Looking beyond the Guided-Bus?

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The development of light rail schemes in the UK has been constrained primarily by funding from central Government and with reluctance to support heavily capital-laden public transport investment. The light rail business case does not appear to exist even though light rail often appears more attractive to potential passengers than a bus service on the same route. The UK solution to this problem to date has seen the further use of kerb-guided buses or the provision of a modern bus-type vehicle that does not have the complimentary infrastructure provision associated with light rail or no new vehicles or infrastructure at all! In mainland Europe this issue has been addressed with a number of guided-bus schemes that use modern vehicles with new guidance technology and distinctive infrastructure more akin with a fixed-network light rail system. The Phileas vehicle used in Eindhoven is one such vehicle – but does this look, feel and behave like a light rail system? Does it have the potential to offer the quality of light rail but without the cost? This article investigates these questions

LIGHT RAIL IN THE UK

In the UK, light rail schemes seem to be popular with city authorities and appear more attractive to potential mode-transfer passengers than bus, but often proposed schemes are shelved due to the capital required to build the system. Recent examples of cancelled developments include Liverpool, South Hampshire, Bristol and Leeds. The alternative seems to be to use conventional buses; albeit with kerb-guidance. The overall solution of a potentially outmoded vehicle technology and insufficient infrastructure results in a provision that does not have the attractiveness of light rail.

However, in mainland Europe higher-technology systems are being developed, such as the Phileas vehicle which is a bus-based system with extensive infrastructure provision that attempts to imitate light rail system characteristics. This development is seeking to provide light rail qualities more economically. In round terms the costs of Phileas and a UK light rail development (Nottingham Express Transit – NET) can be compared. The Eindhoven Phileas system cost circa E100m (about £60m or £4m/km) for the 15km route completed in 2004, whereas the 14km NET system also completed the same year cost £13m/km (£180m, E263m) (NAO, 2004).

A visit to Eindhoven to test the new bus system provided an opportunity to experience Phileas from a passengers' perspective and more systematically to compare the characteristics of the system to a light rail operation. The passenger experience of Phileas was a way to qualitatively compare the system to light rail – does it feel like a tram? The systematic view is used to try and 'test' the equivalence of the system – does it perform like a light rail system?

The Phileas vehicle that operates on the system, named after the fictional traveller, is externally quite bus-like in appearance, even though the manufacturer APTS, 'refuses to call it a bus' (TU/e, 2002). However, it does have some key technological advances over a conventional bus. In some locations on the route all wheels of the vehicle can be steered automatically by magnetic guidance allowing the vehicle to crab sideways and stop very accurately alongside low height platforms, so-called 'precision docking' (APTS, 2006). The vehicle traction power is provided by a LPG powered internal combustion engine (ICE) with generator, flywheel, parallel batteries and electrical final drive. All axles are powered except for the front wheels.

THE ROUTE 401 PASSENGER EXPERIENCE

The central bus station and rail station co-located in Eindhoven form the hub of the radial bus routes from the town centre outlying districts. This was also very close to the town-

Above: An 18m Phileas vehicle is shown here en-route to Eindhoven Town Centre passing the Eindhoven Football Stadium. Photo: S Potter, Open University
Left: The Phileas Routes in Eindhoven. Adapted by S Boyle, Open University

Diesel Bus Interior. Photo: S Potter

Phileas Vehicle Interior. Photo: APTS, 2006

centre, thus providing direct penetration in to the key shopping, business and social areas of the town centre. Given the operational speed of the bus system to the airport this also permits quick access to the airport from the town centre. The key routes of interest were the guided-bus routes operated by the Phileas vehicle to Veldhoven (route 402) and the 9km to Eindhoven airport (401).

The first available bus observed on route 401 was a conventional diesel-engine single-decker, non-articulated bus. This was externally clean and when compared there is little discernable difference. Perhaps the Phileas overall looks more airy with larger windows and noticeably the Phileas vehicle does not have a rear window. The finish of the Phileas interior seems to be high quality with veneer and brightly coloured fabrics and finishes. The Phileas also had a multilingual ticket machine on-board. The Phileas vehicle appears to be quieter and accelerates quicker but both vehicles have low floor access to the route stops with a platform height of 30cm (APTS, 2006).

