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## CAN BUS BE THE NEW TRAM?

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### Abstract

The UK currently only has one new light rail (tram) scheme being implemented. By way of contrast, a number of high-quality bus systems have been developed; for example Cambridge and Luton Guided-busways, Thames Gateway Fastrack, Crawley Fastway and 'streetcar' bus operations in York and Swansea. What appears to be emerging is the idea that a high specification bus system can provide a near-light rail performance at a much lower cost.

This paper reports systematic research intended to test this hypothesis. A model has been developed, using Reading as a case study, to compare the implementation and operational costs of a comparable light rail and a high-quality guided bus system. The Reading system design is based upon service performance where infrastructure and vehicle specifications for the bus-based system are sufficient to deliver equivalent performance to light rail. Performance equivalence considers the passenger experience and how this is achieved with a fast, reliable service using modern high-capacity vehicles. Equivalence tests address vehicle guidance, capacity and segregation to ensure availability, reliability and identity requirements are met.

The results indicate that for an equivalent high quality guided bus system, the overall capital costs are approximately two-thirds of light rail, and operational costs are about the same. Interestingly, using hybrid-engine vehicles, even CO<sub>2</sub> emissions are similar. The flexibility of the bus system can reduce the operational costs and the equivalence can be fine-tuned to reduce the capital costs, but this will have a trade-off with the 'system attractiveness'—because the more the system feels like a tram the more likely people are to use it.

The analysis provides support for the continued development of high quality bus schemes in the U.K. in lieu of the more costly light rail schemes. This can also provide the flexibility to demonstrate ridership numbers and the business case for incremental upgrading.

### Light Rapid Transit in the U.K.

There is a current dearth of light rail schemes being implemented in the U.K., only Edinburgh is seeing the development of a new system and this appears to be beset with programme and overspend issues. There are some extension projects, including Nottingham (NET), Birmingham (Midland Metro) and Manchester (Metrolink). Also, a new concept for the U.K. is being promoted by Network Rail (Network Rail, 2009), who are looking at the conversion of an existing heavy rail route to tram-train operation between Sheffield and Rotherham.

On the other hand, guided and higher-technology bus-based systems have seen growing popularity in the U.K; Guided-buses have been recently introduced in Leeds, Bradford and Crawley (Fastway). Segregated bus running (no guidance) has been developed for the Thames Gateway (Fastrack) and the ftr Streetcar high-technology bus has been used for services in Swansea, York and Luton. All of these systems or services have been developed or improved since 2001.

Edinburgh aside, there are no new light rail schemes being developed and it seems unlikely that an investment case can be made for any new light rail developments for the foreseeable future. The extension of the existing schemes is making better use of the existing infrastructure; this means the capital outlay is not as great as if being developed for the first time.

This issue leads to the question being considered here by looking at the environmental and cost performance of light rail compared to guided-bus. How does the cost and environmental performance of guided-bus compare to light rail with an equivalent service provision? A key aspect of the research is the evaluation of the two systems on the basis of 'Equivalence'.

### Light Rail and Guided-bus Passenger Experience Equivalence

The implementation of a guided-bus system as opposed to a light rail scheme would have a better business case if the system could generate similar modal transfer from private vehicles. The attractiveness of light rail seems clear whereas bus-based systems are anecdotally seen as not as attractive to potential passengers, who generally seem wary of public transport and certainly not buses whether guided or not.

The chances of generating rider-ship numbers for buses similar to light rail would be to make the bus look and feel like a tram, in other words provide an equivalent experience to the light rail system and vehicle. A visit to the *Phileas* guided-bus system in Eindhoven in 2006 provided a good insight to the look and feel of a high-technology guided-bus system. The *Phileas* bus operating on magnetically-guided busways in Eindhoven was internally and externally very tram-like and obviously identifiable to the specific branded service being operated. This gave the impression that the passenger experience could be near equivalent to that of a modern LRT tram.

From a system perspective however the definition of equivalence has been dealt with more systematically. A typology was defined to enable the classification of all forms of light rapid transit across four modes: tram-train, light rail, trolley-bus and guided-bus; the latter two defined as BRT or Bus Rapid Transit (Hodgson, 2005). There were three tests that were derived from the system definition exercise that would enable a bus-based system to be determined as being equivalent to light rail. These were that the vehicle must have:

- the capability of being guided
- the ability to run on-street, non-segregated
- a capacity of between 100 and 300 passengers per vehicle, or combination of vehicles operating in tandem or multiple

These tests were important as they not only define the vehicle configuration but inherently provide a specification for facets of the infrastructure that would be required. By defining the equivalence tests these should ensure guided-bus availability, reliability and identity requirements meet the light rail aspiration.

### Measures of Performance

Whilst the proposed guided-bus system has defined equivalence tests for inclusion in the model to be tested against light rail, a model was needed to provide performance measures that could best describe the environmental and cost performance of the system mentioned above. This would enable direct comparison between the systems.

