific costs associated with each element cannot be provided. It was found, however, that the cost per kilometer of the BRT was forty percent (40%) less than that of LRT. The cost of overhead catenary wires to provide electrical power to LRT vehicles in the corridor served by TEOR was equivalent to eighty (80) articulated bus vehicles.

A side-by-side comparison of bus and LRT costs in Rouen (which has both types of systems) showed operating cost advantages for buses, based on lower maintenance for both vehicles and right of way, and even larger cost advantages when the capital costs were annualized, as shown in the table below:

	Annual Operating Costs	Total Annualized Costs (Includes Amortized Capital and Operating Costs)
Non-guided Buses	€6,700,000	€18,000,000
BRT TEOR Guided Buses	€6,750,000	€24,000,000
LRT	€8,000,000	€32,000,000

It is noted that driver costs for BRT are more than LRT, however overall operational costs for BRT are less than LRT. Maintenance cost for LRT is estimated to be four to five (4-5) times the cost of BRT, mostly due to the limited number of vendors and customization of parts. The City of Rouen considers annualized costs of their investments, which include operating costs plus capital investment amortization at eight percent (8%) over sixty (60) years.

Financing issues will still need to be addressed for deployment of future systems and expansion of existing ones. The recent shift from national to local funding has resulted in local authorities placing more emphasis on economical solutions while the riding public is used to more “luxury” systems that were subsidized by the national government’s capital cost funding. Around sixty to seventy percent (60%-70%) of the riders are youth and students, so using farebox recovery to pay for “luxury” infrastructure puts too great a burden on a typically lower income rider.

2. Optically Guided Bus in Rouen, France

Optical guidance system has been deployed in Rouen, France for a number of years. The delegation visited city of Rouen and met with Rouen Regional Government (Agglomération de Rouen), the transit operating company Connex and the technology developer Siemens/MATRA.

2.1 Background

MATRA, the French aerospace company (which also has experience in automated guideway transit and railway control systems), developed the optical guidance system for the CiViS bus, which is now also being used on another bus, the Agora model from Irisbus. MATRA was subsequently acquired by Siemens. The optical guidance system is currently being used for precision docking in Rouen, but in Clermont-Ferrand it is also being used for lane guidance between stations on a relatively short section of track (about 1 km). Rouen has been a pioneer in deployment of the Siemens/MATRA precision docking on its TEOR bus services, representing three east-west bus lines with high passenger volumes.

The Rouen urban area has a population of about 400 K, and the local bus system serves 163 K passengers per day. Of this total, 30 K passenger trips are on the TEOR lines, the BRT services which have precision docking. The overall farebox recovery ratio for the system is about 40%. The main efficiency measure used by the transit authority is the number of passenger trips per vehicle kilometer. The values of this measure for the three primary transit modes are 10.67 for the LRT system (part of which runs as an underground Metro service), 4.13 for the TEOR buses and 1.76 for the remaining buses.

The capital costs of the system are funded by multiple layers of government agencies, but the operations are the responsibility of a private concession operator, Connex, who are paid based on their ability to provide the quality of transit service specified by the public sector sponsors. This visit included a briefing and rides on the optically-guided buses, as well as rides on the LRT system that provides north-south trunk transit service in Rouen.

2.2 Application

The TEOR BRT service was initiated after the costs for a new LRT service on the intended route became too high (twice the amount budgeted). It was still initiated as a comprehensive project analogous to LRT, involving the complete curb-to-curb reconstruction of the streets on which it runs. This provided for one or two bus-only lanes in most places, with a distinctive pavement color based on use of red aggregate in order to discourage ‘normal’ drivers from trying to drive in the bus lane.

The system planners believed that it was important to provide both enhanced image and improved quality of service (trip time and reliability) in order to attract new choice riders. The en-route trip time and reliability improvements are mainly associated with use of traffic signal pre-emption (at most intersections, except when crossing national roads) and with the use of one or two dedicated bus-only lanes. These are estimated to save 6% of the overall travel time, while the precision docking is estimated to save another 4% of travel time, but it is not clear how much supporting data are available to back up these estimates.

The system was designed to emulate LRT as much as practicable, including similar station designs and spacings (500 m) and even the use of a similar-sounding bell-like alert to warn passengers about imminent door closure. They stop and open doors at all stations and operate on similar headways to LRT.

2.3 Experience

System costs are generally estimated per route kilometer, incorporating the costs of both vehicles and infrastructure. They estimate that their guidance system adds a cost of about €500K ($650 K) per kilometer, which is less than 10% of the total cost of €6.3 M ($8.2 M). By contrast, an LRT system would cost €15 M to €20 M per km ($20 to 26 M) in the same environment.

Since the start of precision docking service in 2001, the TEOR system has performed a total of over 5 million docking maneuvers. Although no formal study has been made of the dwell time savings from precision docking, the MATRA representative offered an off-the-cuff estimate that former dwell times of 40 seconds were being reduced to the range of 15-20 seconds in Rouen. Although there have been some failures, none of them have led to movement of the bus outside the prescribed "safety envelope".

The speed limit for precision docking approaches (typically, 40 km/h) is painted on the pavement upstream of each station to remind the drivers of this limit, since the drivers are completely responsible for controlling bus speed. The speed limit marking was required as part of the certification process, but the system owners and operators do not see any need for automatic speed control of the buses to limit the docking speed.

Rouen chose to replace the originally-planned CiViS buses with more conventional Agora model buses after testing the first two CiViS buses. They had problems primarily with the CiViS' hybrid propulsion system, particularly regarding poor fuel economy and reliability and high acoustic noise levels.

At some stations, the guidance line follows a complicated trajectory, with built-in overshoot. The design of the layout of the guidance line requires some sophistication, including use of a computer simulation of vehicle response, and is a significant cost item associated with system implementation. It starts upstream of the stop, and needs at least 20 m of straight line prior to the stop in order to allow the articulated bus to straighten out so that all door openings are close to the platform.

When drivers start to work on the TEOR lines, they have a 5-day training period to adjust to the new vehicle and guidance system, as well as to learn how to activate the signal pre-emption system. Both the TEOR drivers and the LRT drivers are required to drive a regular bus route for one week of each 12-week schedule period in order to ensure that they maintain their driving, and especially their docking, skills.

Figure 1. Optically Guided TEOR in Rouen

Surveys of passengers have shown comparable levels of satisfaction among passengers on the TEOR bus lines and on the LRT system, which was one of the primary goals for the system. Surveys of the bus drivers have also found them generally favorable to use of the guidance system, especially in the locations where the dedicated lanes are available to segregate them from other traffic. They find it more convenient than doing the docking themselves and it also relieves them of some workload so that they can interact more with the passengers. Bus drivers also say that it helps reduce their level of stress. They believe that it improves their vigilance by letting them devote more attention to their surroundings, rather than low-level vehicle maneuvering. As drivers have become more comfortable with the guidance system, they have even begun to ask for extensions to the guidance lines to help them exit stations with complicated geometry or with difficult maneuver profiles. Based on limited questioning of drivers during our visit, they appear to like the lane assist system as it is now for docking, but do not seem to be interested in seeing it extended to use between stations. However, Siemens plans to provide continuous lane guidance between stations by 2007 in Rouen and Bologna. Siemens believes that the distinctive paint stripe markings that serve as their guidance reference can be continued through intersections without necessarily confusing drivers because they are no more visually distracting than trolley tracks, which are frequently encountered through intersections.

Even though the precision docking helps speed up passenger boarding and alighting, the full potential of this cannot be gained because of the need for passengers to queue up at the ticket validation machines near the doors. Political difficulties have impeded the development of a new national fare collection system in France, which could ultimately reduce the bottlenecks associated with fare collection and validation

Figure 2. TEOR Precision Docking at Bus Stop

Siemens said that the vision based guidance system does better than the driver at detecting the guidance lines under bad lighting conditions because of the low mounting height of the camera and the use of sophisticated filtering, but they noted that it still has a few problems. The system sometimes can not engage when the sun angle is low and pointed toward the bus, as well as in the special condition of glare off wet pavement. The drivers do not have any indicators of how far along the platform to stop the bus, which led to some of the drivers over-shooting the platform on our demonstration rides and stopping so far forward that the platform edge was already receding from the curb line, leaving a larger than intended gap for passengers at the front door. There are only a few snowy days per year in Rouen, and drivers are advised to turn off the system when it is snowing. The guidance system occasionally experiences failures. When it fails, the driver is informed and will take over and control the bus. The transit operating company conducts fault diagnoses and replaces components under most circumstances.

French cities use asphalt pavement rather than concrete, regardless of the density and weight of the traffic on that pavement. Along the TEOR route, there was noticeable pavement rutting at several stations, after 4 years of service. They are not concerned about this, but said that they expected to replace the top 5 cm layer of pavement after 7 to 10 years. At one station, the city said that the paving was not done correctly and they are pursuing the contractor to replace it. The painted reference stripes on the road surface need to be cleaned off periodically and then repainted annually, according to the public agency people (although Siemens/MATRA refers to it as annual “refreshing”). They use a template to improve the accuracy of the painting.