The first section of the route to the Eindhoven football stadium from the central bus station is not segregated, a short distance later the route becomes segregated from the main road and is demarcated by white lines for a short section prior to kerb separation. The kerb is used only for demarcation, at no point is kerb-guidance employed. Phileas uses magnetic guidance where required, the guidance-magnets were identified at the Flightforum stop in the road surface and confirmed as being 4m apart (APTS, 2006).

The transport routes around the stadium area are modal-dedicated, as shown in the photograph below. The bus-way is incorporated in the overall transport layout at this point and whilst appearing congested, the overall vista is not obtrusive. Even though there was little traffic the road construction quality was sufficient to mitigate road noise. The public road highway only accounts for about one third of the road space allocation with the remainder made up of bus-way, cycle-way and footpath.

For the majority of the journey the vehicle travelled at the permitted speed limit, up to 60kph, as there was no congestion – this made for a fast journey. At one point the route uses a roundabout and the bus appeared to be given priority and did not appear to slow appreciably; however on the return journey the vehicle was brought to a stand at this intersection. The driver on the return journey seemed to anticipate junction priority by accelerating toward red signals – somewhat unnerving! It was noted that the magnetic guidance was not in use during the visit as the driver steered the vehicle meaning that the guidance system's all-wheel steering (allowing the vehicle to 'crab' for 'precision-docking') was also not functional.

After passing the Stadium, the separation between the concrete bus route and public highway widens to form a grassed area with trees interspersed with lighting columns. Except for a short single-lane section near the airport, the bus-way was two-lane. At one stage the vehicle stopped for passengers to disembark allowing the following bus to overtake the stopped vehicle. The bus only stopped where requested by passengers on-board or would-be passengers at the stops. The bus was approximately half full leaving Eindhoven and there were few passengers who boarded after this; however this was off-peak. There were few passengers still on-board at the airport terminus and these were probably users or employees of the airport and associated businesses and not residential passengers as the area around the airport is primarily a developing business zone. The return journey was slightly busier.

One interesting element of the route was the number and spacing of the lighting columns. The initial section of segre-

A diagrammatic and photographic view of the road and rail transport infrastructure near the Eindhoven Stadium. Drawing: A.Hussain

The Bus-way with dated lighting columns. Photo: P Hodgson

New-style Bus-way with new lighting columns interspersed with trees. Photo: P Hodgson

gated running appears to use older and more lightweight fittings – suggesting these were installed pre-Phileas. The columns closer to the airport are large structures with a much larger than normal footprint, a column diameter of around 210mm compared to a 'standard' diameter of 150mm (Stainton-metal, 2001). In the long term it is believed that the lighting columns could support overhead power supply infrastructure – the spacing of the structures also supports this view as well as providing some aesthetic value. If this is the case it appears that for a marginal increase in cost, passive provision has been made to upgrade the system to overhead line. As shown in the photographs below, the regular spacing of trees and lighting columns is not visually invasive when compared to the older style infrastructure.

At the airport route terminus the bus stopped kerb-side about 100 metres from the main airport entrance. There was no infrastructure associated with the stop. Near the airport the bus-way runs on a grade separated elevated section for approximately 950m from Zanddreef to Luchthavenweg. From ground level, ie around 5 metres below the bus-way surface, this did take the appearance of a light rail operation – are those lighting columns or overhead line equipment (OLE) masts? It is unclear why the section was elevated and it felt like the infrastructure provision was somewhat over-engineered and unnecessarily costly. However, the segregated elevated section does provide a feeling of permanence associated with light rail and being mode-dedicated is uninterrupted and hence operationally fast.

Of further interest in this area is the stop called 'Flightforum'. This provided an opportunity to investigate the fabric of the stops on the system. The stop itself is located in a development area, like a business park with many commercial properties under construction about 1km from the Airport and no residential properties. Although it is not particularly obvious, the Flightforum stop is intended as a Park-and-Ride facility for the Airport where passengers can travel for free on the 401 service upon presentation of an air-line ticket.

