Can Bus really be the new Tram?

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ABSTRACT

BRT appears to be less expensive to build and operate than tram systems but can it really approach the performance level of a tram system and what is the environmental performance of comparable systems?

This paper reports systematic research on these issues, particularly relating to where an urban transit system seeks to attract discretionary car users. A model has been developed to compare the implementation, operational costs and environmental impacts of a comparable tram and high quality guided BRT system. This models a UK situation, but draws upon information from elsewhere in Europe and North America. The design of the BRT system delivers equivalent performance to trams in capacity and passenger experience.

This 'equivalence' model shows that the capital costs of the high-spec BRT system are two-thirds those of tram. This is less of a cost saving than is often claimed, suggesting that, in practice, BRT is built to a lower specification that tram systems. Operational costs do not significantly differ. Using hybrid-engine BRT vehicles, CO_2 emissions are similar, BRT has lower PM_{10} emissions, but NO_x from BRT remains higher than for trams.

Although the cost differences for equivalent systems are less than is often claimed, there are substantial benefits in the flexible development of BRT, with it less vulnerable to variations from forecast ridership numbers, and development can be split into fundable stages, growing the business case for incremental upgrading. High-spec BRT can to be the new tram, but the 'value for money' case for BRT should not be at the expense of quality and transport planning impact.

1. The demise of Light Rail and emergence of Bus Rapid Transit

The development of new light rail systems in the U.K. has all but ceased after the construction of a handful of large city schemes. Only Edinburgh is now seeing the construction of a new tram system, and this is beset with serious programme, project overrun and overspend issues (Foster, 2011). There are some extension projects underway to existing tram systems, including Nottingham (NET), Birmingham (Midland Metro) and Manchester (Metrolink), but these are exploiting the existing investment in their initial systems.

A number of schemes have failed in the planning stages, including Liverpool, Leeds and South Hampshire. In the wake of this, a UK National Audit Office report (NAO, 2004) concluded the failings of light rail to be:

- Too costly when compared to buses
- Existing schemes financial performance is poor
- Local funding is necessary in addition to central government funding but is difficult to obtain
- The planning timescales are excessively long

These points were picked up in a recent review by Hall (2011), who compared the UK institutional and funding context to that of France, with its plethora of light rail schemes successfully implemented even in quite small urban areas.

Faced by this difficult institutional and regulatory context for new tram schemes, guided and higher-technology bus-based systems have seen growing popularity. Guided-buses have been recently introduced in Leeds, Bradford and Crawley (Fastway). Segregated bus running (without guidance) has been developed for the Thames Gateway (Fastrack) and the ftr Streetcar high quality bus has been used for services in Swansea, York and Luton. All of these systems or services have been developed in the last 10 years.

BRT is advocated as a lower cost alternative to light rail, but a crucial issue whether it can be made equally attractive to car users to produce modal shift? Furthermore, what is its environmental performance compared to electrically-powered light rail? These questions are at the centre of the Open University project reported in this paper.

A central conceptual issue in answering these questions is how to construct an evaluation of the two systems. This paper reports on how a basis of 'Equivalence' has been developed to do this and how this framework has been applied in a validating test case study.

2. Light Rail and Guided-bus Passenger Experience Equivalence

2.1 Defining Equivalence
In situations where a transit system is intended to cut car use, a guided-bus system would have a better transport policy case if it could generate similar modal transfer from private vehicles as can be achieved by light rail. The attractiveness of light rail has been demonstrated whereas bus-based systems are seen as less attractive to potential passengers, who generally seem wary of public transport and have a low opinion of buses whether guided or not.

One way of generating ridership 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. An example is the *Phileas* guided-bus system in the Dutch city of Eindhoven. This low emissions hybrid-engined powered bus operates on magnetically-guided busways, segregated from other traffic along most of its route, including some elevated sections. The vehicle is internally and externally very tram-like and operates a clearly identifiable branded service. It provides a passenger experience that is near equivalent to that of a modern LRT tram.