The high-level reporting of the assessment of the light rail and guided-bus systems is based upon webTAG. The web-based Transport Appraisal Guidelines is a mechanism implemented by the Department for Transport (DfT) to provide a framework for the assessment of transport studies (DfT, 2009). The outputs from a transport study analysis conducted under webTAG are summarised in the 'Appraisal Summary Table' (AST), of which there are two 'objectives' of direct concern to this study – the Economic and Environment objectives. To assess the performance of the light rail and guided-bus systems, the following measures needed to be established:

- Environment – The emissions of NO<sub>x</sub>, PM<sub>10</sub> and CO<sub>2</sub> with a commentary on aesthetic and noise impacts (ENVEM). Also costs would be identified to provide mitigation of environmental emissions; especially during construction (ENVEX).
- Cost – Initially to construct the system, procure the vehicles and put into service (known as CAPEX – capital expenditure) and also a cost per annum to operate and maintain the system (OPEX – operational expenditure).

## **Model Background and Development**

With a framework defined and the basis for development for equivalent guided-bus and light rail systems, it was necessary to develop and populate a model to provide the cost and environmental measures.

The model framework was developed from a top-down methodology that provided an increasing level of detail to the infrastructure systems. The model was coded providing a breakdown of each element of the system that at the highest level ('level 1') confirmed the system (light rail or guided-bus), phase (build or operate), and the performance measure (Environment – broken down into Local Air Quality, Greenhouse Gases, Aesthetics, Noise and Cost.) The infrastructure was broken down into 11 significant elements including for example, track, control systems, the maintenance facility etc ('level 2'). These were then subdivided further into finite pieces of infrastructure ('level 3'). For example, under track, level 3 information included the length of ballast track, the number of switches etc and the equivalent items to provide the guided-bus highway.

This exercise produced a schedule of elements to be priced for which costs were obtained from a firm of construction economists who had previously used the cost data for estimates associated with light rail and guided-bus schemes in the professional consultancy arena, providing a good deal of assurance on the reliability of this data. This covered both CAPEX and OPEX costs. There were a small number of items that were not available from the same source, so cost data from an alternative transit scheme development estimates were used.

The vehicles to be modelled presented a further complication. As discussed above, a visit to the Phileas guided-bus system was undertaken as a valid demonstration of a bus that was sought to look and feel like a tram. Ideally, the Phileas was to be modelled in terms of the cost and environmental performance. However, in practice although there were a number of sources for cost data on Phileas, emissions data was not available in a useable form. A web search for bus emission and cost data for a vehicle that looked like the Phileas identified a best option – a vehicle called the DE60LF and tram-like derivative BRT-version manufactured by New Flyer in the U.S. Other vehicles were considered in the analysis also, for example the Civis bus, but again insufficient availability of cost or emissions data meant this could not be used in the model.



*Fig. 1 Phileas Guided-Bus in Eindhoven*



*Fig. 2 New Flyer DE60LF-BRT (Weststart-CALSTART, 2006)*

The light rail vehicle selected was the tram used by Croydon Tramlink. This was selected because reliable data were available about the vehicle and the operator, TfL, also publishes data on energy consumption and emissions (TfL, 2008).

The final piece in the infrastructure-jigsaw was to identify a location where light rail and guided-bus systems could be conceptualised. This would provide a basis for data input into the model to generate the results for analysis and comparison.

### **Why study a Real World Application? Why Reading?**

A U.K. location was sought that would provide the basis for comparison where a system could be proposed for the light rail and guided-bus systems. One problem with comparing data for actual light rail and guided-bus systems (e.g. Cambridge busway vs Birmingham Metro) is because site-specific aspects of the systems could make a significant difference.

Hass-Klau (2003) provides a considerable volume of comparative data but concedes that comparisons between light rail and bus can be flawed or incomplete. For example, the comparison between light rail and bus in Houston and San Diego cites 'predictable difficulties' about poor capital expenditure data and how the introduction of light rail had altered some bus routes to form feeder routes. Modelling a hypothetical light-rail or guided-bus system for the same location can mitigate the issues facing the comparison that Hass-Klau observed.

Reading in the U.K. was selected as the test location to develop and model the transit system. This is a large town (pop. 233,000 - Office for National Statistics, 2001) with existing trunk road and rail connections that provide both source and destination locations for social and occupational passenger journeys. Reading also has a University, Hospital, commercial districts and residential areas that could warrant a transit link. Reading was also deliberately selected as it has not been subject to studies on light rail or guided-bus system development, at least to the knowledge of the author.

**Model Data and System Construction**

The system for both the light rail and guided-bus systems was designed for Reading and called *Reading Urban Network* ('RUN'). The system took in all of the significant origin/destination locations in the town and a route diagram shown in Figure 3.

With the route defined this enabled the infrastructure requirement to be determined. The number of stops; road junctions; structures; track lengths, overhead line requirements, substations etc required were all identified. A control room, maintenance and stabling facility was designed that, depending on the system whether bus or tram, had a different footprint and facilities; for example wheel-lathe and overhead line control desk for the light rail and fuel point for the guided-buses.

Furthermore, because the route lengths had been worked out, this allowed the route-length dependant costs to be determined. For example, the utility diversion costs were based upon a pro-rata cost per route length for a previously developed system. Other enabling costs, for example, construction enabling works and demolition could also be evaluated.

The RUN route map (Figure 3) shows key locations including the Hospital, Park and Ride sites, University, Football Ground and Rail Station.

The peak timetable developed for the system was used to find the maximum number of vehicles that would be required and how the service was to operate, i.e. what constituted a round-trip.