The Siemens/MATRA guidance system is provided with a 2-year warranty, after which replacement parts are offered through a service contract. The system is expected to continue in service for ten years before needing a major overhaul, so that one major overhaul would be contemplated within the 20 – year typical operating lifetime of a bus. The on-site regular maintenance work is done by the maintenance staff of the transit operating company.

2.4 Observations

Rouen has successfully implemented the optical guidance system for precision docking, while choosing not to apply it for the broader capability of automatic steering between stations. They are expanding the TEOR services, with the major investments associated with reconstructing the streets for smoother running surfaces and separated bus lanes where there is sufficient room. In their TEOR system as a whole, the major service improvements appear to be in the provision of newly constructed bus-only lanes and the traffic signal pre-emption, rather than the precision docking.

3. Phileas: Magnetic Guidance Based Advanced BRT Vehicle

The city of Eindhoven in the Netherlands is developing and deploying an Advanced Bus Rapid Transit System, Phileas, in collaboration of Advanced Public Transport Systems (APTS) and Frog Navigation Systems.

3.1 Background

Samenwerkingsverband Regio Eindhoven (SRE) is a regional government body in the Eindhoven region comprising 21 municipalities with a population of about 700,000, and has the lead responsibility for deployment of the Phileas guided bus -- 'tram on tires' or advanced Bus Rapid Transit. This is being done in cooperation with their local transit operations contractor, Hermes, and the developer of the bus, Advanced Public Transport Systems (APTS- a subsidiary corporation of VDL Group BV), a local company. A large group of public agencies and a few private entities contributed resources totaling €115 M (about $150 M) to development of a demonstration project to serve two goals -- to improve local public transportation and to provide a stimulus to the local vehicle industry – by testing a guided bus system. The major contributors included:

- National government – €48 M
- Province – €2 M
- Municipalities – €45 M (mainly for infrastructure)
- European Union economic stimulus program – €9 M
- Transportcom (bus company) – €11 M

These costs included the design and construction of a 15 km concrete track in the median of existing roads (in the process reconstructing those roadways from curb to curb), the development of a completely new bus, starting from a clean sheet of paper, and the acquisition of twelve of those buses. The system was designed to be the functional equivalent of an LRT system, but using rubber tire vehicle technology. It was implemented as part of a broader local transportation policy that also includes increasing the cost of parking tickets and encouraging bicycle usage for access to and from stations.

The project began in 1993 with the planning for the western/new growth district of Eindhoven and the official start of the demonstration project commenced in 1999 with an order for 12 Phileas vehicles. The public (customers and bus drivers) was involved (through focus groups) on the selection of the exterior and interior design. SRE utilized an economic development framework for creating the Phileas BRT system. This comprehensive approach included a completely new vehicle design, re-configured infrastructure and ROW and a public policy and logistics component. The framework for the BRT system and the comprehensive scope of the project dictated the decision to test lane assist/electronic guidance technology.

The primary transportation goals of the Phileas project were to provide circulation with regularity and punctuality. Secondary goals included improved service frequency, speed, reliability, flexibility, and comfort, with an ecologically sound and a modern design. It is unclear if the lane assistance technology was introduced to accomplish a primary or secondary goal of the project. However, the lane assistance technology is an integral component of the intelligent vehicle concept that allows for the vehicle location, speed and stops to be tracked. The expectation is that the guidance features would enhance safe operation of the vehicle as well.

The buses were gradually introduced to public service last summer, without the guidance function. Up to seven vehicles were operated for up to 16 hours per day, and in October the guidance function was implemented with considerable public fanfare. By the end of November, all of the Phileas buses were removed from public service for upgrades, based on a variety of reports of needed improvements. They are expected to be gradually re-introduced to service starting in February, but the guidance function will not be reinstated until at least another three or four months. Our group was fortunate to get a special demonstration ride on one of the buses during our visit, despite their having been withdrawn from public service.

3.2 Application

The eventual application is intended to be a network of busways serving the Eindhoven region, but the initial line is 15 km long, connecting the Eindhoven airport to the central downtown railway station neighborhood, passing through a variety of residential and industrial neighborhoods. The Phileas bus was designed to provide this service, but also to help revitalize industry in the region. The design of the bus is unusual in a variety of aspects, including not only the lane assist system, but also:

- Alstom series hybrid propulsion system, with electric drive motors at each wheel except for the front axle, and regenerative braking (in the future it could be replaced by the Allison parallel hybrid, with only the rear-most axle being powered)
- battery energy storage sufficient to propel the bus for 3 km without the engine
- independent active steering of all axles
- completely low floor
- lightweight, modular composite body structure constructed by Fokker, with 18 m and 24 m versions (total body weight for 24 m version is only 4700 kg)
- automatic speed control
- Interior image – doors on both sides, adaptable, suspended furniture
- customizable exterior shape (initial design chosen by the Eindhoven region).

The combination of the lane assist system with other innovative features makes this a particularly complicated system to study.

The Phileas electronic guidance system is based on an intelligent vehicle that ‘knows where it is’ using magnetic markers embedded in the road surface every 4-5 m (13-16 feet). The magnetic guidance allows the vehicles to operate at maximum allowable speeds within the city (50 kph) and up to 70 kph under most weather conditions. Although lateral guidance was designed throughout the corridor, the dimensions of the vehicle travel lane were only narrowed modestly from the standard width to allow for standard buses to share the dedicated ROW. The electronic guidance is designed to allow for precise station docking.

Figure 3. Phileas Bus in Eindhoven

The guidance system is applied within the most ambitious operational concept of any of the systems we visited, involving use of both semi-automated (automatic steering) and fully automated (automatic steering and speed control) modes. Automated mode allows for full electronic control of the vehicle's braking, throttle and steering mechanisms. Semi-automatic mode controls the Phileas' steering while the driver controls the throttle and brake. These automated modes were applied not only in the dedicated bus lanes in the medians of the roadways, but also in mixed traffic while negotiating rotaries between sections of dedicated bus lanes.

The development of the Phileas bus represented an investment of about €40 M ($52 M), of which €4 to €5 M ($5.2 to $6.5 M) was associated with the adaptation of the FROG magnetic guidance system for use on the bus. The initial purchase of buses for use in Eindhoven was for twelve of the 18 m articulated buses. The cost of the buses was not broken out explicitly from the costs of the complete demonstration project, but APTS quoted approximate purchase prices of €1.1 M and €1.34 M ($1.43 M and $1.74 M) for the basic 18 m and 24 m buses respectively.

The vehicle has undergone numerous tests, including the guidance system at speeds up to 75 km/hour. The claim was made that magnetic guidance ultimately will be more reliable and cheaper to implement than optical guidance, although no specific cost figures were available.

3.3 Experience

A distinct characteristic of the Phileas system is that it was developed locally and entirely from the ground-up. Although costly, this approach has merit in the ability to effectively brand a new type of modern transit service that is competitive with light-rail and/or streetcars in terms of comfort, performance and costs. The hybrid propulsion system on the bus is expected to save about 30% energy consumption compared to a conventional powertrain. The ride quality is equal to and in some ways superior to that of light-rail/streetcar vehicles. In terms of noise, the Phileas claims to operate more quietly than a streetcar (although no noise studies have been done to prove this yet). However, starting and stopping still show the vehicle performance to be less smooth than a rail car. It should be said that current performance in this category is noticeably better than competitors and once the electronic guidance technology is more fully developed, the Phileas could match rail technologies in this area.

The electronic guidance system was chosen in order to provide precision docking at stations and enhance ride comfort between stations. It also enabled a modest reduction in lane widths on the busway, from the normal 7.2 m width for a pair of bus lanes to 6.6 m here (accommodating a bus that is 2.55 m wide). However, that busway is currently being used by conventional buses without lateral guidance providing normal public service, so clearly they can also be driven within that width of lane. The guidance system is not designed to directly follow the path defined by the sequence of buried neodymium magnets, which are 30 mm long, 15 mm in diameter and installed 4 to 5 m apart. Rather, the path is defined by multiple manually-steered drives along the track to identify where the drivers drive, and that trajectory is then smoothed out to reduce jerk. According to the transit operator, this trajectory smoothing is not yet perfected and still requires another 3 to 4 months of adjustments before the buses can be returned to automatic service. There is also one section of track with a large amount of reinforcing steel that distorts the magnetic field of the guidance magnets, leading to some ride roughness (both lateral and longitudinal).

In the automatic mode, the bus follows a pre-defined speed trajectory to stop at each station. When the bus operates in the automatic or semi-automatic mode, all stops are programmed as in a tram, and the driver cannot skip stations. The bus does not have any buttons for passengers to request a stop, nor does it have door opening buttons, because the doors always open automatically at the station. When the road conditions are slippery, the semi-automatic mode can be used to provide automatic steering, but the driver must then control the speed.