From a system perspective, the definition of equivalence has been addressed through the development of a typology 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 represent a definition of Bus Rapid Transit (for details of this method see Hodgson and Potter, 2010). This typology method includes three tests that were derived from the system definition exercise to enable a bus-based system to be determined as being equivalent to light rail. These were that the vehicle must have:

- A capacity similar to a light rail vehicle - notionally between 100 and 300.
- The capability to run on-street to penetrate urban centres but also operate with segregated sections to ensure congestion-free running to improve reliability and speed.
- To have some capability for non-discretionary guidance, as this enforces traffic management measures which will enable prioritised running and a sufficiently enforceable segregation of routes where needed.

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. It is possible to have forms of BRT that do not meet the above criteria, but these would fall short of providing equivalence with light rail in terms of operations and passenger experience.

2.2 Measures of Performance

These equivalence tests led to a specification of a BRT system to be tested against light rail. This was developed through a model to provide performance measures that could best describe environmental and cost performance and so enable a valid comparison on a like-for-like basis between the systems.

The high-level reporting for the assessment of the light rail and guided-bus systems is based upon the U.K. WebTAG tool. The web-based Transport Appraisal Guidelines is an evaluation mechanism implemented by the U.K. 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_x, PM_{10} and CO_2 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 – Capital expenditure (known as CAPEX) to construct the system, procure the vehicles and put into service, and also a cost per annum to operate and maintain the system (OPEX – operational expenditure).

3. Model Background and Development

3.1 Model framework

With a framework identified and the basis established 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 method that provided an increasing level of detail to the infrastructure systems. The model was codified to provide a breakdown of each element of the system from the highest level ('level 1'), that confirmed the system (light rail or guided-bus), by phase (build or operate), and the performance measure (Environment – broken down into Local Air Quality, Greenhouse Gases, Aesthetics, Noise and [mitigation] Cost). The infrastructure was broken down into eleven 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 BRT guided-bus highway.

This exercise produced a schedule of elements to be priced. Costs were obtained from a wide range of sources, including a firm of construction economists who had previously developed cost data for estimates associated with light rail and guided-bus schemes in the professional consultancy arena. This provided a good deal of assurance on the reliability of the data that 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 were used.

The vehicles to be modelled needed to be selected. As discussed in section 2.1 above, the Phileas guided-bus system had been identified as a demonstration of a BRT vehicle that sought to equal tram performance and also provide passengers with the look and feel of 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 were not available in a useable form. There were also issues of the Phileas still being at a trial stage, with changes being made in the vehicle design. A search for bus emission and cost data for a vehicle that approached the performance and design of the Phileas identified the DE60LF and its tram-like derivative BRT-version, manufactured by New Flyer in the U.S.A. Other vehicles were considered in the analysis also, for example the Civis bus, but again inadequacies in the 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 Model DE60LF-BRT (*Weststart-CALSTART, 2006*)*

The choice of light rail vehicle was less problematic as standard vehicles are available. The vehicle selected was the tram used by the Croydon Tramlink in south London. This was selected because reliable data were available about the vehicle and the operator, Transport for London (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. A hypothetical system could have been use, but the discipline of using an actual town would overcome any possible bias towards one mode or the other.

3.2 The choice of a comparative case study location

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. the Cambridge busway versus the Birmingham Metro) is that each has site-specific aspects that 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 involves '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 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.

4. Model Data and System Construction

The system for both the light rail and guided-bus systems was designed for Reading and, for the purposes of this study, given the name *Reading Urban Network* ('RUN'). The system took in all of the significant origin/destination locations in the town, as illustrated in the 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.

With the route lengths being specified, 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 the key locations including the Hospital, Park and Ride sites, University, Football Ground and Rail Station.