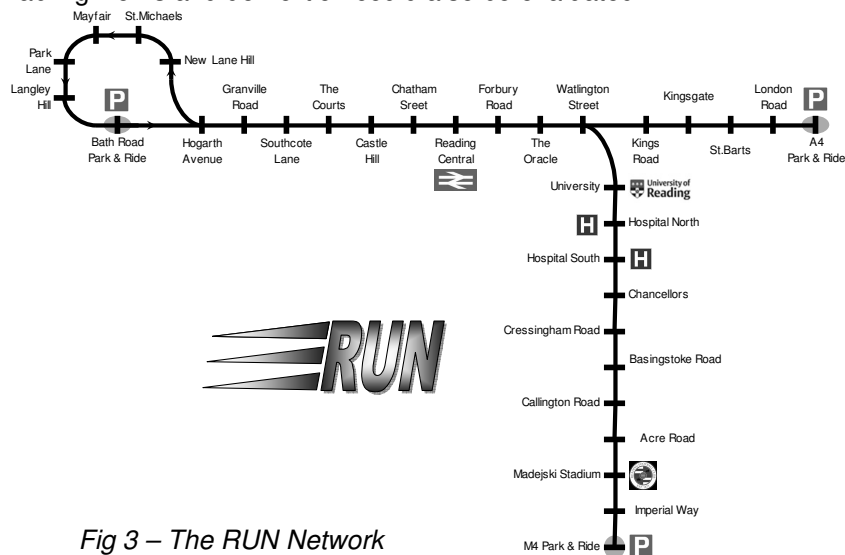


Fig 3 – The RUN Network

The timetable was initially designed for the light rail service based upon 6 services per hour (sph) in the peak, 4sph outside of peak and 2sph for early morning and late evening services. With this information, the total number of seats provided by light rail then formed the basis of the guided-bus services, noting that each tram had 208 seats and the DE60LF bus 115 seats. The equivalent guided-bus peak service was at 12sph (i.e. every 5 minutes), off-peak was 6sph. The light rail fleet was sized at 18 and the guided-bus at 30. The services operated per week were planned (timetabled) as 260 for light rail and 420 for guided-bus. This means that 54080 seats are provided on the tram and 47840 on the DE60LF per week. This is not strictly capacity-equivalent but attains 88% and for the purposes a realistic timetable was deemed to be satisfactory.

**Model Results**

As discussed above, the model was to generate data for costs in the form of CAPEX and OPEX, and also environmental mitigation costs (ENVEX) and emissions (ENVEM).

**CAPEX**

The CAPEX costs can be summarised in diagrammatic form as illustrated in Figure 4 that also shows the cost build-up from infrastructure materials and labour to the full system implementation cost.