The furniture is basic but modern stainless steel and glass and similar in construction to light rail-style shelters. The design of the signage and passenger information displays are also modern in style and function, showing the expected arrival time of the next service; however, it seemed these were not real-time displays. A service was indicated as being at least 1 minute from the stop as it raced through without stopping. From the picture it is possible to see two ground to bus-way level lifts, the service information display and the rail style name-plaque for the stop. Again, note the rather dominant heavy-gauge lighting columns. The provision of two lifts seems questionable from ground to platform level; although a crossing at bus-way level is feasible and far more cost effective. However, it is expected that eventually this will become a very busy interchange and business destination.

SO, DOES PHILEAS FEEL LIKE A TRAM?

Well, yes. The quick, quiet, clean, spacious vehicle is pleasant to ride in and did not feel dissimilar to a tram experience. The ride quality is high with no road bumps but it does lean somewhat when cornering at speed. The infrastructure is clearly demarked and the stops were obvious and well-provisioned in terms of the level of information and general aesthetic. The segregated sections and junction prioritisation enabled a fast journey and the system does have a feel of permanence and identity – the lighting columns, and elevated section are the most obvious facets of this. The vehicle also has a distinct identity – it doesn't look or feel like a regular bus.

The Eindhoven system appears to have some costly infrastructure provision, especially with the elevated section and potential for OLE implementation. These provisions make future development potentially more attractive with reduced future capital expenditure – this provides flexibility and modularity in the option for development.

Having considered the qualitative, tangible analysis of the system in comparison to light rail, it is appropriate to look at a more methodical assessment of Phileas.

THE SYSTEMATIC VIEW OF EQUIVALENCE

Modern guided-bus systems like Phileas attempt to imitate light rail system characteristics, notionally 'light rail on the cheap'. To consider a comparison of Phileas and light rail more systematically three tests that address key facets of light rail operations are proposed to assess equivalence between light rail and modern guided-bus.

The issue of equivalence to light rail is particularly important in a UK context. One of the key issues that faces UK light rail development lies with difficulties in funding from central Government, and a more cost effective, but equivalent transport solution being sought. The key characteristics of light rail and the Phileas-type transit systems have been compared based upon experience from the visit to Eindhoven.

A Phileas vehicle on approach to the Flightforum stop, shown traveling on the mode-dedicated elevated section. Photo: P Hodgson

Test 1: Segregation	For equivalence a bus-based system must have on-street running capability to enable penetration in to the central commercial, social and residential areas of the town.
Test 2: Capacity	The key test of the vehicle and system is that the guided-bus service provision should have a capacity comparable to light rail service provision with allowances for the vehicle operations and headway.
Test 3: Discretionary Guidance: Control of vehicle direction.	A light rail vehicle operator only has control over the speed and acceleration or deceleration of the vehicle, not direction. The non-discretionary control over the vehicle direction ensures system permanence and identity. This also effectively reduces the width of the route. To imitate this light rail characteristic, a guided-bus system must have the capability for some non-discretionary guidance.

SEGREGATION

The Eindhoven route is for the most part integrated at grade with no or small barriers onto the route. This was clearly an indication that the vehicles, like conventional buses, can run non-segregated and penetrate in to the main commercial and social areas of the town. The only area where pedestrians are discouraged to cross the bus-way is on the elevated section.

VEHICLE AND SYSTEM CAPACITY

The maximum capacity of transport systems is a function of vehicle capacity and the controlling infrastructure, for example, signals. The capacity of the system is complex and in evaluating this Hass-Klau (2003) makes assumptions to determine comparative capacity between modes. Some of the assumptions cannot be accepted based on the experiences of the Eindhoven visit: the assumed headway is 3.5 minutes and allows no overtaking, clearly given the witnessed ridership (albeit mid-afternoon off-peak) of route 401 it did not require more than a quarter-hourly service; however, there was overtaking taking place during the trip. There should be an allowance for overtaking for bus systems that is clearly not possible for light rail. Multiple-working for light rail vehicle is permitted in the analysis; an obvious advantage over buses, yet the headway assumption disallows bus-convoy working – an apparent disparity. The system capacity appears to assume, although un-stated, that any given system would have sufficient vehicles to maintain 60 second headway for a full hour, ie the system would need to have 60 vehicles to maintain this level of service for a cycle-time of more than 1 hour. The assumed headway does not allow for station dwell time and the calculated capacity appears to be flawed on this basis. The Phileas headway could be less then 3.5 minutes and allowing for overtaking and convoy working is at least comparable to light rail.