Fig 3 – The RUN Network

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

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 the early morning and late evening. With this information, the total number of seats provided by light rail then formed the basis of the guided-bus services, noting that the tram had 208 seats and the DE60LF bus 115 seats. The effect was that the guided-bus peak service was at 12sph (i.e. every 5 minutes), and off-peak was 6sph. The light rail fleet was sized at 18 and the guided-bus at 30. The services operated per week were
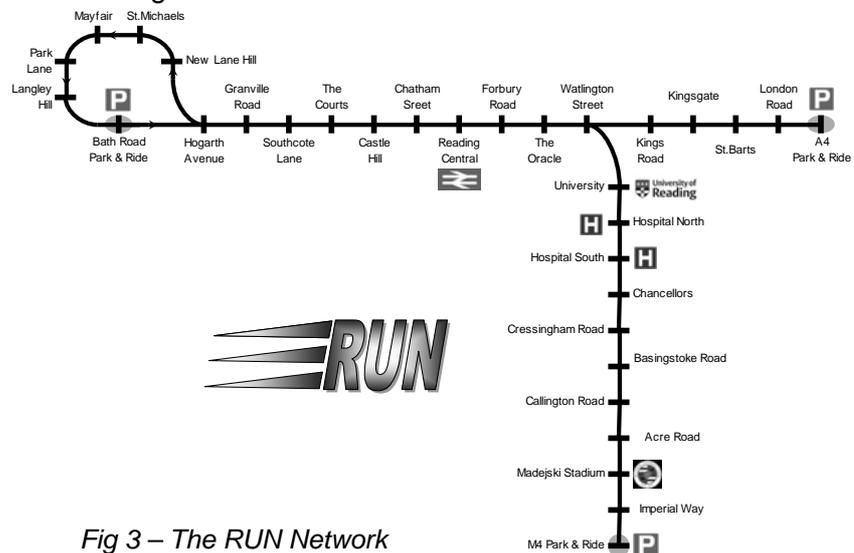
timetabled as 260 for light rail and 420 for guided-bus. This means that 54 080 seats are provided on the tram and 47 840 on the DE60LF per week. This is not strictly capacity-equivalent but attains 88% and for the purposes a realistic timetable was considered acceptable.

5. 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).

5.1 CAPEX

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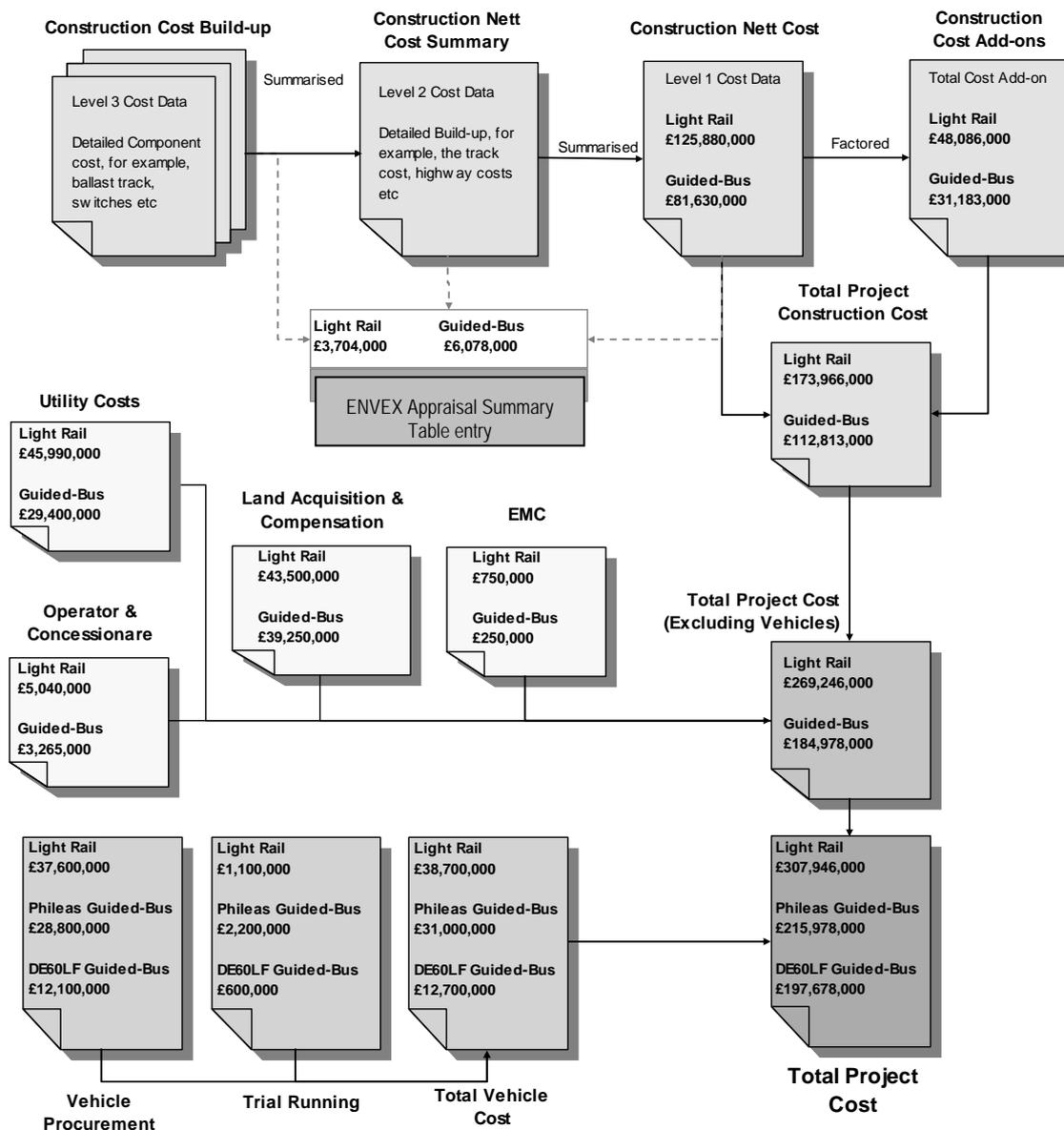