Fig.4 Project Cost distribution, showing costs for each sub-module

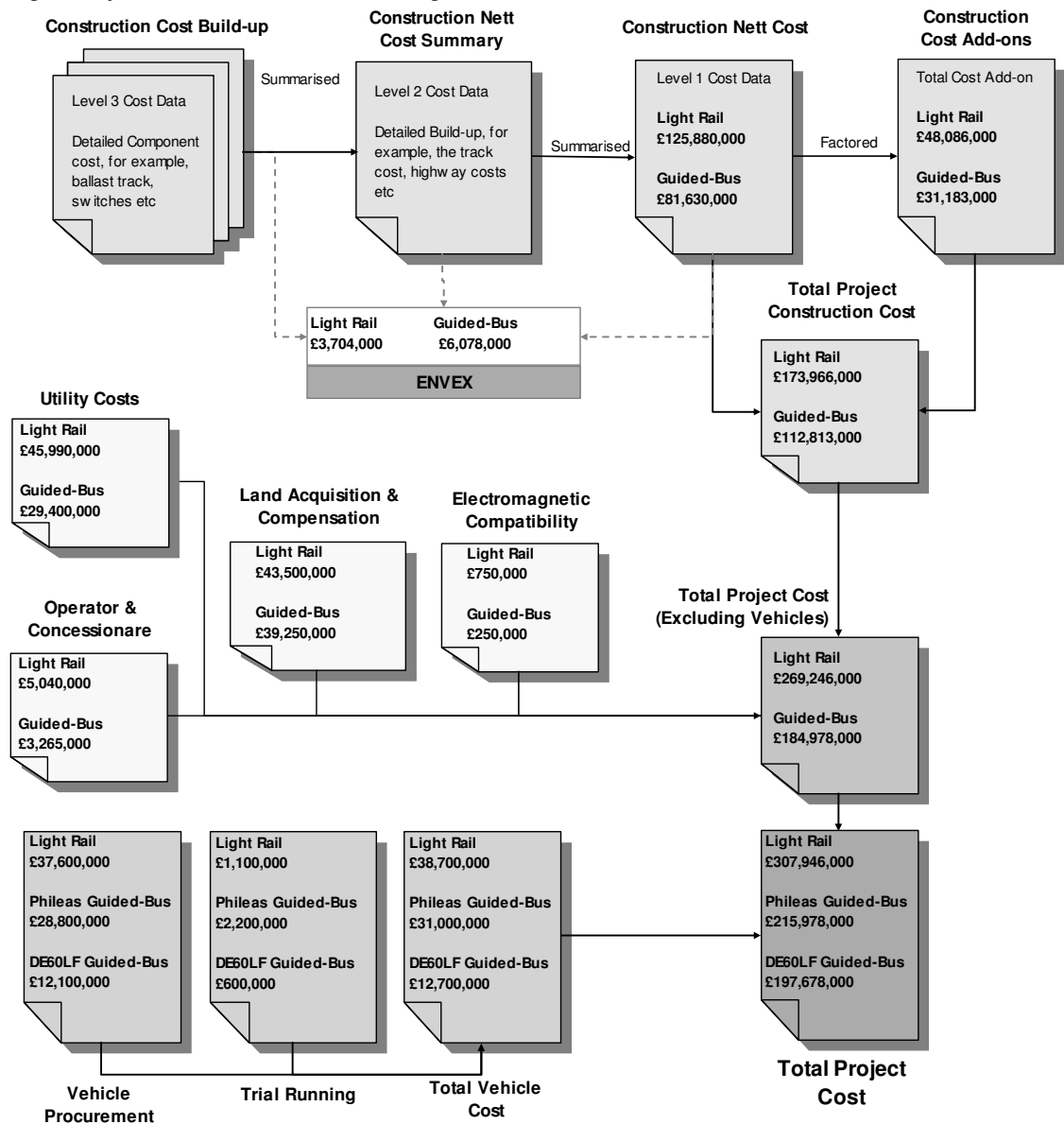


Figure 4 maps the total CAPEX project costs, which amount to £308m for light rail, £216m for Phileas Guided-bus and £198m for DE60LF Guided-bus.

**ENVEX**

The costs for the mitigation of environmental effects were limited to the impacts during construction. The longer term mitigation, such as landscaping works and permanent noise barriers were captured as a CAPEX construction cost. The cost attributed for mitigation was dependant on the nature of the works. For example, highway and track construction

attracted a mitigation cost whereas the control and communications system implementation did not require mitigation and hence cost allowance. The ENVEX costs were evaluated as shown in Table 1 (a summary was also included in Figure 4):

*Table 1- Construction Environmental Emission Mitigation Costs*

<b>Environmental costs</b>	<b>Light Rail Cost (£'000)</b>	<b>Guided-Bus Cost (£'000)</b>
Greenhouse Gases	£1,239	£736
Local Air Quality	£1,183	£745
Aesthetics	£2,581	£1,728
Noise	£1,075	£495
<b>Total Construction Mitigation Cost</b>	<b>£6,078</b>	<b>£3,704</b>

### **OPEX**

The operation and maintenance costs considered all aspects of operating and maintaining the system. The Operations element included the over-arching business administration team and facilities as well as the ground-floor staff, for example, drivers, operators, revenue collection, cleaners and security staff (British Transport Police). Other Operations allowances included the power supply or vehicle fuel and utilities. The Maintenance covered all maintenance of the infrastructure and vehicle supported by an engineering team and technicians and artisan workforce. The maintenance cost included consumables and specialist maintenance contracts.

The annual costs were evaluated as follows in Table 2:

*Table 2 – Annual Operation and Maintenance Costs*

Maintenance and Operation Cost	<b>Operations</b>		<b>Maintenance</b>	
	<b>Light Rail Cost (£'000)</b>	<b>Guided-bus Cost (£'000)</b>	<b>Light Rail Cost (£'000)</b>	<b>Guided-bus Cost (£'000)</b>
General Overheads	£4,474	£4,346	£93	£93
Vehicle	£2,022	£3,093	£1,091	£1,454
Infrastructure	£602	£738	£873	£461
Mechanical & Electrical	£44	£44	£1,495	£766
Sub-Total	£7,143	£ 8,222	£3,553	£2,774
<b>Total Annual Operation and Maintenance Cost</b>			<b>£10,696</b>	<b>£10,996</b>

### **ENVEM**

The emissions were calculated based upon a derivation of the number of route kilometres to be travelled by the vehicle fleet multiplied by the emissions per kilometre. The guided-bus (DE60LF) data were obtained from tests run by the U.S. National Renewable Energy Laboratory (Chandler and Walkowicz, 2006). This also provided a fuel consumption value.

In the case of the light rail data there were two sources that needed to be modelled. Transport for London (TfL) produce annual data for the energy consumption and emissions due to each of the public transport systems in its domain (TfL, 2006). The Croydon Tramlink system and the data provided for CO<sub>2</sub> was for fuel lifecycle emissions. However, the PM<sub>10</sub> and NO<sub>x</sub> values used by TfL were those measured as local emissions only, which is also the case in webTAG. Alternatively, data published by Government Department of Energy and Climate Change (DECC), U.K. Energy Sector Indicators 2008 (Environmental objectives dataset) provides a different set of values for PM<sub>10</sub> and NO<sub>x</sub> based upon emissions per kWh at the power station smoke stack (DECC, 2008). The emission values are summarised in Table 3. Note the difference between DECC and TfL values for PM<sub>10</sub> and NO<sub>x</sub> and the similarity in CO<sub>2</sub> values.