The actual vehicle capacity for the Phileas vehicle (18m) used in the visit is 103 for 4 persons/m^2, whereas the longer vehicle on the route (24m) can carry 129 passengers (again, 4 persons/m^2). The Croydon Tram vehicle can carry 208 passengers also with 4 persons/m^2 but the Croydon vehicle, however, is 30m long. By way of comparison Docklands Light Rail permits 6 persons/m^2 with a total vehicle capacity of 218 (Serco, 2003).

On face value, the Phileas capacity appears less than for light rail. To match the Croydon capacity using an 18m vehicle, Phileas would need to provide around 2 services for every one tram service over the same period. This may be unrealistic and actually a benefit with lower capacity in quiet periods where a lower-capacity vehicle would be more efficient without significant over-provision of space as was the case in the mid-afternoon off-peak in Eindhoven. With an appropriate headway, a system such as Eindhoven can use the Phileas vehicle for comparable capacities to light rail by reducing the headway. This means more vehicles which could of course drive up cost.

VEHICLE SPEED AND DRIVE TECHNOLOGY

The average speed of the vehicle operating within the system speed limits affects system capacity. The measure of system speed is a function of the vehicle acceleration and deceleration, dwell time, route prioritisation at junctions and the extent of segregated or reserved route and the number of stops on the route. Notionally the Eindhoven system appears to have a fast operating speed (Phileas acceleration up to 1.4m/s compared to, say, Croydon tram vehicles at 1.2m/s (Kiepe Elektrik, 2000) with maximum speeds at 96km/h and 80km/h respectively) and better than the Croydon tram, as an example of light rail, for acceleration and top-speed. This must be in-part due to the constant speed LPG hybrid engine and energy transfer to electrical final drives from batteries or ICE. The use of this hybrid drive contributes to a better than light rail acceleration performance.

The Phileas vehicles use a constant speed LPG ICE with an electrical final drive. In parallel with the ICE (with flywheel) are electronically controlled battery supplies that are charged as the vehicle brakes, providing regenerative braking and energy storage, thereby reducing overall vehicle fuel consumption. It is claimed (APTS, 2006) that the Phileas vehicle uses 30% less fuel for a comparable LPG ICE vehicle. However, it is noteworthy that a further refinement in power train has been provided in the Phileas vehicle believed destined for Douai in France and the vehicle is 1500kg lighter as a result (Green Car Congress, 2006). Whilst this has reverted to a diesel-based ICE, it still has an electrical final drive and regenerative braking and with reduced mass of the vehicle and improved diesel technology should still reduce emissions for a like-for-like diesel ICE bus.

The Phileas vehicle is also available with overhead wire/trolley wire power supplies; hence is directly comparable to conventional light rail or trolley-bus.

DISCRETIONARY GUIDANCE

The guidance system employed by Phileas is complex. APTS (Klostermann, 2006) emphasises the fundamental differences between the FROG (Free Ranging On Grid) magnetic guidance employed by Phileas and 'simpler' systems, by example, white-line guidance of Civis. Phileas calculates the driven path independently of the infrastructure using electronic maps and the distance and direction traveled is ascertained by counting wheel revolutions and steering angle, this method is called odometry. The magnets embedded in the road surface are used as additional sensors to correct 'possible small inaccuracies' (FROG, 2005). This system provides non-discretionary guidance and speed control.

A further consideration to guidance is the overall width of the route – with non-discretionary guidance the route width can be maintained within tight margins in the knowledge that the vehicle cannot stray outside the permitted running area. This is potentially not the case with an unguided vehicle without automated speed supervision. The driver of an unsupervised vehicle (consider a car or bus, for example) has direct control over the position of the vehicle and non-guided sections may need to be wider to allow for human error compared with a fixed route on a guided-section.