Fig.4 Project Cost distribution, showing costs for each sub-module

The total CAPEX project costs amount to £308m for light rail, £216m for Phileas Guided-bus and £198m for DE60LF Guided-bus. This shows that the cost for a

guided-bus system that is equivalent to light rail is approximately two-thirds of the light rail implementation cost. To achieve equivalence, the specification for the guided-bus system needs high infrastructure requirements to match light rail's operational performance and provide a light rail quality for passengers.

The significant cost difference between light rail and bus-based system is in the infrastructure needed for power and guidance; the overhead power system, power supplies, utility diversion and track.

The light rail vehicle CAPEX is also significantly higher per vehicle, but this is difference is reduced as fewer trams are required to provide the equivalent system capacity. The vehicle fleet cost difference between light rail and the relatively expensive Phileas is comparatively small, at £7.7m. The more mature DE60LF fleet has a larger cost advantage of £26m over light rail.

5.2 ENVEX

The costs for the mitigation of environmental effects considered 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 (part of the higher level summary included in Figure 4):

Table 1- Construction Environmental Emission Mitigation Costs

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

5.3 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 costs covered all maintenance of the infrastructure and vehicle supported by an engineering team, technicians and artisan workforce. The maintenance cost included consumables and specialist maintenance contracts.

The annual costs were evaluated as shown in Table 2, with there being little difference between guided bus and light rail.

Table 2 – Annual Operation and Maintenance Costs

	Operations		Maintenance	
	Light Rail Cost (£'000)	Guided-bus Cost (£'000)	Light Rail Cost (£'000)	Guided-bus Cost (£'000)
General Overheads	£4,474	£4,346	£93	£93
Vehicle	£2,022	£3,093	£1,721	£2,354
Infrastructure	£602	£738	£873	£461
M&E	£44	£44	£1,495	£766
Sub-Total	£7,143	£ 8,222	£ 4,183	£3,674
Total Annual Operation and Maintenance Cost			**£11,325**	**£11,896**

5.4 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 NREL (NREL, 2004). This also provided fuel consumption figures.