*Table 3 - CO<sub>2</sub>, PM<sub>10</sub> and NO<sub>x</sub> Emission Rates*

<b>Emission</b>	<b>Light Rail (DECC)</b>	<b>Light Rail (TfL)</b>	<b>Guided-bus (NREL)</b>
NO <sub>x</sub> (g/km)	4.6	0.024	8.97
PM <sub>10</sub> (g/km)	0.14	0.0004	0.002
CO <sub>2</sub> (g/km)	2360	2360	1859

The data above were factored by route kilometres operated to provide the following results:

*Table 4 - CO<sub>2</sub>, PM<sub>10</sub> and NO<sub>x</sub> Emission Values*

<b>Emission</b>	<b>Light Rail (DECC)</b>	<b>Light Rail (TfL)</b>	<b>Guided-Bus (NREL)</b>
CO <sub>2</sub> Emission/vehicle/annum	100.7 t	100.7 t	76.6 t
CO <sub>2</sub> Emission/fleet/annum	1812.5 t	1812.5 t	2297.0 t
NO <sub>x</sub> Emission/vehicle/annum	196.3 kg	1.0 kg	369.4 kg
NO <sub>x</sub> Emission/fleet/annum	3.5 t	0.02 t	11.1 t
PM <sub>10</sub> Emission/vehicle/annum	5.6 kg	0.17 kg	0.08 kg
PM <sub>10</sub> Emission/fleet/annum	107.5 kg	3.06 kg	2.5 kg

Whether to use the DECC or TfL figures depends on whether life cycle emissions or emissions affecting local air quality are the main need.

The review of the aesthetic and noise impacts of the guided-bus and light rail systems was completed using aerial mapping to form a view on the sensitivity of receptors. At this stage of the development no significant differences could be seen between the aesthetic impacts; any issues tended to involve the potential effects of providing overhead wires for the tram. This assessment would require far more detailed analysis through the development of the system if being developed for full planning submission.

The noise issues were determined to be limited to the impacts of construction. This was verified by consulting the Environmental Impacts Assessments (EIA) for the Edinburgh Tram (Transport Initiatives Edinburgh, 2003), Cambridge bus (Cambridge County Council, 2004) and ill-fated Merseytram (Mitchell, 2004) projects. Short-term mitigation measures were quantified in ENVEX costs as a factor of the construction cost by element depending on the nature of the construction as discussed above.

### **Model Results Analysis**

#### **CAPEX — Capital Expenditure: Infrastructure**

The key areas to review are where significant areas of difference exist, and these are not unsurprising – trackwork and traction power, and to a lesser extent Communications and Control, Road Signalling and the Depot.

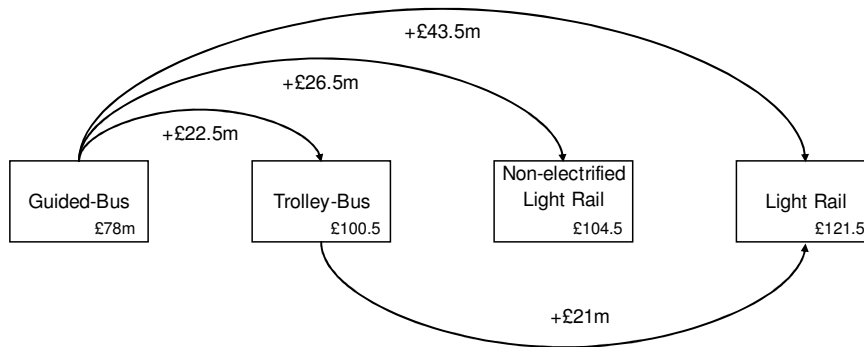
The two key areas where there is a requirement for light rail system infrastructure and not for guided-bus are the trackwork and traction power systems. These are core pieces of infrastructure that can differentiate between the light rapid transit systems, for example without rails, but with overhead power, results in a trolley-bus system. Conversely, no power but with rails would be a non-electrified light rail system.

The cost for these elements is significant; the trackwork cost is £21.1m, amounting to 47.9% of the cost difference between light rail and guided-bus and traction power is £16.9m (40.2%). This means that track and power constitutes nearly 90% of the cost difference between the two systems. Additionally, the control systems associated with traction power and the track results in an additional light rail cost £1.9m. This further increases the

percentage difference between the systems as being due to the provision of track and power to 95% of infrastructure construction. The depot costs are greater for light rail due to the additional equipment requirement but also the footprint for the depot is greater for the light rail system and this is represented by an increase in cost of £4.5m.

The construction of a light rapid transit system with or without track and/or overhead power can be viewed as stepping stones to full light rail. Where light rail is currently considered very expensive it may be possible to introduce a lower technology solution and grow the system incrementally when there is a business case that supports it. The costs shown in Figure 5 are the base construction cost including land purchase but with no preliminaries or add-ons, or vehicle costs that will also affect the overall system cost when upgrading from guided-bus to light rail. It should also be remembered that the guided-bus base cost of £78m is for a 'gold-plated' bus system.