The width of the route is determined by vehicle width and the space it can occupy when moving – the kinematic envelope. The vehicle width affects the overall width of the straight running sections whilst the wheel position (from the ends of the vehicle) determines the kinematic envelope of the ends of the vehicle when cornering (throw). In a key work, Hass-Klau (2003) assesses the gauge and width of vehicles but neglects vehicle throw. Whilst potentially a minor issue, 'throw' may impact on-street areas where the route has to negotiate tight radii. The Phileas vehicle (APTS, 2006) has a swept path of 4.4m with a swing out of less than 0.5m within a minimum permitted radius of 12.5m. A light rail vehicle by comparison typically has a longer minimum radius (25m) with a smaller kinematic envelope of 2.9m. For reserved running areas the route width is an issue for land-take where the available width of the highway may be critical. This would be of particular importance in town and city centres with constrained road space for tight cornering. The characteristics of light rail and Phileas are similar. Any requirements for route alignment would need to be specifically addressed for the proposed system to determine impacts of the proposed route on the existing town or landscape.

INCREMENTAL SYSTEM DEVELOPMENT

One facet of the system noted during the visit to Eindhoven was the potential for upgrading the system to light rail – two elements of infrastructure provided appeared to support this view, ie the elevated section and lighting columns. Could Phileas be developed incrementally toward light rail? Would this provide a mechanism that the UK could adopt in opposition to the big-bang approach of a full steel-railed, overhead wired light rail system?

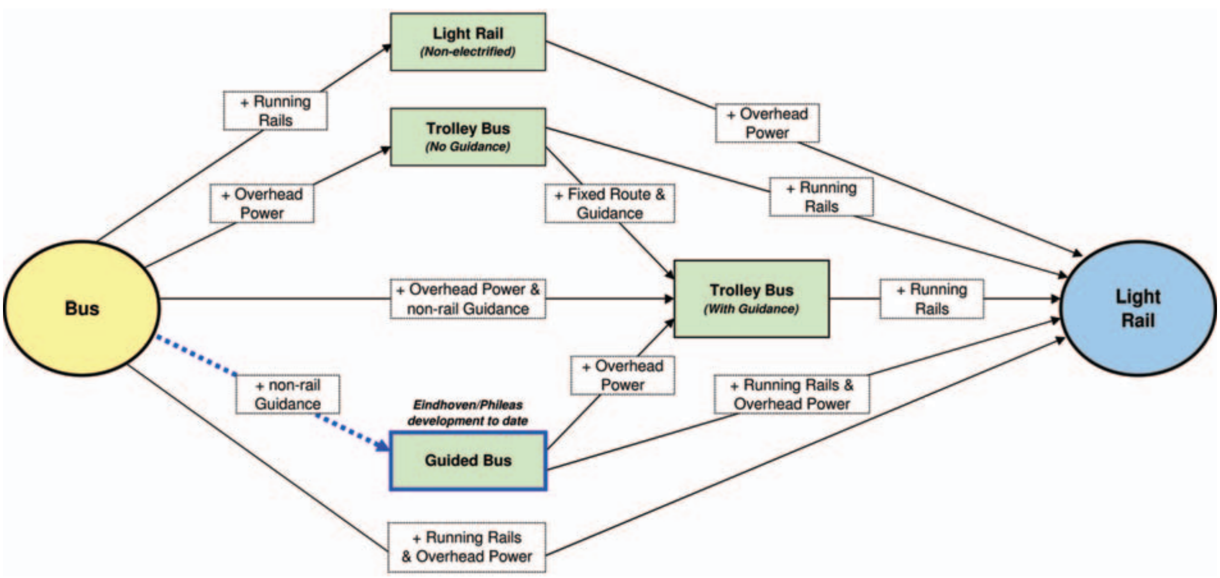
The development of rapid transit systems in the UK has until recently centered on full light rail implementation. The Merseytram and Bristol schemes are examples of projects not implemented due to the scale of funding required for the big-bang scheme. The systems delivered in Croydon and in 2003 in Nottingham were cases where this approach worked – but there are no new systems under development today, except for the Edinburgh Tram. The Manchester network has been developed incrementally: whilst there was complex new-build works in the on-street areas the outlying zones used former heavy-rail alignments where the track was already provided. Leeds had a kerb-guided bus system but failed to get funding for a light rail system. There are a number of kerb-guided bus schemes being implemented in the UK (Crawley, Luton and Cambridge) but the options for future upgrade have not been tested, or at least not explored

The key to incremental development is that the system is delivered to a level that a business case can be justified and subsequent upgrades are based upon achieving passenger numbers and revenues that warrant further capital investment. This approach should allow for more flexible development of the system in terms of the technology solution (of vehicle and infrastructure) and the timescale over which it needs to be implemented.