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 for all of the public transport systems in its domain (TfL, 2006). The Croydon Tramlink system and the data provided for CO_2 were for fuel lifecycle emissions. However, the PM_{10} and NO_X values used by TfL were for local emissions only, which is also the case in WebTAG tool. Alternatively, data published by Government Department of Energy and Climate Change (DECC), uses U.K. Energy Sector Indicators 2008 (Environmental objectives dataset) that provides a different set of values for PM_{10} and NOX based upon fuel lifecycle emissions per kWh (DECC, 2008). This allows, for example, for emissions from electricity power stations. The emission values are summarised in Table 3. Note the difference between DECC and TfL values for PM_{10} and NO_X and the similarity in CO_2 values.

Table 3 - CO_2, PM_{10} and NO_X Emission Rates

Emission	Light Rail (DECC)	Light Rail (TfL)	Guided-bus (DE60LF)
NO_X (g/km)	4.6	0.024	8.97
PM_{10} (g/km)	0.14	0.0004	0.002
CO_2 (g/km)	2360	2360	1859

The data above were factored by route kilometres operated to provide the following results shown in Table 4:

Table 4 - CO_2, PM_{10} and NO_X Emission Values

Emission	Light Rail (DECC)	Light Rail (TfL)	Guided-Bus
CO_2 Emission/vehicle/annum	100.7 t	100.7 t	76.6 t
CO_2 Emission/fleet/annum	1812.5 t	1812.5 t	2297.0 t
NO_X Emission/vehicle/annum	196.3 kg	1.0 kg	369.4 kg
NO_X Emission/fleet/annum	3.5 t	0.02 t	11.1 t
PM_{10} Emission/vehicle/annum	5.6 kg	0.17 kg	0.08 kg
PM_{10} Emission/fleet/annum	107.5 kg	3.06 kg	2.5 kg

Whether to use the DECC or TfL figures depends on if life cycle emissions or emissions affecting local air quality are the main policy need. These figures are discussed in section 6.5, below.

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 related 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.

## 6. Model Results Analysis

6.1 CAPEX – Infrastructure

The total construction cost (excluding vehicles) for light rail is £269m against £185m for a high quality guided BRT system. The key areas to review are where significant cost differences exist within this total. The areas identified by a more detailed breakdown are not unsurprising – trackwork and traction power and, to a lesser extent Communications and Control, Road Signalling and the Depot.

The costs for these elements are shown in Figure 5. This also shows the costs associated at various stages between guided bus and light rail following two possible upgrade routes for a light rapid transit system with or without track and/or overhead power. Where light rail is currently considered unaffordable, it may be possible to introduce a lower technology solution and grow the system incrementally should a business case support it.

For example, upgrading from BRT to a trolley bus system would cost an additional £49m and then adding track to make this a light rail/tram system would cost a further £35m. Upgrading via non-electrified light rail involves different costs at each stage.

Fig.5 RUN Infrastructure Incremental Costs from Guided-Bus to Light Rail
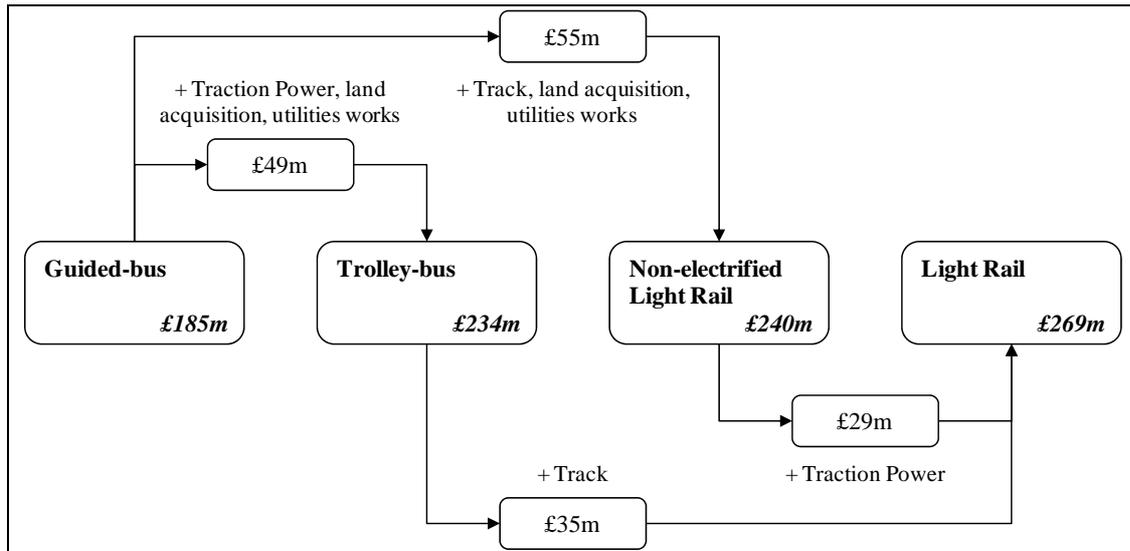
6.2 CAPEX – Capital Expenditure: Vehicle

