A proposal for the modelling of alternative fuel traction supplies for light rail systems

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Abstract

This paper will present the thinking behind a new PhD research project that is exploring whether the use of alternative fuels for light rail developments could (a) match conventional electrification for environmental performance, and (b) provide other benefits such as cost reduction and flexibility for emerging transport needs.

U.K. light rail is expanding and wherever employed in the U.K. vehicles are powered via an overhead line electrification (OLE) traction supply. There will soon be, if not already, too many systems being promoted by local authorities requiring financial support from central government. Against a backdrop of questionable financial viability and seemingly weak passenger forecasts, even with perceived 'successful' systems light rail consortia will be looking for more public finance, not less.

The level of integration and penetration in light rail implementation is key in developing a system that will attract financially sustainable passenger numbers. On-street running with OLE in complex urban areas can become prohibitively costly, especially given the funding issues. There is a clear opportunity to develop LRT systems (and in this case light rail systems specifically) that can offer a high level of integration without being burdened with unnecessary cost.

Given this situation, an appropriate strategy would seek greater flexibility with the development of light rail systems being incremental (in geography and technology); building a business case around passenger numbers to warrant further capital outlay for OLE systems and route expansion.

The rationale for the research is demonstrated, indicating the use of transferable technologies from other LRT systems. The stand-alone nature of light rail and LRT systems will allow the use of bounded, discrete, credible data to be used that is not burdened, for example, with the financial complexities of the U.K. heavy rail network.

Current U.K. Light Rail Perspective

In the U.K. each post-1992 light rail system (Manchester Metro, Sheffield Supertram, Midland Metro, Croydon Tramlink and Nottingham Express Transit (NET)), has been implemented with (costly) OLE power supplies. This has appeared to be without consideration to other means of traction power supply. As will be discussed, one of the key issues regarding the probability of financial viability is the sustainable number of passengers that can be attracted to use the system. This paper proposes a model to present alternative solutions to conventional LRVs with OLE power supplies for LRT systems that at least maintains the level of integration and penetration.

A significant success criteria for an LRT system is the level of integration and penetration achievable into key locations along with many other dynamics; for example, fare structure, route design and stops, frequency, speed and service availability. For example, whilst the Midlands Metro from Birmingham to Wolverhampton provides a connection between the centres, there is a heavy rail link that is far quicker (18 minutes by heavy rail, 37 minutes by tram for the same fare). Whilst the light rail route is convenient for some passengers on the route the final destination points are removed from the main heavy rail interchanges and in Birmingham it does not run into the main shopping areas. With expansion plans under development it could be argued that the initial single–route system was always intended to be a 'stake in the ground' to establish the light rail concept, demonstrating the benefits and building a business case for expansion with greater city centre penetration.

Manchester Metrolink is fundamentally different. From the outset the system reached residential suburbs and on-street areas in the city centre giving easy access for recreational use. There are platforms at the main heavy rail station (Piccadilly) for easy interchange. There are park-and-ride sites on the periphery of the network to enable the longer distance (car) traveller easy access to the City centre. The subsequent phases of the Manchester system have further improved suburban links, building on the city centre integration established with Phase 1.

The ability to integrate and penetrate can depend on the extent of works required and the flexibility of the system to be implemented within the constraints of the existing infrastructure and it's environment. To radically change City layouts to accommodate LRT systems will be more expensive for the greater degree of change. Alternatively a route can be selected to avoid high-cost routes but as potentially seen with the Midland Metro this may be at a cost to the service provision and passenger numbers.

The Financing of U.K. Light Rail and LRT

The number of light rail systems in the U.K. is set to grow. Areas where LRT implementation has been formally proposed include Bristol, Edinburgh, Liverpool, Cardiff, Newcastle, Leeds, South Hampshire and Hull. There are also further extensions to the existing U.K. systems under development. There is only a finite amount of Central Government funding available and if the demand for system investment is too great then a queue will form. The U.K. Transport Secretary, Alaistair Darling, issued an ultimatum to Bristol and South Gloucestershire councils to resolve their issues or risk losing £160m funding for a proposed light rail system, "I announced money before Christmas (2002) for extensions to Manchester and Liverpool light rail schemes. I would like to do more, so Bristol needs to get on with it." (Symons, 2003b). Darling's threat is clear if not explicit.