The Phileas bus uses an all wheel steering design with each axle of the bus being steered independently, using a triple-redundant computer system, based on measurements of lateral displacement at that axle, in order to emulate LRT tram steering along a track. This independent steering makes it possible for the bus to do a "crab steering" lateral motion to dock at each bus station, requiring less approach distance than a conventional bus to line up all doors parallel with the platform. The all-wheel steering also provides high maneuverability, to the extent that the bus developers claim that it drives like a car rather than a bus, and that the drivers do not take full advantage of its handling characteristics until they learn it well. On the approach to the Eindhoven Airport, it successfully negotiated a very tight turn. The developers cite a turning radius of 11.8 m to the outer side of the bus.

The defined positioning tolerances are 1 cm at stations and 5 cm at a speed of 50 km/h. The gap at docking stations was reported to be 6 cm, but when we rode the bus it appeared to be more like 10 cm, which is larger than shown on videos of vehicle tests. The larger gap appears to represent an additional safety margin, but once the system is proven reliable, the nominal gap could be reduced to the 3 cm range.

Figure 4. Phileas Bus Docks at a Station

The electronic guidance system can only be used at speeds up to 45 km/h on the public route in Eindhoven, but the bus can be driven manually up to 85 km/h. When the bus enters the guideway equipped with magnets, it needs to read about 100 m of magnets in order to recognize its location and activate the guidance function. If the bus deviates from its intended path by more than the 25 cm maximum tolerance, it will be automatically shut down (described as “electronic wall”).

Traffic signal pre-emption (emulating tram operations) and automatic vehicle speed control are used to maintain schedule times. If the bus gets ahead of schedule, the speed control system can slow it down accordingly, and the speed control appears to be integrated with the signal pre-emption system, although the specifics of how that works were not discussed.

The Driver Vehicle Interface uses a text display that identifies the current mode of driving (manual, semi-automatic or automatic), as well as the distance to the next station and time ahead of or behind schedule. Kill switches to disable the automation functions are in a console to the driver’s left. Driver training was reported to take about one day, but there did not appear to be as formal a training program as in Rouen. No special measures are taken to ensure driver vigilance while operating in the fully automated driving mode. The drivers are expected to operate more like tram drivers than bus drivers, which may require some more fundamental shifts in their culture and training. Drivers responded most positively to the specially designed cockpit for operating the vehicle.

The comprehensive nature of the project required significant R&D efforts and has greatly added to the complexity of the BRT project. The complexity of the vehicle has led to a number of issues that still are not fully resolved. These included a variety of problems not directly related to the guidance function such as doors occasionally popping open by about 5 cm while the bus was in motion, engine shutting down unexpectedly, loss of hydraulic steering assist when the engine dies (severely restricting maneuverability of the bus), and difficulty starting the engine. Releasing the vehicle into public service before the technology was fully operational proved to be problematic. The Phileas project has received negative press in the region and as a result, was perhaps pressured into taking all of the vehicles off the road simultaneously until the problems could be resolved. The perfection of the guidance system (responsibility of FROG) is taking longer than expected.

The automation functions did not require any special certification for road use in the Netherlands, where the certification authorities were comfortable assuming that the driver remains fully responsible for the operation of the bus. The certification process is 90% paperwork, and does not involve any testing. The manufacturer provides a 2 year warranty on the Phileas bus, and the bus body has a 20-year warranty.

3.4 Observations

The Phileas operation in Eindhoven was the most audacious application of vehicle guidance that our delegation encountered, in that it included fully automated driving along most of the route, including in mixed traffic at rotaries (where it has priority for right of way, but not exclusive use). It was also a remarkably ambitious undertaking from the broader perspective, in that its sponsors committed $150 M to a demonstration

project in order to determine whether it could be successful. This is equivalent to what we would call a Field Operational Test in the U.S., rather than a full deployment of a mature technology.
When its functions were all working, the Phileas bus displayed excellent performance. However, it is not yet fully debugged. During the demonstration ride, there were two occasions when the bus clearly encountered problems, the driver reported an error message on the display and the propulsion and power steering systems were shut down. There are questions about whether the inherent complexity of its design will make it possible for it to be sufficiently reliable and easy to maintain for transit operators to accept it on a broad scale.

The project also clearly demonstrates the advantage of a smooth running way in achieving a quality of ride comparable with rail. It was unclear to some how significant an impact the lane assist technology had on the ride quality throughout the corridor, because in sections where the pavement had not been improved, ride quality was negatively affected.

The cost and complexity of the Phileas vehicle is the biggest drawback to transferability to the U.S. market. Given that the vehicle is still in a demo project status, perfecting the outstanding problems is needed before transit agencies would likely be interested. The potential is there, however, given the attractiveness and many desirable features the vehicle potentially offers. However, the developers of the Phileas bus noted that they do not have any additional firm orders for vehicles, although they are under consideration for orders for another 10 to 15 units in other cities. If the Eindhoven network is built out to the full extent originally planned, it would use a total of 50 buses. The bus manufacturer needs a minimum of 7 to 10 vehicle orders per year in order to remain viable, so there are questions about whether they will be able to survive. With the completion of the initial Eindhoven order, they are vacating their current office and assembly facility in Eindhoven and relocating a skeleton staff to the site of a sister company to await the next order. They stated that in order for them to participate in the U.S. market they would need to make some (unspecified) adaptations to the bus and to find a marketing partner in this country. They are also concerned about the more difficult liability environment here. Their strategy in Europe is to market to cities that are oriented toward trams rather than buses, because they want to be considered as a more cost-effective rubber-tired equivalent to conventional trams rather than an expensive bus (compared to the normal price of about €400 K ($520 K) for an 18 m articulated bus in Europe).

The magnetic guidance concept is an attractive feature that holds promise for the U.S. market because it can be used for all weather and a variety of operating conditions. Because Eindhoven’s design of the busway considered the dual use by both guided and manually driven buses, the benefit of operating the bus on narrow lanes was not apparent, though one can envision that this benefit would be substantial if the narrow lane design is applied.

4. Safety Assessment and Certification

The delegation met with TNO in the Netherlands to learn about safety certification issues related to guidance technologies.

TNO Automotive is a part of TNO, the largest research company in the Netherlands employing a total of 5000 people. TNO Automotive has been developing a uniform approach, called “Integral Safety of ITS,” to apply to safety assessment and certification for both fully automated and partially automated vehicle control systems, recognizing the need for an approach that is simple enough to be practical to apply, but that also accounts for the inherent complexity of automated vehicle systems. This complexity includes challenges based on:

- control partly taken away from the driver
- complicated input/output relationships
- tightly integrated systems
- impossible to do simple tests on systems this complex
- there are no accepted certification standards.

TNO has developed a certification approach that follows the following principles:

(a) System safety must be incorporated in the initial system design. A safety critical system design that does not consider safety requirements at the early stage will make it difficult to achieve safety goals.

(b) Define an accepted safety goal, based on risks that people are already willing to accept. TNO’s philosophy on defining a safety goal for automated systems is to design vehicle control systems as safe as necessary rather than as safe as possible in order to make the system affordable and they believe that a completely safe system design, even if can be achieved technically, will make the system overly complex and unaffordable. Therefore, the safety levels of existing transportation systems have been referenced. In Europe, the current fatality rates of existing automobile, bus and train systems are 6.4, 6.4, and 3.0 per 1 billion traveled kilometers respectively. TNO recommends that the fatality rate be twice as good as that of current road traffic for new automated systems, which translates into no more than 3 fatalities per 10^9 kilometers of vehicle operation.

(c) Analyze system using standard methods such as failure mode effects and criticality analysis (FMECA), and identify the likelihood of occurrence of failures of various levels of severity, focusing primarily on the failures that could cause fatalities. TNO has defined five levels of severity and five levels of likelihood of occurrence for each, and has put them into a matrix, in which each cell has a numerical entry showing the acceptable level for that combination of severity and likelihood.

(d) Establish if the system meets the acceptable safety level through analysis of typical operating conditions, considering the expected mean time between failures. It is important that the evaluation enables assessment of the system as a whole, not just components.

(e) Check compliance by means of technical tests, preferably not on public roads (which would require government permission).

It is recognized that some stages of the evaluation and certification process are dependent on analyst judgment, so it is not possible to make them totally objective. However, if multiple independent analysts go through the process in parallel, their respective subjective biases should be cancelled out and the results could be accepted as objective. TNO hopes that the industry establishes a 'code of practice' for safety assessment and certification for automated systems.

Systems that successfully pass the review through this approach could be issued a TNO certificate of compliance, but it was not clear what the liability consequences would be for TNO if a certified system produced a fatality. Current European laws require a driver to be in control of any vehicle operating on public roads. It is also not clear what are the liability implications if the system is under full automated control and the driver is not given adequate response time to intervene in the operation when a failure occurs. In private locations, laws regarding driver-in-control would not apply (such as the driverless people movers at Schiphol Airport, the Rivium business park near Rotterdam or the Floriade flower exhibition).

5. Mechanically Guided Transit Buses in Essen

Essener Verkehrs, AG (EVAG - public transit agency for Essen, Germany) is the first to deploy mechanical guidance system for transit buses on dedicated busways and the system has been in operation since 1980. The delegation visited EVAG to learn their knowledge and experience on the mechanical guidance.