The above figures are for the infrastructure, to which vehicle costs need to be added. Two guided bus options were examined. At a total fleet cost of £31m, the Phileas vehicle is considerably more expensive than the £12.7m cost of the DE60LF. To a large extent this represents the more mature production state of the DE60LF compared to the batch production Phileas vehicle. The light rail vehicle cost of £38.7m is for a standard vehicle available in Europe. 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
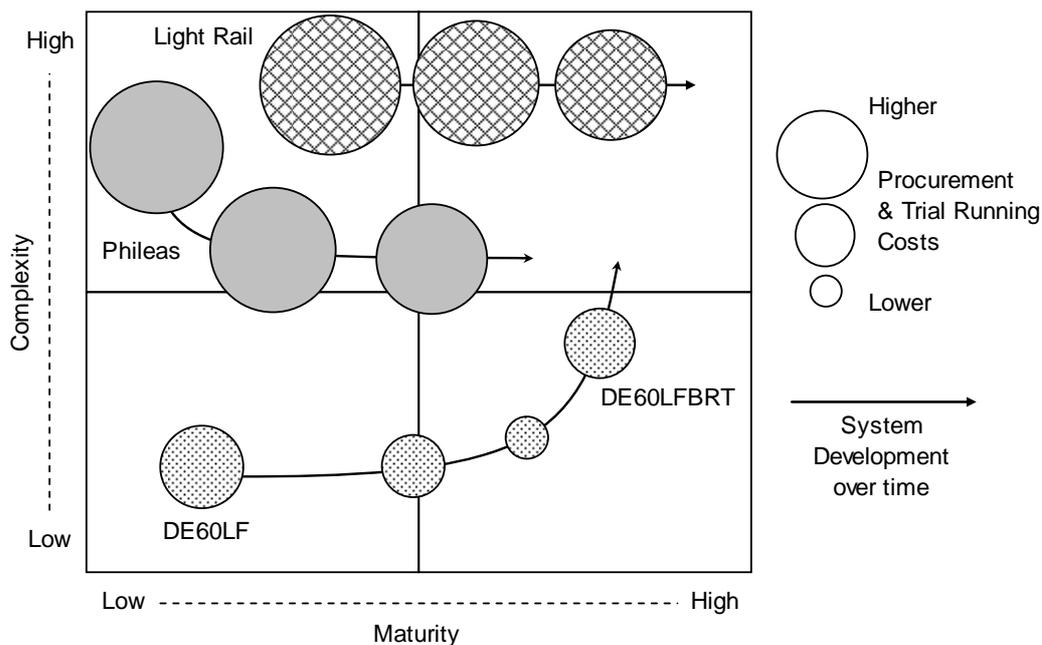
The light rail vehicle is a complex vehicle (associated with drive systems, power supplies etc) but is a mature technology and whilst the costs are high to procure and

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 should bring about a lower procurement and commissioning cost. The DE60LF 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. 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 it seems that the DE60LF will be still more cost effective, having reached this point from an established technology base; hence the smaller diameter circle.

6.3 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/tram mitigation cost is £6m compared to the BRT 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.

6.4 OPEX – Operational Costs

As shown in Table 2, the operational and maintenance costs are overall very similar for both systems with the guided-bus having slightly (5%) higher cost. However, 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) the guided-bus diesel fuel is more expensive. The costs have been estimated 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 still 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.