The financing of LRT systems will receive renewed interest as two of the first four systems have struggled financially. Midland Metro is perhaps the least surprising because as discussed this does not necessarily attract sufficient passenger numbers for financial sustainability given route and termini location. Croydon however, is perceived to be successful but has below predicted passenger numbers (revenues below predicted levels in 2002 equated to a £1.58m loss (Symons, 2003c)). Both systems are planning extensions: Croydon to build on 'success' with neighbouring boroughs wanting to be a part and Midland Metro as the way to make it a success. Key to this issue is the reliance on accurate forecast data, which is not just a U.K. problem; Camden-Trenton, (a diesel LRV in the US) will need the initial operating period to justify the system at all, let alone further investment in OLE.

So, for a robust business case it is necessary to maximise revenue, thereby improving the 'return on investment' (ROI). Figure 1 illustrates the issue for improving the revenue through passenger receipts.

Following the process logically it becomes a 'vicious-circle' set against a backdrop of uncertain revenues (weak passenger forecasts) and uncertain build and operate costs. This latter issue has been addressed by the U.K. Government as each light rail system bidding consortia has to include an build cost 'optimism-factor' in the bid (Faulkner, 2003).

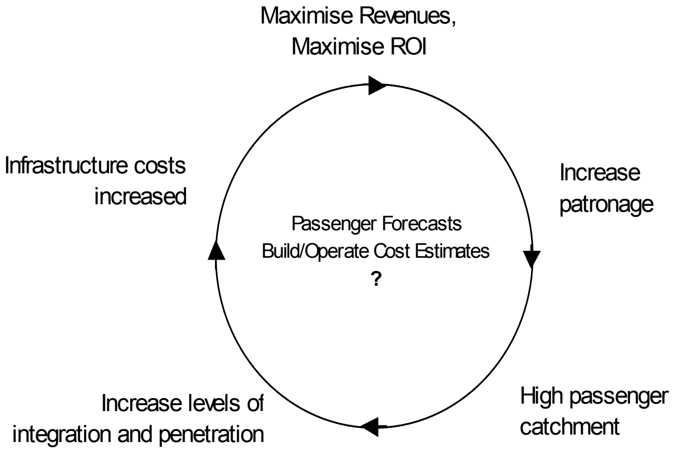

Figure 1 – How to Improve Revenue?

LRT system costs and hence the extent of funding required can be affected by the two key system elements (infrastructure and vehicle) and the level of technology applied to each. Typically, the need for new technology LRVs will be to support the overall system needs to achieve greater levels of integration into the existing environment or city centre penetration. Technological developments will be driven by infrastructure requirements with the vehicle 'made to fit'. For example, consider:

- Bordeaux LRVs have 3rd rail to support the need for non-visually intrusive infrastructure

- Caens has rubber tyre vehicles to access areas where steel rail could not be used
- Camden-Trenton does not have a business case for OLE; so a low cost equivalent vehicle was required that did not require electric power supplies

The only real exception where infrastructure advances could impact future systems (and the level of integration) is in the development of a 'current collection' system that could make OLE implementation practicable where previously not possible. However, the mechanical aspects of the OLE system can only be reduced given significant reductions in the vehicle power demand, hence reducing the weight of the conductors and support system.

Although the key technological developments can be made in the vehicles, a large proportion of the impact cost will be met in the infrastructure necessary to support the demands on system design. There are cost trade-offs in the two generic types of supply, electrified and non-electrified broadly illustrated in Table 1.