5.1 Background

Essen, Germany, is a medium-sized city in the Ruhr Valley, with a population of about 600,000 people. The city was born out of the coal-mining and steel production industries, similar to Pittsburgh in the U.S. but today the heavy industry is no longer in existence. Its population is aging and the community is decentralizing. Approximately 120 million passengers a year are carried by public transport in the Essen region, with half the passengers carried by bus and half carried on rail. The transit usage of 125 trips per year per inhabitant is in the medium range for Germany. Within the central part of the urbanized area, all homes must be within a five-minute walk of a transit stop and for the entire region, they must be within a ten-minute walk.

EVAG, the public transportation system in Essen, operates a network of streetcars that has been in operation for 110 years. The city also operates 230 buses which provide bus service to neighboring cities. In the ‘90s low-floor LRT was introduced. The city is converting its streetcar lines into LRT lines as finances permit. In the heart of the city, the LRT lines are underground. Currently there are seven streetcar lines (total of 80 vehicles) of one-meter gauge and three LRT lines (total of 50 trains) of 1.43-meter gauge with high platforms.

Guided buses were introduced in the early 1980s on former streetcar lines, at a time when streetcars were “out of fashion”, representing a form of “modernization” that could be implemented within the existing right of way. Up until that point, the federal and state governments funded 90 percent of the costs of construction of urban rail services. The poor image of the streetcar resulted in the state adopting a policy to replace the existing streetcar routes with heavy rail services on higher-volume lines, while lower volume lines were being converted to bus services. Consequently, the state funding priority moved towards heavy rail lines. With the narrow rights of way in the city, the city needed a technology that allowed buses to be operated in a limited right-of-way. EVAG viewed a demonstration project of new bus guidance technology as an alternative way of upgrading the streetcar routes in order to provide improved customer acceptance and image.

EVAG researched both the wire guidance and “O-bahn” mechanical guidance concepts developed in the 1970s by Daimler Benz. EVAG chose to use mechanical guidance over electronic (wire guided, using electromagnetic induction) because of its simplicity and the fact that it did not need an independent mechanical back-up system for safety purposes. The electronic technology available at the time, which was field tested in Fürth, a suburb of Nürnburg, required active electric current in a buried wire, which introduced a significant maintenance challenge and a single-point failure mode. Essen was the first operator to use guided buses in Germany and, since it was a transportation technology research and demonstration program, 75 percent of the project funding was from the German Ministry of Research and Technology. The construction took approximately six months and the system began operation in September 1980. Since the 1980s, the city established a total of four guided bus routes, including the 1.4-kilometer route Fulerumer Strasse to Wickenburgstrasse in the southwest of the city, the 0.9-kilometer Wittenbergstrasse to Stadtwaldplatz in the south of the city, the 3.9-kilometer Dortmunder Strasse, a median- running system on the A40 Autobahn to Kray, and a 3.0-kilometer section running through the central tramway tunnel. In 1997, the guided bus line that operated underground in a tunnel shared with streetcars was converted back to streetcar-only operation.

The current buses are articulated Mercedes, between 8 and 12 years old, already representing replacements of the original guided buses. Some of the original buses had dual propulsion systems, with diesel propulsion for use above ground and electric trolley propulsion for use in tunnels, but these were found to be too heavy and expensive so they were sold off. They currently operate 15 two-axle guided buses and 31 three-axle articulated guided buses.

EVAG does not expect any expansions to the current guided bus system because light rail and streetcars are now back in fashion and will therefore be selected for any future upgrades of bus lines to higher levels of service.

5.2 Application

The Essen guided buses have three pairs of guidewheels; one at the front axle, one at the middle axle, and one on the rear section, connected to the main body of the vehicle. The O-bahn guideway is made of prefabricated concrete track sections installed atop concrete “sleepers” (like railroad ties), which are on a specially constructed foundation. The track sections have an L-shaped cross-section, with a curb that is 18 cm high, to serve as the running surface for a horizontally-mounted guidewheel. The width between curbs is 2.6 m for use by a 2.5 m width bus, and the guidewheels are installed to tight tolerances so that they are slightly “squeezed” between the curbs, maintaining contact on both sides of the bus. The maximum speed for guided operation is 75 km/h, but the same technology is used in Adelaide, Australia up to 100 km/h. The cost of the vehicle-related guidance equipment accounts for approximately 3% of the purchase cost of a standard bus. Construction costs for the running ways for the guided buses are comparable to those for a streetcar. Since its operation, there has been little maintenance needed on the tracks. Because the system uses buses, the legal requirements for light rail don’t apply.

5.3 Experience

Essen has had longer experience with guided buses than any other city, and they were able to share some important lessons learned from that experience.

5.3.1 Guideway infrastructure

Figure 5 Automated Guided Bus at Essen

The construction of the busway needs to be done to tight tolerances, and poured-in-place concrete was judged to be insufficient, leading to poor ride quality. Steel guidance rails and asphalt paving were also judged to be insufficiently smooth. The busway geometry includes some fairly complicated curve sections, with overshoots beyond the expected trajectory of the bus. The prefabricated sections are six to eight meters long, and are either straight or in a limited number of constant-radius curvatures, generally without spirals. Transitions between sections sometimes involve steel side rails if they do not fit one of the standard profiles.

The main drawback of mechanical guidance is the need for the curb, which makes it unsuitable for pedestrian areas and is a problem in areas with a high number of driveways and other curb interruptions. To accommodate pedestrians, the guidance curbs are designed to have gaps for pedestrian crossings up to 4 m wide. If a larger gap is needed, such as at a street intersection, a tapered entrance section is needed for the bus to re-enter guidance, at a speed of about 30 km/h. No ride quality problems were observed associated with the initiation of guidance at these locations.

The tight construction tolerances mean that the cost of busway construction was found to be essentially the same as the cost of track construction for a streetcar line (exclusive of the electrification costs). This means that this form of bus guidance does not have the lower infrastructure cost advantages typical of electronic guidance systems. However, the guideway has required negligible maintenance during its 25 years of operation.

Figure 6 A Close Look at Guiderail

Busway running surface maintenance only appears to involve repair of the edges of the individual prefabricated elements, at the expansion joints. These repairs are done with a concrete filler that cures over night or over a weekend when the busway is removed from service.

The delegation members observed variability in the quality of ride when we rode the bus on the busway in the freeway median, with some sections being noticeably rougher than others. In the rough sections, the vibrations appeared to be associated with the joints between prefabricated sections, which are 6 to 8 m long.

5.3.2 Vehicle modifications

The modification needed to the bus for this form of guidance is merely the attachment of guidewheels to the axles of the bus. The front axle guidewheels are used to steer the bus, while the guidewheels on the trailing axles are used to keep those tires from scuffing against the curbs. These experience significantly higher forces, and therefore higher wear, than the front guidewheels. The bus cannot be driven in reverse on the guided track, because the guidewheels do not provide correct steering guidance and the driver would be fighting their effects, leading to potential derailment of the bus. EVAG has not tried bi-articulated buses on the guideway because this would require active steering of the rear axle. The current buses use old technology axles. The last buses were ordered for this system in 1989 with conventional axles.

Figure 7 Guide Wheel

The guidewheels are not expensive, but there is currently a problem finding an axle manufacturer willing to approve the installation of the guidewheels without voiding the axle warranty. EVAG does not expect this problem to be solved until after 2008 because until that time the bus manufacturers are preoccupied with developing new propulsion systems to meet stricter emissions regulations.

5.3.3 Operational and safety issues

In earlier stages, EVAG experimented with in-track switches, but found them too complicated. Therefore, the switches are now all open sections, where the driver steers to one side or the other. There was one instance in which a driver crashed into the gore point of the open switch. Because of the tight tolerances on the guideway and vehicles, the docking at stations is achieved with very small gaps (5 cm).

The most common form of failure is breakage of the guidance arm if the driver hits a curb with it at a normal bus stop. This is most likely to occur with the sweep of the rear of the bus as it departs the stop, but still only occurs once or twice a year. The guidewheels are designed to run at about the same height as the curb in the guideway (18 centimeter curb). When buses are running in normal streets, the curbs (13 centimeters high) can be problematic if the driver makes contact with a curb in an unguided section. The guide arms have a small cut which acts as a weak point for the guide wheel to break off without damaging the entire guidance arm or the axle. A cable is attached in order to retain the wheel in case it breaks off.

Environmental factors can also impact the system operation. A potential, but rare, problem is the buildup of compressed snow of 3 cm or more, which could potentially cause a bus to climb above the guide rail. EVAG removes snow from the track by putting a snowplow on a service vehicle, which can also be used to spray salt on the running surface.

If a bus breaks down on the busway, a service vehicle needs to fetch a towbar, which the following bus can then use to push the failed bus. This is reported to take about 15 minutes, but such breakdowns have been infrequent.

One of the big issues in introducing the system was concern about the effects of a tire burst on a guidewheel. To overcome this, the guidewheels are not inflatable, and a safety wheel was installed inside the rubber coating of the guidewheel, enabling the vehicle to safely drive out of the guideway section. A similar safety feature is used on aircraft. EVAG also undertook tests to determine the effects of obstacles in the running way; which proved not to be a problem.