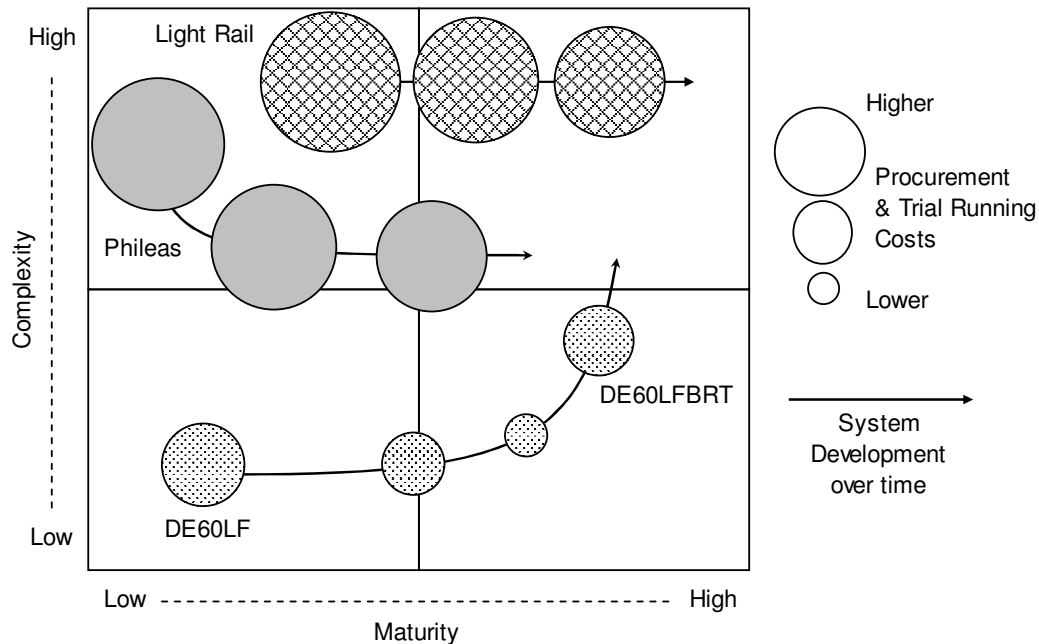
Fig.5 RUN Infrastructure Incremental Costs from Guided-Bus to Light Rail



**CAPEX – Capital Expenditure: Vehicle**

The difference between the costs of the vehicles provides some scope for discussion and the diagram in Figure 6 below assists in framing the issues. The vertical axis in Figure 6 represents the complexity of the system and the horizontal axis the maturity of the technology.

Fig.6 Relative Vehicle Costs



The light rail vehicle is a complex vehicle (associated with drive systems, power supplies etc) but is a mature technology and whilst the costs are high to procure and commission into service these are reducing relatively slightly over time. The Phileas started out in Eindhoven as a complex vehicle that has proved both costly and difficult to commission to the point that

this version has been re-engined and a new drive train used. In effect this is reducing the complexity of the vehicle and this will bring about a lower procurement and commissioning cost. The DE60LF however is migrating towards the same place as the Phileas in terms of complexity, but starting with a low technology vehicle building-up maturity in the systems with reducing the cost of the vehicles to minimal levels. Now though, with the introduction of new systems and a restyled version (Weststart-CALSTART, 2006), the overall cost will increase with these improvements. The Phileas and DE60LF will ultimately provide a similar offering but the DE60LF-BRT will be still more cost effective, having reached this point from an established technology base; hence the smaller diameter circle.

### **ENVEX – Environmental Mitigation Costs**

The ENVEX costs, for mitigating environmental impacts, are negligible when compared to the overall construction cost of the system. The light rail mitigation cost is £6m compared to the guided-bus £3.7m but the £2.3m difference represents only 0.75% of the light rail total project cost. The cost difference is to be expected as the ENVEX costs are calculated as a percentage of the construction costs for each system.

### **OPEX – Operational Costs**

The operational and maintenance costs are overall very similar for both systems with a difference of £0.3m, with the guided-bus having the slightly higher cost. The make-up of the operational and maintenance elements does differ. The greater use of electrical systems on the light rail operation has a higher maintenance cost than the guided-bus. The difference amounts to £0.8m with light rail costs estimated at £2.4m per annum to operate and maintain the infrastructure as a whole.

Total vehicle-based operation and maintenance costs are significantly higher for the guided-bus over the light rail. The guided-buses require more staff to operate, clean and maintain them. The guided-bus cost is £1.4m more than the light rail bus at £4.5m.

The costs associated with fuelling or powering the vehicles is also similar. The cost per unit-kilometre for the guided-bus is cheaper than the light rail vehicle, but as the guided-buses cover a greater distance per annum (0.77m km for light rail against 1.24m km for guided-bus) and the guided-bus diesel fuel is more expensive. The costs have been evaluated as £223,000 for electrical energy for light rail and £252,000 of diesel for the guided-bus. Whilst the cost difference is small (£29,000), this represents 11% of the guided-bus fuel bill. The cost per passenger space/km for fuel is £0.08 for light rail and £0.10 for guided-bus.

If the total OPEX is considered, the cost to operate the vehicles per kilometre is £13.93 for light rail and £8.90 for guided-bus. So again, whilst guided-buses cheaper to run per vehicle-kilometre, ultimately the OPEX cost is greater for guided-bus simply because more buses are required to run a near capacity-equivalent service.