	Cost Considerations	
Detail	**Non-electrified (Self-powered)**	**Electrified (OLE and 3rd rail)**
Vehicle Procurement	Higher depending complexity and novelty of fuel supply solution	Standardised, modular units – less benefit if vehicles are leased
Vehicle Operation	Fuel costs – pending fuel type, transport and delivery thereof	Costs of electricity supply and management
Vehicle Maintenance	Longer duration/more frequent maintenance, requires more units to cover unavailable vehicles	Lower-cost maintenance on electrical systems well established
Power Supply Infrastructure	Depending fuelling infrastructure required, may need solution with additional (costly) safety aspects	OLE, 3rd rail and substations and supporting infrastructure and cost to environment to accommodate
Stations & route infrastructure	No special requirements except in tunnel sections if non-electric vehicles emit fumes	Electrical clearance in build/ operation of LRT - increased safety requirements on maintenance in OLE area
3rd Party effects	No additional burden on lineside infrastructure, allowance for fuelling point and road traffic to import fuel	Stray current & EMC mitigation specific to electrified systems, e.g. services diversion and stray current monitoring
Emissions, noise and visual impact	Will depend on solution chosen for specific environment	Emissions of electricity generation (and use) can be scheduled but relative position against other modes is unknown

Table 1 – Cost Consideration Electrified/Non-electrified Light Rail System

Table 1 describes the likely cost impact for each generic traction power supply mode - electrified and self-powered. The impact has been detailed for all conceivable areas of light rail operation; however, the relative position of the effects of emissions cannot be quantified at this time. This provides rationale for pursuing this course of research.

LRT and other Urban Transport System Examples

This section considers some of the light rail and LRT alternatives to OLE powered light rail, however, but does not account for systems with marked differences in rights of way or guidance means, for example, standard diesel ICE buses, metro or heavy rail networks.

Conventional Light Rail OLE (Overhead Line Electrified) Powered Vehicle

These systems are wired with OLE typically at 750 or 1500v d.c. and energy is transferred to the vehicle by a roof-mounted pantograph. This design appears to be used wherever practicable. Recent developments in this area have been a move toward less maintenance-demanding a.c. traction motors (from d.c.) and the capability for regenerative braking. The OLE powered LRV is seen as perceptively very environmentally friendly in emission terms; hence, any alternative to the OLE LRV will need to be able to demonstrate comparable emissions to electric traction.

There are two environmental emissions relating specifically to electrified systems that require close attention; electromagnetic compatibility (EMC) and stray current. EMC is the generic term given to electrical systems (power, control, telecommunication) and the unwanted interaction between separate systems. For example, the magnetic emission from an LRV could adversely affect road traffic controls, television reception, wheelchair controls, cash registers, etc, unless adequate controls are put in place. The electrified light rail system can be both EMC aggressor and victim; requiring emission and immunity controls respectively.

Stray current is the term given to electrical charge dissipated in an uncontrolled manner by light rail infrastructure that uses an incidental path for return current. For example, electrical potential present on the running rails can establish a path for return current via an existing metal pipe water main. Whilst this is likely to be a small magnitude current, it will erode the pipe construction over time. This can be a particular problem where stray current uses reinforcing bars in concrete as an incidental path, with breaking-out of the concrete around the re-bar being the ultimate outcome. Stray current mitigation can include services diversion and implementation of protection measures on the electrified light rail distribution system.

Bordeaux LRV: 3rd Rail (Innorail)

A very recent development has seen the advent of an on-street 3rd rail (APS – Alimentation par sol) powered system. As an extension to an existing system the local authority in Bordeaux elected to implement a route that crossed a medieval stone bridge. At the insistence of the local mayors (Briginshaw, 2003) the section across the bridge and at other locations totalling 10.5km (of a total of 25km) of the Phase 1 development will use Innorail to combat the unsightliness of OLE.

Conventional 3rd rail would be exceptionally dangerous on anything but fully segregated routes. The Innorail system is switched (by a control radio device on the vehicle) such that the only live section of the road-flush 750v d.c. rail is that which is directly beneath the vehicle. In this way it cannot be inadvertently or maliciously energised or touched by the general public and thus reduces the risk of electrocution.