The system has a very good safety record, with only one serious crash in the 25 years of operation history. The crash was attributable to the guidance system, when the improper substitution of an experimental aluminum guidance arm for the normal steel guidance arm led to the guidance arm breaking while the bus was in operation, causing the loss of steering control and derailing of the bus.

There are no special training courses for drivers, who are informally trained by going out on the guideway with an instructor. No special certification was required for operation of the system. A survey of drivers in 1981 indicated that over 95% of drivers experienced no difficulty using the guideway. The bus was classified as a normal road vehicle because it has a steering wheel and is able to operate on normal streets, and the guideway was classified as a private road rather than a public road because other vehicles are not permitted to use it. Exceptions had to be granted for the extra vehicle width produced by the protrusion of the guidewheels on the side and for the extra length and weight of the original dual-propulsion buses.

5.3.4. Maintenance

The trailing axle guidewheels typically last about one year, with exceptions if the wheel breaks off due to hard contact with the curb. The only special maintenance actions needed on the vehicles are visual inspections of the guidance arms to check for cracks, and checking the rubber rings on the guidewheels for wear.

The gauge of the guidewheels is 2.605 meters, which is slightly wider than the 2.6 meter channel. This provides a snug fit for the vehicle and ensures that guide wheel contact on both sides of the vehicle is maintained. Maintenance of the guideway has been minimal, however expansion and contraction at the joints between the sections has resulted in cracking of the concrete. These fractures in the concrete have not caused any long-term problems and have been easily repaired.

5.4 Observations

The guidance technology for the Essen application seemed appropriate at the time it was implemented. The guided buses took advantage of old streetcar right-of-way, and were able to fit within the space available. The locations selected for the guideway application are in areas where the curbs do not disrupt left turning traffic or other vehicle maneuvers. However the need to accommodate access and auto turns limited the application to those discrete sections of the bus route. The need for a vertical surface is the major drawback of the system; however this same surface also provides a form of safety barrier should the vehicle try to veer out of control. The mechanical linkages are easy to repair and no additional staff are required. Although the vehicle cost and complexity are modest, the tight tolerances on construction of the guidance surface make the infrastructure costs significantly higher than the electronic guidance systems, comparable to the cost of streetcar tracks.

The O-Bahn busway in Essen provides accurate and reliable guidance for its buses, but it does not have the flexibility or smoothness of ride of some of the more modern electronic guidance systems. The “bumping” over the joints was clearly discernable, although this may also be partly attributed to the age of the vehicles used for the system.

The mechanical guidance technology developed 25 years ago has demonstrated effectiveness for its designed purpose. The most remarkable experience about the guideway system is the lack of wear and tear on the running surfaces. These surfaces have been exposed to constant bus traffic for 25 years and there were no visible signs of deterioration. Nevertheless, the city of Essen decided not to expand its applications. Worldwide, the technology has only been adopted in a few other locations in Australia and the U.K. in the past 20 years.

6. Magnetic Guided BRT and People Movers

FROG Navigation Systems developed the magnetic guidance system used on the Phileas bus and the Park Shuttle automated (driverless) people movers. The delegation visited GROG in Utrecht, Netherlands.

6.1 Background

The company was started 20 years ago, and its primary products and experience have been automated guided vehicles (AGVs) for industrial applications including factory automation and automated freight transport systems. The company moved into people moving applications in recent years, which they noted are much more challenging because of issues of ride comfort, passenger safety and customer acceptance.
The company name is an acronym for “Free Ranging On Grid”, which is their approach for defining vehicle paths based on a grid of fixed reference markers. Their original reference markers were Texas Instruments radio frequency transponders, but since 1998 they have been developing systems based on permanent magnets, which are cheaper, last longer, permit higher operating speeds, require much smaller sensors on the vehicles, and use less computer power. Typical FROG guidance systems are designed based on (1) mapping layout (routes, obstacles and stopping points are programmed in the on-board computer of the vehicles), (2) odometry (measuring the steering angle and counting wheel revolutions to calculate the positions on the map) and (3) calibration (comparing the calculated position to the actual position by means of the reference points, e.g. magnets embedded in the road surface).
FROG designs vehicles and their control systems and integrates systems on the vehicles, but they do not do the mechanical work of vehicle assembly. They have about 70 employees. They have a modular system design with a “FROG box” that is used for lower-level control of vehicle functions, regardless of the type of vehicle (from factory or warehouse AGV to container carrier in port, automated people mover or bus), but with parameter adjustments to accommodate the vehicle differences. They also have a supervisory control system for monitoring vehicle status and traffic conditions, which they call “Super-FROG”. Their overall design philosophy is based on putting relatively more intelligence on the vehicles and less in the infrastructure, because they believe this makes it easier to control, maintain and upgrade the system, so that even changes in vehicle routing can be accomplished as software updates.

6.2 Applications

The initial people mover application by FROG was the Park Shuttle driverless vehicle guided using TI radio frequency transponders, which they began developing in 1995 to provide shuttle service between a subway station and a business park called Rivium in a suburb of Rotterdam (Capelle an der Ijssel). A similar vehicle was demonstrated at Demo ’98 in Rijnwoude, NL, and then put into public service to provide “horizontal elevator” shuttle service in one of the parking lots at Amsterdam’s Schiphol Airport. These vehicles were prototypes with room for only 10 passengers, and operated for almost 7 years, but have now been withdrawn from service. Those operations provided useful experience on issues of passenger comfort, safety and reliability.

FROG has also implemented automation for 4-passenger Yamaha golf carts that were used to carry passengers at the Floriade flower exhibition outside Amsterdam in 2003. That experience showed that golf carts designed to drive 20 km per day on average were not robust enough to provide continuous transit service. The guidance system for the Floriade was an inductive cable follower because it would have been too expensive to install the grid of magnets that FROG would normally use. The inductive cable follower system was vulnerable to shut-downs because of static electric charges associated with nearby thunderstorms.

In addition to the Phileas bus system described in an earlier section of this report, FROG has also developed a second-generation Park Shuttle driverless people mover, six of which will be put into service at the Rivium this summer. These vehicles have 12 seats and can carry up to 15 passengers, in a more robust design than the first generation.

6.3 Experience

The FROG experience is subdivided into three categories, for generic experience with vehicle guidance, followed by more specialized experience with guided buses (Phileas) and with automated people movers (Park Shuttle).

6.3.1 General guidance experience

FROG's experience is that selection of sensing technology is the most critical step in developing guidance technology. They experimented with various sensing technologies. In the mid 90's, FROG developed the people mover system based on Texas Instrument's radio transponders. However this approach was abandoned because of the size of the antenna needed on the vehicle, the cost and limited lifetime of the transponders, and their limitation to low-speed vehicle operations (because of computational complexity). FROG later worked with their French partners to implement a wire guidance system on Yamaha automated people movers and found that the wire guidance system is significantly impacted by lightning. They disfavored GPS because of concerns about reliability and availability, but noted that it could be used to supplement another technology (not, however, as the primary guidance reference). They did not think that a vision based guidance system was sufficiently reliable. FROG later switched to magnetic guidance for their people mover products. They prefer the combination of magnets and mapping, which is their approach, but they noted the need for generally-accepted standards in order for this to become widely adopted. When asked about safety issues involving electronic vehicle guidance, the response from FROG was an in-depth explanation of the advantages of magnetic guidance over other technologies.

FROG's reference magnets for vehicle guidance are installed within an accuracy of 5 cm, but are then surveyed after installation to identify their actual locations to within 2 to 3 mm. The survey for a one-kilometer demonstration track in Antibes last year took one day. The vehicle is driven manually along the desired path several times, and its position relative to the magnet locations is recorded. These recorded trajectories are then smoothed to reduce jerk in order to produce the final desired reference trajectory that the vehicle is commanded to follow. This trajectory smoothing function appears to be one of the current problems in the Phileas installation in Eindhoven. The actual vehicle positions are estimated primarily by odometry (counting wheel rotations), and calibration corrections are applied based on the measurements of position relative to the reference magnets. This is used to continuously update the calibrations to eliminate errors associated with changes in tire radius (from tire inflation changes, for example).

Figure 8. Automated Park Shuttle People Mover

Guidance system performance requirements have been defined jointly with customers, but the driver interface and legal requirements on the systems have been defined by the customers. For example, the widths of the guidance path as compared to the vehicle are defined differently for Park Shuttles and Phileas. In the former case, the Park Shuttles need “an obstacle free space”, but its width was not explicitly defined. In the case of Phileas, the bus developer, APTS, asked for a path that would be 20% narrower than a conventional bus lane.

FROG indicated that their system has already matured considerably through thousands of vehicle miles of operating experience, but there are additional refinements that they would like to be able to make to reduce the current four control units per vehicle to two.

FROG indicated that safety is the most important part of the design of the automated guidance system.

FROG's philosophy is to train customers to be self-supporting for system maintenance and modification. Maintenance is typically done by the vehicle customers, but their staff are trained by FROG. FROG provides parts and software updates.