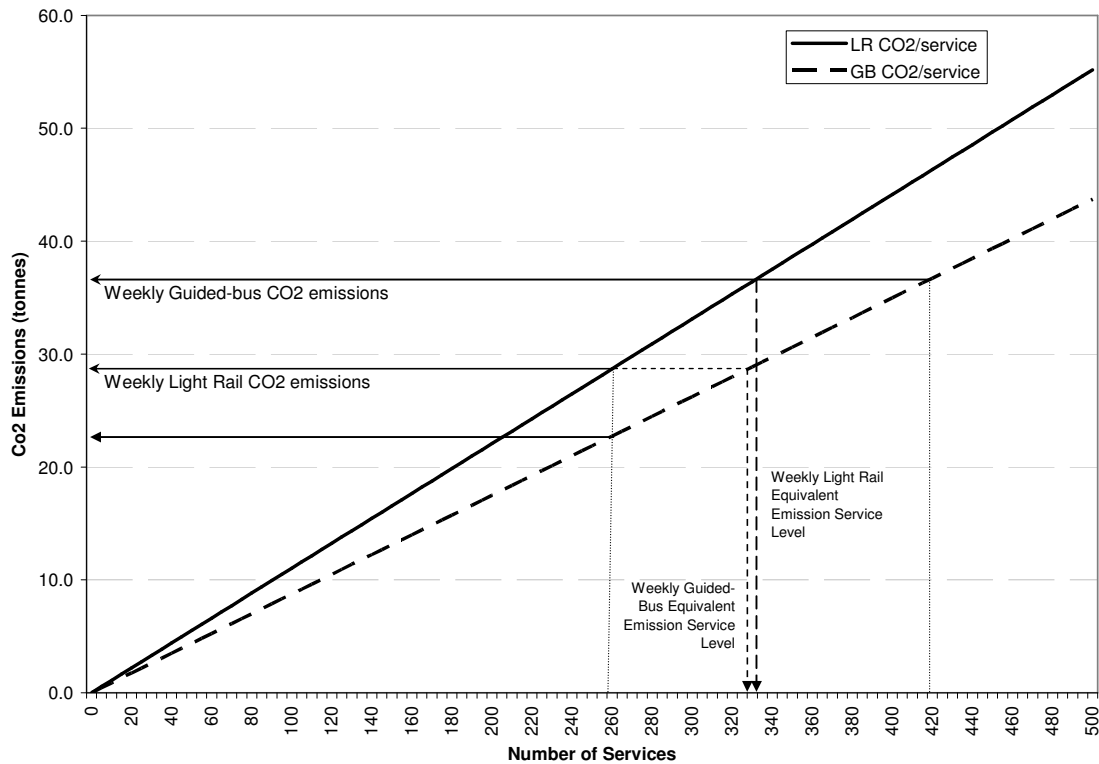
### **ENVEM**

The noise emissions and aesthetic impacts do not warrant further discussion in this paper as any difference between light rail and guided-bus are not discernable.

As has been noted above, in Table 4, the annual CO<sub>2</sub> emission per vehicle is higher for the tram (100.7t) over the guided-bus (76.6t). However, to achieve an equivalent service, a greater number of guided-buses need to operate than light rail. The graph shown in Figure 7 illustrates the CO<sub>2</sub> emissions per service and hence the effect of running more guided-bus services can be seen.

The solid line on the graph in Figure 7 represents the light rail CO<sub>2</sub> emissions and it can be seen that for 260 services per week, the emissions are 29 tonnes. The dashed line represents guided-bus CO<sub>2</sub> emissions. To provide the same passenger capacity as 260 tram services requires 420 guided-bus services, so weekly CO<sub>2</sub> emissions are 36.5 tonnes. To cut the guided bus emissions to the same level as tram emissions, then only 328 guided-bus services could be operated; lowering seat capacity to 37720 compared to the 54080 on light rail. Doing this does not appear to support the equivalence approach of this research as guided-bus seat numbers are only 70% of light rail. However, if the guided-bus timetable was configured so that the number of off-peak mid-week services is reduced from 10 to 6 and an overall reduction across all Saturday services from 6 to 4 or 10 to 6 then the 328 services can be achieved while still operating at least as frequently as light rail.

Fig.7 Infrastructure Incremental Costs from Guided-Bus to Light Rail



This ability to potentially match services with demand demonstrates that the guided-bus offers greater flexibility to change service patterns to ensure the vehicles are optimised – over-capacity on a bus can lead to a reduction in the number of seats but not the critical number of services, whereas over-capacity on the tram will mean running services with empty seats. This optimisation has the effect of making the CO<sub>2</sub> emissions equitable between light rail and guided-bus systems.

The NO<sub>x</sub> emissions are viewed in two ways for the light rail system. The TfL data, which focuses purely on local air quality issues, evaluates the NO<sub>x</sub> emissions at 0.02t annually; whereas the DECC data, for the power station electricity generation emissions, has this at 3.5t. The DE60LF is higher at 11.1t. It is clearly not possible to reduce the guided-bus service to achieve the TfL-based NO<sub>x</sub> emissions as less than one service per week would operate! However, to achieve an equivalent emission to the DECC value then 132 services per week could be operated; however this would only represent 15180 seats – which is only 28% of the light rail capacity and re-timetabling could not achieve equivalence. In either case of using TfL or DECC data, the guided-bus has higher NO<sub>x</sub> emissions but the advances in engine technology could see a reduction in this to achieve values closer to the light rail national emission values. However this would still be a long way from the local air quality measure.