The development of the Phileas system in Eindhoven potentially supports the incremental development proposal. The use of heavy gauge lighting columns that could potentially be used for supporting an overhead wire system and the segregated-elevated section were very reminiscent of a light rail system. There was little evidence of any constraint to developing the next stage either with rails for self-powered light rail, overhead wires for trolley–bus or a combination of both for light rail. The development of the route through the segregated sections and on to the elevated section would readily support (in engineering and operational contexts) a light rail system. Once a business case can be proved (ie passenger numbers and revenue) then the system can be moved to the next stage.

The incremental development – the pathway from bus to light rail is illustrated below.

The Eindhoven routes 401 and 402 have been developed



Pathways from a Bus to Light Rail System. Produced: P Hodgson

A conventional bus and Phileas vehicle at Eindhoven Stadium illustrating the potential for convoy working. Photo: S Potter

from conventional bus to 'Guided Bus' status, but with separated bus lanes indicated by the blue arrow in the figure above. The next step is to Trolley-bus (with Guidance) or to full overhead powered light rail. The incremental step is to the former and would be in the interest of the Phileas manufacturer (APTS – Advanced Public Transport Systems) as they could market the Phileas Trolley-bus as a ready replacement for the current fleet. If Eindhoven went for the light rail option, this could end APTS's interests there, based upon their current fleet options.

Anton Klostermann, a Project Manager with APTS, (Klostermann, 2006) was kind enough to provide some further insight of the technical aspects of Phileas. Of particular note, he described the magnetic-based guidance as being technically and operationally superior to white-line guidance, such as that used on Civis vehicles and confirmed that the drive system configuration (LPG with regenerative braking and electrical final drives) was sought for the environmental benefits over a diesel ICE.

Klostermann considered the UK as a potential market but the significant barrier to entry is the safety regulation and regulatory bodies. The mainstay of the UK safety framework, at that time, considered guided transit modes from canals to high speed heavy rail as coming under the same regulatory umbrella. This was also recognised as a cost issue (NAO, 2004) noting that costs of light rail are artificially inflated as light rail systems adapt heavy rail specifications and safety standards. This is set to change with the introduction of the Rail Safety Directive (HSC, 2004) that part of the objective of the new regulation is to streamline the safety requirements to allow greater proportionality to risk and reduce costs. This may yet bring Phileas or a similar system to the UK

So, is Phileas an equivalent to a Tram?

To all intents and purposes, yes. From the perspective of the passenger, the Phileas vehicle and to some degree the infrastructure does have the look and feel of a tram system. The bright, airy and fast vehicle was complimented with the style and technology of the stops and the elevated section, guided-running, junction priority and lighting columns suggested a system of greater permanence that a regular bus service.

Phileas can be considered an equivalent to conventional light rail although the systematic view is less clear. Equivalence varies as the speed and acceleration of the vehicle is easily comparable but the overall system capacity is less. The capacity is comparable with light rail; even though the individual vehicle capacity is not as high. The system headway and operational flexibility allowing convoy working and overtaking more than makes up for any deficiency. The hybrid engine and drive technology means the vehicles are more environmentally sound than a conventional diesel bus, a considered advantage of light rail (zero emissions at point of use) and the attainable acceleration is easily a match for light rail. Other characteristics appear comparable to light rail – the width and throw of the vehicle and the build of the stops, by example. The guidance technology, when working, will provide a high quality ride-experience and interfaces to the stops, very much in the guise of light rail as if working on fixed running rails. The vehicle is easily integrated into the existing highways network and would relatively easily support an upgrade to overhead wires, running rails or both.

The Phileas system does meet the criteria of the three tests and can therefore be considered as being an equivalent to conventional light rail: the route was not fully segregated and could run 'on-street'; although the vehicle capacity is less the reduced headway means the system capacity is comparable; and the Phileas does have capability for non-discretionary guidance.

Given the above factors, Phileas could be a consideration to one of the 'failed' UK light rail schemes, such as Merseytram. It does have the apparent capability to provide many of the benefits potentially without the same degree of capital investment. The opportunity for incremental, phased development and passive provision for upgrades would be an important element of any implementation that could help realise light rail – eventually.

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