6.3.2 Guided bus systems

FROG believes that rear wheel steering is needed for articulated buses in order to ensure the tail of the bus stops in parallel to the bus stop curb. FROG indicated that the current tracking accuracy for the Phileas guidance system is 2-3 cm. The crab steering of the Phileas bus was estimated to save 20% of the docking time, as well as reducing the required length of the docking platform. The advantage could be greater for a system with off-line stations, by reducing the length and complexity of the access ramps that would be needed.

When drivers were first exposed to the guidance system, they feared it, from both technology and job security perspectives. The system gained drivers' acceptance over time, as the drivers learned that they could still take control of the bus when necessary. The transition to automated operation of Phileas is triggered based on detection of the bus position upstream of a station, after it passes over a coded section of magnets. The driver can take over control by applying torque to the steering wheel and can re-engage the automation by pushing a button. However, when under manual driving, driver behavior changes. Drivers drive Phileas like a car and make sharper turns, which could induce safety implications when drivers switch back to regular buses.

When asked about feasibility of retrofitting their guidance system onto a normal bus (rather than a special bus like Phileas), FROG thought it was probably feasible, but at a penalty in system reliability and robustness. They expressed concern about how to guarantee the alignment of the rear section of an articulated bus unless it has active steering of the rear axle. They also noted the need for special sensors to detect the articulation angle in real time.

Although FROG was not involved in the development of the buses used in the Zuidtangent BRT service around the southern side of Amsterdam, they noted that it achieved close station docking tolerances with manual steering of the buses. In order to do that, the tires rubbed up against a special-shaped curb, however, that has produced accelerated tire wear and is therefore now being discouraged.

When asked about possible applications to bus maintenance yards, FROG suggested that an automated "tug" could be used to pull buses through the maintenance facilities, analogous to some of their industrial automation applications. In this way, not all the vehicles would need to be equipped, but only a limited number of "tugs".

6.3.3 Automated people mover systems

The first-generation Park Shuttle people movers were designed as low-cost prototypes and were therefore not very refined in terms of passenger amenities, propulsion system or durability. However, a survey conducted at the Rivium business park showed that most passengers thought the automated people mover system was friendly and pleasant. For the Schiphol airport application, because the people who use the system may not be repeat riders, passengers were generally not familiar with system operation and therefore some passengers became frustrated with it. FROG has learned from the experience with those vehicles in developing the second generation vehicles, which were described as "more balanced" designs.

Obstacle detection is a major issue for the driverless people mover systems. Initial obstacle detection sensors were designed to detect all possible obstacles. However, the obstacle detection system was often tricked into stopping the vehicles by swirling leaves or rabbits in the path of the vehicles. FROG designed a more intelligent detection for the second generation people movers, using two Sick laser scanners, which can detect objects within a range of 40 to 50 m ahead of the vehicle. FROG would like to combine these with infrared detection of body heat in future systems in order to be able to identify people with high reliability, to ensure that the vehicles do not hit pedestrians. They would also like to add side obstacle detection so that the paths of pedestrians approaching the vehicle trajectory on potential collision courses can be predicted. Additionally, the right of way for a driverless vehicle needs to be clearly demarcated so that pedestrians and other vehicles do not unintentionally stray into it. This could be done with curbs, fences or shrubbery. In the Schiphol application, the places where other vehicles crossed the path of the driverless vehicle were controlled with crossing gates, while pedestrian crossings had audible warnings (particularly since the electrically propelled vehicles make almost no noise) but no gates.

Video cameras are installed in front of the driverless vehicles, and their outputs are sent to a control room where the operator can use their information to diagnose any problems that arise. The cameras face ahead of the vehicle, inside the vehicle and under the vehicle in order to help the operator diagnose problem causes that could be located in any of those places. They are also logged on the vehicle to record any incidents that may have liability implications.

A driverless people mover system still needs a system operator in a control room to monitor performance and handle unexpected circumstances (determining if a halted vehicle should be returned to automated operation) and somebody to handle maintenance, regardless of whether it involves a single vehicle or multiple vehicles. This indicates a potential economy of scale for systems with larger numbers of vehicles.

The driverless vehicles have significant user interface challenges, so that users can readily understand how to use them to get where they want to go, but also to make sure that users do not mis-use them (hitting external emergency stop button to catch a departing vehicle, or deliberately going in front of it to force it to stop). This is particularly important for vehicles that are frequently used by one-time passengers (such as at airports), as compared to vehicles used by daily commuters.

For the new generation of Park Shuttles, FROG is trying to define the most appropriate relationship with the vehicle operator, Connexxion, for system operations and maintenance. This involves questions of handling immediate repair needs as well as more general monitoring of system operations, and appears to have significant cost implications.

6.4 Observations

Although the group did not get a ride in a demonstration vehicle at FROG, we had a chance to see both first-generation and second-generation Park Shuttle vehicles, to observe the differences in quality of construction. We also heard about the many technical lessons learned through the process of developing and refining these vehicles. It is not clear how applicable such driverless vehicles would be in the U.S., with different concerns about personal security and liability than in Europe. The guidance system for Phileas appears to be fully integrated with the overall vehicle design, which might offer both pros and cons. The integration offers opportunity for synergies to be designed for different system functions. On the other hand, if not designed properly, when one component breaks down, several functions can be affected.

7. Transit Operator's View on Guided Buses

Connexxion is the only transit operator in Europe that operates automated guided transit vehicles as part of their regular services and has accumulated valuable experience. The delegation visited Connexxion and ANT Consultants in Hilversum, Netherlands. The purposes for this visit were to learn about (1) how the decision is made for deployment of new guidance technologies, (2) their experience with the Park Shuttle people mover vehicles, and (3) how transit systems are operated in the Netherlands and about other bus operations such as the Zuidtangent.

7.1 Background

Connexxion, which was formed by a merger of several predecessor organizations in 2000, is the largest contract (concession) operator of public transit services in the Netherlands (with 65% to 70% of the market). It is currently wholly owned by the national government, but they are planning on privatizing it within the next couple of years.

Only Amsterdam, Rotterdam and Utrecht operate their own public transit systems, while all others in the Netherlands are contracted out. Connexxion has annual revenues of about €1 B, with 15 K employees and over 1 M daily passengers. They operate 2600 buses, two trains and 27 trams (only in Utrecht), 2 long distance train lines, 3,125 taxis, 22 ambulances, 310 tour cars, and 16 vessels. The public transit operations account for about half of the company employees and revenues. Their operations include the Phileas buses in Eindhoven and the Park Shuttle people movers at Rivium, as well as the Zuidtangent, which is the largest BRT system in Europe (24 km of dedicated bus lane on a 41 km route, 33 articulated buses, 25 K daily passengers).

7.2 Applications

It was particularly important to understand the relationship between the public transit agencies and the operating companies such as Connexxion. The public agencies issue "tenders" (essentially RFQs) for contractors to provide transit services, with specified levels of service required (in terms of number of passengers carried, schedule adherence and percentage of scheduled trips operated). However, the process is not yet mature and they do not have good measures for quality of service.

The public agencies pay for the vehicles and associated infrastructure, so they are the ones to decide whether to introduce a new system, technology or service. Through tenders, government may ask for technologies to be included. Because farebox revenues typically cover only 40% of operating costs, the public agencies also need to provide the subsidies to make up the difference.

The main context for this visit was Connexxion's role in operating the Park Shuttle driverless vehicles at the Rivium business park. The implementation of that system was a joint decision by the local government and the transit operating company at the time (a predecessor to Connexxion), but surprisingly no mention was made of the role of the business park developer or owner.

The Park Shuttle connects the Rivium business park and a subway station in Rotterdam. Connexxion had been searching for a high quality and economically viable means to provide connections between the business park and the public transportation station in order to make public transportation more attractive. In 1995-1998 the pilot project was developed, involving 1.5 km of elevated and dedicated roadway and three automated Park Shuttle vehicles.

The operating speed of the first generation Park Shuttle is 30-40 km/hr. It makes 5 stops with 1.5 minutes waiting time at each stop. Every 15 minutes a shuttle makes a complete circuit. The capacity is 12 people per vehicle, with hourly system capacity of 500 people.

7.3 Experience

When the Rivium Park Shuttle system was first created, the major investment was in the track infrastructure, and it was important to make sure that this investment would not be lost if the automated vehicles did not succeed, so the backup plan was to use it as a bicycle right of way. The national government provided research funds to support its financing.

The usage of the Rivium system grew from 200 to 500 people per day during the time it was in service, and it was generally well accepted by the travelers. However, the scale of the system was judged too small to be economical, considering the number of passengers and distance covered, versus the need for full-time operating and maintenance staff. Also, with only three vehicles, the headways were much longer than the 2 minute headway between trains on the subway line to which it was providing the connection.

Passengers were initially skeptical about the driverless shuttle, but it gradually became accepted. In the first phase of operations, availability was 98% (which was not worse than normal buses) and there have been no major safety incidents (a couple of incidents occurred during the pilot period, but there were no injuries), but that is not considered good enough for this type of system. People were getting impatient when failures occur because a failed vehicle can block the track for the entire system and there was no dynamic information to inform passengers about the failures and the expected arrival time. Additionally, the speed was not optimal, constrained by a passing point of the single lane infrastructure. Connexxion decided to shut down the system for an expansion and to develop the next generation shuttles. The new system is scheduled to start service in September 2005.