6.5 ENVEM

The noise emissions and aesthetic impacts do not warrant further discussion in this paper as there are no discernable differences between light rail and guided-bus.

As has been noted above, in Table 4, the annual CO_2 emission per vehicle is higher for the light rail tram (100.7t) compared to 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_2 emissions per service and hence the effect of running more guided-bus services can be seen.

The (upper) solid line on the graph in Figure 7 represents the light rail CO_2 emissions, showing that for 260 services per week, the CO_2 emissions are 29 tonnes. The (lower) dashed line represents the BRT guided-bus CO_2 emissions. Because the guided buses carry fewer passengers than a tram, to provide the same passenger capacity as 260 tram services requires 420 guided-bus services. This results in weekly CO_2 emissions of 36.5t. For guided bus to match the tram emissions, then only 328 guided-bus services could be operated; lowering seat capacity to 37,720 compared to the 54,080 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, the smaller buses do permit service levels to be matched more closely to demand than for trams. 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 from to 6, then the 328 services can be operated while still providing at least the same frequently as light rail.

Fig.7 Infrastructure Incremental Costs from Guided-Bus to Light Rail
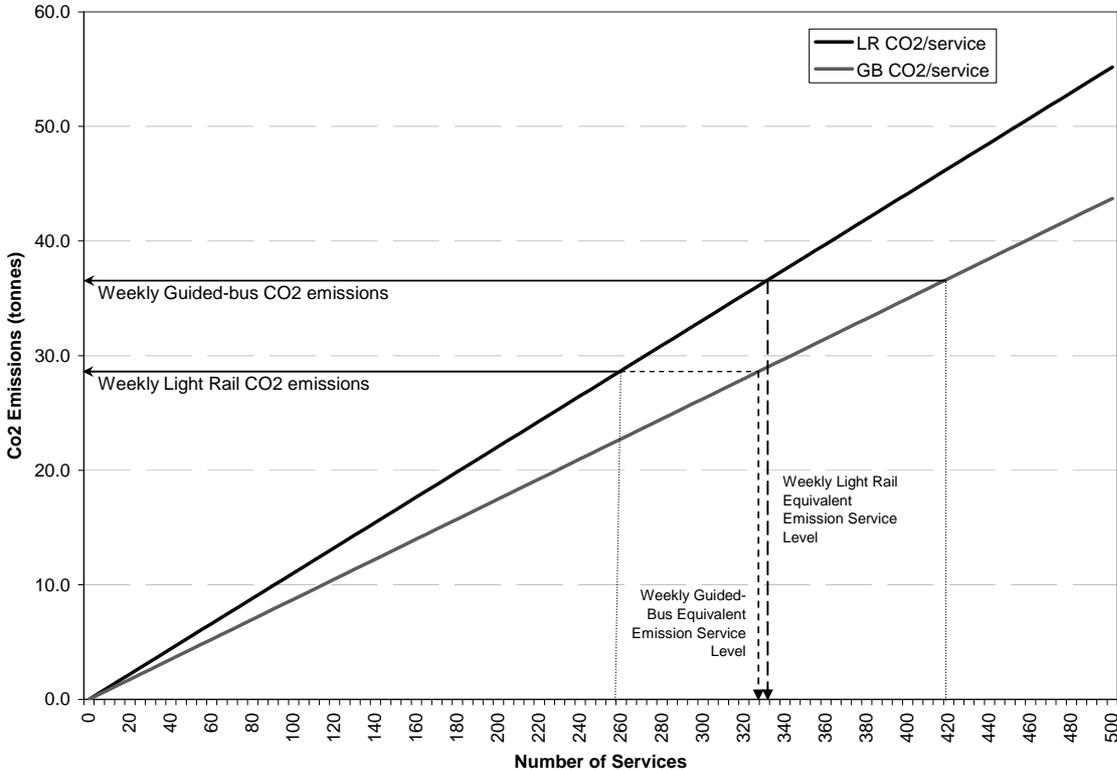
This ability to potentially match services with demand demonstrates that the BRT guided-bus offers greater flexibility to change service patterns to ensure the vehicles are optimised – over-capacity on a bus can lead to a reduction in the number of seats but not the critical number of services, whereas over-capacity on the tram will mean running services with empty seats. This optimisation has the effect of making it possible for light rail CO_2 emissions to be matched by a guided-bus system.