The PM<sub>10</sub> emissions are also considered for the TfL and DECC values for light rail. The PM<sub>10</sub> emissions for guided-bus tail-pipe emission is lower than the DECC value in terms of g/km. The DE60LF is a U.S. manufactured vehicle and the heavy duty truck and bus emissions standards in the U.S. equate to 0.013g/kWh maximum emissions of PM10 (U.S Environmental Protection Agency standards provided by DieselNet, 2007); whereas by comparison the Euro IV standard was 0.02g/kWh – higher than the U.S equivalent. A comparable standard for power station emissions could not be located but von Blottnitz (2006) identified the U.K. power station PM<sub>10</sub> emissions were 0.11g/kWh when comparing coal-fired power stations predominantly across Europe. Hungary was the worst-case proposition at 1.18g/kWh, 90 times higher than the U.S. bus emission standard.

The effect of the data source for the PM<sub>10</sub> emissions means that the DECC data for national air quality emissions makes the light rail option significantly more polluting than the guided-

bus (by a factor of 43). The TfL and DE60LF PM<sub>10</sub> emission values are very similar with about a 500g difference over a period of a week's operation. In some respects it is difficult to contend what the PM<sub>10</sub> emissions could be for the Croydon Tram measured locally directly associated with the operation of the system.

### Summary

The results indicate that for an equivalent high quality guided-bus system, the overall capital costs are approximately two-thirds of light rail with, the light rail system costing £308m and a guided-bus system (assuming a variant of the New Flyer DE60LF vehicle) costing £198m. This assumes that the bus-based system is to be implemented to a high standard, with the infrastructure essentially be the same for both systems; only the guided-bus will not have overhead power or track.

The cost to procure the vehicles does not seem contentious for trams. Light rail vehicles are based upon established technology and whilst there is inherent complexity in the systems used by the vehicle, this is a known process. The guided-buses however present a different situation. The DE60LF is relatively cheap to buy and has the benefits of large scale production with associated economies of scale. Also, whilst the DE60LF uses a hybrid-engine and power train, this is an established technology that the Phileas cannot lay claim to. The Phileas vehicle cost is much higher than it's U.S. counterpart and has suffered costly delays in commissioning a fully-working fleet. Indeed, the problems have resulted in a new engine and drive train being used in the Phileas.

The cost to operate and maintain the two systems do not significantly differ. Whilst the make-up of the costs is different with a greater emphasis on the guided-bus vehicle and light rail infrastructure; ultimately the costs are effectively balanced over a year.

In terms of the emissions the CO<sub>2</sub> emissions are close for bus and tram systems. The guided-bus per vehicle actually has better emissions but to achieve the same capacity as the light rail means more services have to be run and the overall weekly CO<sub>2</sub> emissions are higher for the guided-bus. However, by optimising the guided-bus timetable, based upon passenger numbers in the real world, it may be practical to reduce the number of off-peak bus services (while still operating the same number of services per hour as the tram) and thereby reduce the CO<sub>2</sub> emissions. A reduction from 420 to 328 weekly services would give the same CO<sub>2</sub> emissions as 260 light rail services.

The NO<sub>x</sub> emissions are higher for the bus-based system and it is not viable to adjust timetables to change this much as the difference is too great. The PM<sub>10</sub> emissions for the bus and tram are roughly the same if the TfL local air quality measure is used but favours the guided-bus if the national power station emissions are considered. In the case of the latter the current emission standards for road vehicles has ensured a low PM<sub>10</sub> output.

The costs for environmental mitigation measures do differ between the systems but this is not surprising as the costs are based upon a factoring of the construction cost and the light rail cost is obviously higher. Noise and aesthetic impacts cannot be assessed in any detail but may marginally favour guided-bus.

### Conclusions

This analysis provides support for the continued development of high quality bus schemes in the U.K. in lieu of the more costly light rail schemes. High quality guided-bus can also provide the flexibility to develop ridership numbers and make the business case for incremental upgrading.

Provided the capital outlay is made to implement a high-specification guided-bus infrastructure system then modal transfer and other benefits appear achievable using a bus-based system. An important point is that the bus-based system can be implemented in an incremental manner, potentially eventually leading to conventional light rail when the business case exists.

The equivalent passenger experience can be achieved by a high-technology guided-bus at a cost of around two-thirds of a light rail scheme. A system specified in this manner would have the potential to provide the same key features of a light rail scheme in terms of reliability, speed, capacity, comfort and identity. The costs to operate and maintain a guided-bus scheme are only marginally higher for the bus compared to light rail.

The environmental performance of a high-technology guided-bus is broadly comparable to light rail, if the greater flexibility for timetable optimisation is taken into account. Guided-bus can have CO<sub>2</sub> emissions to a level equitable to the tram. The notional CO<sub>2</sub> emission-free electrically powered light rail vehicle is only the case when considered the point of use; this is clearly not the case when power station emissions are also included.

Local air quality does not appear to suffer greatly in the case of the guided-bus. For PM<sub>10</sub> the bus is roughly the same as the light rail for local air quality and much improved on the national emissions due to power station electricity generation. However NO<sub>x</sub> emissions favour the light rail system on both a local and national level.

The flexibility of the bus system can reduce the operational costs and the equivalence can be fine-tuned to reduce the capital costs but this will have a trade-off with the 'system attractiveness' – the more the system feels like a tram the more likely people are to use it (PTEG, 2005).

Can Bus be the new Tram? This research suggests that, in cost and environmental terms it can be, provided sufficient emphasis is put on achieving an equivalent passenger experience.

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