The expansion will increase passenger capacity (up to 2000 passengers/hour) and the length of the track (to 2 km), and will add four secured grade crossings for other vehicles and pedestrians to the dedicated lane (with traffic signals and barriers). The new system will operate on a scheduled basis during the peak periods and on demand in the off-peaks in order to maximize efficiency of vehicle usage. The peak-period headways between vehicles will be short enough to reduce the wait time to 1.5 minutes. Since the vehicles are entirely battery powered, the batteries need to be recharged during the mid-day off-peak period, when fewer vehicles are needed to provide public service.

The new system will include automated functions at the maintenance area so that the role of the human operator can be minimized (door opening, docking for battery recharging, parking spare vehicles). The improvements were based on experience with the first generation system and include enhanced reliability, dynamic passenger information about vehicle arrivals, improved travel speed, reduced wait time and improved trip time reliability; increased capacity; and reduced maintenance costs.

The capital cost of the expansion includes €4.8 M for construction of the two-lane track, five stations, a bridge extension and garage/maintenance facility plus €2.2 M for six vehicles, with their hardware and software, but without including FROG's costs for development. The financing of the new system involves the Rotterdam regional government paying for infrastructure, while Connexxion pays for the vehicles and supervisory system. A couple of government programs help pay for development of the vehicle system technology.

Annual operating costs for the old system were €190 K per year, and for the new system are expected to be €250 K per year plus a €300 K depreciation expense. The system is expected to carry 500 K passengers per year when re-activated, but the regional transportation authority will have to cover the expected shortfall relative to farebox revenues. The expected farebox recovery ratio is 67% of operating costs.

The longer-term plan involves no full-time operator on-site, but rather a remote operations supervision center that would be shared with other transit services for economies of scale. There still needs to be an on-site support person to handle urgent service needs, but that will be provided on a third-party support contract on an as-needed basis.

The reliability of the vehicles varied widely in the first phase. Sometimes, there could be three or four failures in one day, while at other times one or two months could pass without failures. This appeared to be affected by the operator's setup process when initiating daily vehicle operations. No dominant failure mode or source was identified. For the new system, if maintenance costs on the new vehicles are higher than specified in the contract with FROG, they will have to pay a penalty.

The Schiphol Airport project will not be revived because that was determined to not be an attractive application for a driverless guided vehicle system.

7.4 Observations

Our hosts offered several relevant observations at the end of the discussion about their experiences with the Park Shuttle vehicles:

The decision for moving forward with driverless Park Shuttles was difficult and the initial decision underestimated the difficulties and the cost. However, the first-generation FOT proved general traveler acceptance of driverless vehicles.

If the second-generation vehicles at the Rivium are well accepted and are judged to be successful, this could stimulate interest in using such vehicles elsewhere. However, local officials are unlikely to decide to try them elsewhere until success is shown here.

The Park Shuttle vehicles are twice the cost of a 12 m standard bus, although they have a much smaller passenger capacity. When total life-cycle costs are compared, the savings in driver labor could be an important factor in their favor for applications that require operations for many hours per day. If the vehicles are produced in large quantity, the costs could come down significantly.

Appendix A

Final Detailed Itinerary
Technical Visit to Europe
Vehicle Assist and Automation Technologies

1/24 Monday — Meeting with French DOT at Paris-La Defense

Morning — Research and policy concerning BRT activities within the French national research program on transportation

- Policies
- Technologies
- Supply and demand

Speakers: François Perdrizet, director, Research Administration, French DOT
Jean Orselli, principal engineer , French DOT
Michel Muffat, Research engineer, Research administration, French DOT
Mathieu Goetzke, Research Administration, International liaison coordinator, French DOT
Sylvie Niessen, Engineer, Transit Administration, French DOT
Jean-Luc Ygnace, Researcher, INRETS

Optical guidance systems for buses
Speaker: Paul Edouard Basse, Principal Engineer, Guided Buses Department, Siemens

1/25 Tuesday

Morning — Meetings with Rouen Transit

Jean Rince, public transit manager, Rouen transit authorities

Sebastien Holstein, Technical deputy director, Connex-Rouen

Afternoon — Ride AGORA guided bus

Notes: AGORA is instrumented with Siemens optical guidance (the same used on CIVIS bus) that performs precision docking and lane control capability.
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1/26	Wednesday	Meeting with Phileas Operator
	Morning	Host: Mr. Theo Dijk, Phileas Project Manager for SRE (Samenwerkingsverband Regio Eindhoven), the regional public authority responsible for Phileas bus operations. Phileas bus ride on initial line, out to Airport, and return to SRE. DVD presentation on Phileas bus at SRE, and Mr. Dijk will answer our questions.
	Afternoon	Meeting with TNO Automotive on Safety Certification[1] Host: Jan P. van Dijke Senior Project Manager TNO Science and Industry
1/27	Thursday	Meet with Essener Verkehrs AG (Transit agency for Essen)
	Morning	Meet with Essener Verkehrs AG (Transit agency for Essen) (O-Bahn Guided Bus Operators)[2] at the headquarters of their sister company, ABELLIO GmbH. Host: Prof. Hans Ahlbrecht Project Manager EVAG Information and discussions: - the Essen transportation system (Light rail, streetcars, guided buses, standard and articulated buses) - the technology of the Essen guided buses - questions and answers
	Afternoon	Visit of the guided bus system in operation, riding on the buses
1/28	Friday	Visit FROG Navigation
	Morning	Visit FROG Navigation in Utrecht for briefing and to see new-generation ParkShuttle vehicle for operation next summer at Rivium. Hosts: Carel van Helsingden and Robbert Lohmann

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[1] TNO Automotive in the Netherlands conducts safety certification of the guided systems in Europe and has performed safety certification for Phileas bus.

[2] O-Bahn mechanically guided bus was the first of its kind and has been in operation for decades.

Afternoon	Meeting with Connexxion at their office at Marathon 6 in Hilversum, together with ANT Consultants (Nicolaas de Ronde Bresser), who were responsible for hiring Connexxion. They have had responsibility for operating the ParkShuttle people mover systems, and will discuss experience with operations and maintenance issues on ParkShuttles.

Appendix B

Europe Technical Visit Participants

Federal Transit Administration US DOT	**Walter Kulyk** Director, Office of Mobility Innovation Federal Transit Administration
ITS Joint Program Office, US DOT	**Yehuda Gross** Manager, Mobility Services for All Americans Initiative ITS Transit Program Manager U.S. Department of Transportation
AC Transit	**Jim Cunradi**, AICP Manager, Bus Rapid Transit Project Alameda-Contra Costa Transit District
	David M. Angelillo Planning Operations Administrator Alameda-Contra Costa Transit District
Lane Transit District	**Graham Carey,** P.E., AICP BRT Project Engineer, Lane Transit District,
	Stefano Viggiano Director of Development Services Lane Transit District
LYNX	**Doug Jamison** Project Manager, Strategic Planning Central Florida Regional Transportation Authority
Mitretek	**Matthew Hardy** Lead Transportation Engineer Mitretek Systems
SANDAG	**Dave Schumacher** Principal Transportation Planner, Land Use and Transportation Planning Department San Diego Association of Governments
	Maurilio (Mario) Oropeza

	Senior Project Manager Mobility Management and Project Implementation Department San Diego Association of Governments **Brian Sheehan** Transportation and Land Use Planner San Diego Association of Governments
UC Berkeley	**Wei-Bin Zhang** Leader, Transit Research Program, California PATH Program Co-Director, National BRT Institute University of California at Berkeley
	Steven Shladover Leader, Transportation Systems Group California PATH Program University of California at Berkeley

Appendix C

Questions Prepared Prior to the Visit

Government Agencies and Transit Operators

Institutional/Statutory Overview

- Provide an overview of the acquisition process (selection and purchasing) for transit equipment and technology.
- Does the government provide any incentives to use transit?
- Who maintains the roadway infrastructure on which the transit vehicles operate and/or the technology will be installed?
- What organization had the authority to modify the infrastructure?
- What is the relationship and/or arrangements between bus manufacturers and technology suppliers on liability indemnification?
- Are the transit operators and/or government organizations self-insured or externally contracted?
    - How does the transit agency manage its insurance plan?

Selection and Implementation of Vehicle Guidance Technologies

- What were the reasons for installing vehicle guidance for transit operations?
    - Was a business case made for the technology?
    - Was the technology proven to be cost effective before making the decision?

- What are the most important concerns that you had when vehicle guidance systems were first evaluated? Do you still have concerns in these areas?

- What are the most important factors that influenced your decision to implement a vehicle guidance system and/or precision docking system? Such as:
    - Reduced infrastructure cost through the reduced lane width requirements.
    - Improved system reliability.
    - Reduced travel time.
    - Increased ridership.
    - Reduced dwell time at station/stop.
    - Improving accessibility for persons with disabilities.
    - Improving the public perception and/or image of public transportation
    - What problem(s) was it intended to solve.