The NO_X 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_X emissions at 0.02t annually; whereas the DECC data, which includes power station electricity generation emissions, has this at the much higher figure of 3.5t. The DE60LF is higher at 11.1t. It is clearly not possible for minor adjustments to the guided-bus service to achieve either the TfL or DECC NO_X emissions. The guided-bus has

clearly has higher NO_X emissions, which means that this should be a priority area for attention regarding developments in engine.

The PM_{10} emissions per kilometre for light rail are also calculated differently by TfL (for local air quality) and by DECC (nationally to power stations). It is perhaps surprising that the local tail-pipe PM_{10} emissions for guided-bus is marginally lower than the DECC value for light rail. This is calculated from data for the DE60LF, which 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 PM_{10} (U.S. Environmental Protection Agency standards provided by DieselNet, 2007). By comparison the Euro IV standard was higher, at 0.02g/kWh.

A comparable standard for power station emissions could not be located but von Blottnitz (2006) identified the U.K. power station PM_{10} emissions as 0.11g/kWh when comparing coal-fired power stations predominantly across Europe. Hungary was the worst-case proposition at 1.18g/kWh, which is some 90 times higher than the U.S. bus emission standard. This helps explains why the DECC data for national air quality emissions makes light rail significantly more polluting than the guided-bus (by a factor of 43).

7. 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 BRT guided-bus system (using a variant of the New Flyer DE60LF vehicle) costing £198m. This assumes that the BRT system is implemented to a very high standard, with the infrastructure essentially being the same for both systems, only that 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 tram 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 for guided-bus on the vehicle and light rail on its infrastructure; ultimately the costs are effectively balanced over a year.

In terms of the emissions, for CO_2 the results are surprisingly close for bus and tram systems. The guided-bus per vehicle actually has better emissions but to achieve the same capacity as light rail means more services have to be run and the overall weekly CO_2 emissions are consequently higher. However, by optimising the guided-bus timetable, based upon passenger numbers in the real world, it appears practical to reduce the number of off-peak bus services (while still operating at least the same number of services per hour as the tram) and thereby reduce the CO_2 emissions. A reduction from 420 to 328 weekly BRT services would give the same CO_2 emissions as 260 light rail services.

The NO_X emissions are higher for the bus-based BRT system and are not amenable to timetables adjustments as the difference is too great. The PM_{10} emissions for the bus and tram are roughly the same regarding local air quality but favours the guided-bus if power station emissions are considered. In the case of the latter the current emission standards for road vehicles has ensured a low overall PM_{10} 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.

8. Conclusions

This analysis provides support for the continued development of high quality bus schemes where modal shift from car is desired. Particularly in the U.K. context, BRT can be effectively deployed in lieu of 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.

So long as a high-specification guided-bus infrastructure system is provided, then modal transfer and other benefits appear achievable using a BRT system. The quality of the BRT infrastructure is crucial, but it 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, a guided-bus system can match the CO_2 emissions of trams. The notional CO_2 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.

For local air quality-related emissions, the guided bus has a remarkably good case. For PM_{10} 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_X emissions favour the light rail system on both a local and national basis.

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).

However, this research did note that the UK institutional context not only increases the cost and adds risk to light rail schemes, but has a similar impact upon advanced BRT schemes also (albeit at a lower cost level). Thus policymakers in the the U.K. should not simply restrict their view of BRT to cost effectiveness. The regulatory context, appropriate financial structures and sources, and effective project implementation all need addressing. Establishing a financial case for BRT does not mean that these other crucial factors can be ignored.

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. But, although BRT is less susceptible than trams to the problems produced by the UK's institutional context, for BRT to achieve this level of quality also requires addressing the UK's institutional barriers to transit development.

Note: a full report on this project will be available on Paul Hodgson's website (http://design.open.ac.uk/people/PaulHodgson.htm) towards the end of this year.

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