- What were the institutional challenges you had to overcome in order to select the vehicle guidance technologies? Such as:
    - Legal issues.
    - Liability.
    - Labor issues

- What were the technical issues you considered in selecting the specific vehicle guidance technology you use?

- For station docking, how tight are tolerances for street and sidewalk design and how has real world experience effected its operation (drainage, weather, transit vehicle design, other vehicles that may operate in or near the station area, etc)?

- What process did you go through in placing the vehicles into service in order to insure a safe and reliable service? Such as:
  - Obtaining approval for using innovative (non-proven) technologies
  - Safety certification.
  - Rigorous system testing.
  - Public outreach.
  - Employee Outreach.

- How did you provide requirements to the manufacturer for the technology? Such as:
  - Agency-developed functional specifications or performance specifications.
  - Relied on manufacturer's knowledge and requirements.

- What decision, if any, has your agency taken with respect to:
  - Whether future procurement of new buses would have automation as part of the procurement?
  - Whether future lines (or service) would be using buses with automation? and
  - Whether any of unequipped buses now in use will be retro-fitted with automation equipment?

Operation

- Explain the process for introducing the technology to the drivers

- What was the initial impression drivers had regarding the technology when it was first introduced?

- How do drivers respond to it now?

- What kind of driver training is provided in order to for the vehicle guidance technology to be used?

- Regarding the overall public image of the vehicle guidance system:
  - How do passengers like the vehicle guidance technologies?
  - Is there any evidence that ridership has increased because of the vehicle guidance technologies?

    - Have there been any type of surveys of passengers regarding the technology?
    - How has the system been treated in the public media (newspapers, magazines, radio, TV)?

- How well does the vehicle guidance technology meet your expectations in terms of:
    - System performance.
    - System reliability—mean time between failure; mean time between *working* failure
    - Maintainability

- What "surprises" have you encountered because of the technology?

- How often does the system break down?
    - Minor breakdowns that can be handled without removing the bus from service
    - Major breakdowns that require removing the bus from service

- With regards to system failures and malfunctions:
    - What policies and procedures (for drivers and operations center) have been established if there is a system failure?
    - What course of action should be followed in the event of a guidance system failure (fail-safe/fail-soft)?
    - What actions are taken by the driver in the event of a system failure?
    - What actions are taken by the control/operations center in the event of a system failure?

- What are the capital, operating and maintenance costs of technology to date?

- Are there any aspects of the guidance technology (e.g., tolerance) that you have deployed but do not need or did not deploy but wish to have?

<u>Benefits</u>

- In the area of cost-benefit analysis:
    - In what respect do you feel the money used for vehicle guidance has been cost effective?
    - How do you evaluate the cost-benefit of vehicle guidance technology?
    - How did you measure the benefits of the technology?
    - What were the benefits after 1 year in operation?
    - How many years do you estimate it will take to break-even between the cost of the technology and benefits derived?
    - What is your estimation of the net benefits over the life of the vehicles?

  - Do you see electronic guidance as a key element to BRT’s success, or is this a desirable but non-essential amenity?

- What were the benefits that you believed the vehicle guidance system would offer when you selected it?
  - Did the technology meet your expectations?

- How has the vehicle guidance and/or precision docking technology impacted:
  - Travel Time: Running way, station dwell, wait and transfer.
  - Reliability: Travel Time, Service.
  - System Capacity.
  - Connection protection at transfer points.

- What is your overall opinion of the vehicle guidance technology?

- Do you believe your agency made the correct decision in choosing vehicle guidance? Why?

Liability

- What is the liability implication of the implementation of vehicle guidance systems?
  - How does your agency handle it?

- What issues did your agency have to address with regard to liability and vehicle guidance before implementing the system?
  - Do you believe there is a difference in liability implication and/or severity if an accident is caused by driver or by the vehicle guidance system?

  - Do you have any special data recording systems to help determine the causes of accidents?
  - Will the cost of a guidance failure be passed back to the manufacturer?
  - Were any special agreements or legal changes needed?

- What is the process involved in determining countermeasures to reduce liability exposure?

Safety certification:

- How do you define safety?

- What are your safety action plans?
  - What happens when a vehicle guidance system fails?
  - What happens when the vehicle guidance system shuts down or is inoperable?

- What level of safety certification did you go through?
    - Can you provide an overview of the certification process?
    - What were the lessons learned from this process?

- Who is involved in safety assessment and certification before equipment is deployed?

Maintenance

- Please provide an overview of your maintenance policy and/or program.
    - What repairs do you take care of in-house and which do you outsource?
    - What types of training programs are carried out for maintenance crew?
    - How often are maintenance crews trained?
    - Is training conducted through external institutions or internal programs?

- What is the size of your vehicle fleet?
    - Conventional buses
    - Buses with guidance systems

- What is the size of your vehicle and equipment maintenance staff?

    - For entire bus fleet
    - Specifically added to handle guidance systems

- What changes to the maintenance system were required because of the vehicle guidance technology?
    - Significant changes in maintenance procedures
    - Purchase of additional maintenance tools and equipment.
    - Expertise, training, knowledge.
    - Expense with regard to preventive maintenance
    - Diagnosing system problems
    - Infrastructure (e.g., lane markings)
    - System calibration.

- What is the current frequency of:
    - Preventive maintenance and repair work on major bus systems *prior* to vehicle guidance technology.
    - Preventive maintenance and repair work on major bus systems *after* vehicle guidance technology.

- Is the maintenance of vehicle guidance systems similar to or very different from the maintenance of other electronic vehicle technologies?

Deployment and Institutional Issues

- How has your agency worked with other transportation organizations (transit agencies, planning organization, local DOTs) in your local and/or regional area on projects relating to the implementation of new technologies or new services?
    - How important to the success of these projects is inter-jurisdictional coordination and communication?

- How easy or difficult is it to *sell* or *market* the changes associated with bus rapid transit (BRT) and vehicle guidance systems?
    - Have special or customized approaches been taken such as educating motorists and pedestrians on interacting with other vehicle guidance system operators?

- How do the passengers that ride your buses or local/regional media currently view your agency in terms of the service it delivers, its current performance and its reputation?
    - Has the vehicle guidance technology changed the current image?

- What is the level of passenger acceptance of buses operating with vehicle guidance systems? Was it immediate or was there a need for a "breaking-in" period that could offer lessons learned for implementation of new systems, such as transit lane assist?

- Has there been any discussion or deployment of vehicle guidance technologies to improve the daily maintenance operations of buses? (washing, refueling, cleaning)

For the Meeting with TNO Automotive

- What is your process for safety certification?
    - How do you approach the safety certification process?
    - How are requirements developed?
    - How are these requirements measured and met?
    - How are new systems, one that has never been tested before, addressed?
        - How much can be done “on paper” by reviewing design documentation and software?
        - How much must be based on testing the actual systems?

- What do you think the main issues are for safety certification, based on your experience?

- What kinds of performance and safety problems have you encountered in the vehicle systems you have worked on?

- Based on your experience with the systems you have worked on, how would you do things differently in the future?

- What do you recommend to system developers in order to minimize the difficulties they are likely to encounter in attaining certification for new vehicle guidance systems?

- To what extent are your certification processes based on specific national or European regulations, and to what extent are they based on more broadly applicable engineering and safety principles?

- How mature is the certification process for automatically guided vehicles? Do you expect it to change significantly within the next 5 or 10 years? If so, in what ways?

For French DOT

- Please provide an overview of the French DOT role in local transit operations and the decision-making process with regards to:
  - Purchasing new vehicles/technologies
  - Planning
  - Other

- What is your vision on the development and deployment of new technologies for transit operations?
  - What is the role of the French DOT (vs local transit agency vs. private sector) ?
  - How is a research and development plan for new technologies created, funded and implemented?
  - What is the role of new technology within transit operations?

- What are the deployment status and issues related to vehicle guidance technologies?

- We understand that Clermont-Ferrand was using CiViS with guidance system but stopped the service recently. What were the reasons for stopping this service?

For the Meeting with Siemens and Frog

- What are the most common requirements from transit operators when they want to purchase your vehicle guidance/automation technology?
    - Among these, which are the most critical requirements from manufacturer's perspective?
    - Have they wanted some capabilities that are not possible to provide?

- Is the electronic guidance technology tailored to a specific vehicle or can be applied to any conventional bus?

- What feedbacks did you receive from the customers?

- What is your market projection for transit vehicle guidance, precision docking and automation in Europe and other countries?

- What improvements to the current technology do you plan to make?

- Who makes the decision to choose a special guidance system such as yours for use in a specific transit system?

    - Local public agency
    - National government
    - Transit operating company
    - Bus manufacturer

- What is your relationship with the bus manufacturer?
    - What is the boundary in responsibilities between your company and the bus manufacturer?
    - How hard or easy is it to define that boundary when a project is started?
    - How do the local transit authorities get the technology installed on their buses?
- What is the estimated life of the vehicle guidance technology?