The vehicle is a multimode powered with OLE capability and a back-up battery for use if the 3rd rail power fails. The control systems and costs of implementation and maintenance are expected to be considerable, at least as much as the OLE equivalent.

LRT: Tram-tyre

In Caens (operated by ’Twisto’) from November 2002 and Nancy (operator, CUGN) a derivative of the trolley-bus was introduced which is an OLE-powered guided tram with rubber wheels and no running rails; it is has a central guiding rail. The vehicles were supplied by Bombardier and have been used as opposed to standard ‘steel wheel on steel rail’ rail vehicle due to the gradients on the route; Bombardier states minimum radii of 12m and a maximum gradient of 13% for a tram-tyre vehicle. A similar build tram, the Bombardier Eurotram can only contend with gradients of 8.5% and a minimum radius of 25m (Bombardier, 2001).

The use of rubber wheels also can reduce the effects of vibration over conventional permanent way; the advent of ‘floating slab-track’ has been developed to alleviate this problem with steel rail. These examples demonstrate how LRT systems can be integrated with the existing environment and can cut infrastructure costs. There are clear advantages of rubber-tyre guided systems over the steel rail equivalent.

Diesel-powered LRV

There are a number of new installations of light rail where diesel powered units are being used. Significantly there is a system under development in New Jersey, in the U.S. The Camden-Trenton line has new diesel-electric vehicles provided by Stadler-GTW. (Monaghan, 2003).

Other North American (Ottowa and Hudson-Bergen) systems have been developed on existing heavy rail (freight) lines and diesel LRVs have been used to as a stopgap whilst a business case for electrification is developed. Given that these are freight lines they are unlikely to run on-street in urban centres and are more akin to a metro installation. The particular case for Camden-Trenton system is suffering from some controversy as passenger figures have been quoted as optimistic

(Pearsall, 2001), putting the business case for electrification and the overriding need for the link in the first instance under serious doubt.

In Kassel, Germany, a further example is proposed (Anon 2002a) with some vehicles having electric and diesel-electric drives. The electric vehicles are configured for dual voltage operation. This follows another German example in Dortmund. Zwickau, also in Germany employs ‘lightweight diesel trains’ (Anon, 2002b) which have low floors and are used in on-street areas.

Alternative Fuel ICE LRV
One and possibly the only U.K. example of LPG (Liquefied Petroleum Gas) LRV is the Parry People Mover (PPM) range of vehicles (PPM, 2003). Typical in this range is the PPM50 model with traction power provided by a 2.0l Ford Focus engine and regenerative braking energy storage using a flywheel with auxiliary power provided by batteries. The total capacity of the unit is 50 people (30 standing) used for example on the heavy rail line from Stourbridge Junction to Stourbridge.

Fuel Cell LRV
There are not currently any fuel cell LRVs commercially available, although the TfB (Trams for Bath) site loosely promotes the option of the fuel cell as an alternative fuel source providing background information on fuel cell basics without making it clear whether this is a viable option. Fuel cells have been developed for commercially viable buses however, see non-diesel buses.

Guided Bus Routes
This option is lowest on the cost and technology scale of guided development options. The most recent U.K. example is the Leeds guided bus-way. The bus on this system is a conventional, discretionary-steered vehicle whilst not in the guide-way. On the approach to a guided section the driver aligns the bus and guide–wheels mounted low on the bus and smoothly guides the vehicle into the guide-way that is formed of short, raised concrete kerbs. Rouen has recently introduced a similar system (Civis) but the guidance is optically-read white lines painted in the road, and so infrastructure costs are much reduced compared to the Leeds system. Once in the guided section the driver controls only velocity, like on an LRV. A similar product is under development for use in Eindhoven, called the PHILEAS. This is also a guided bus; however it uses road-surface flush, fingertip-sized magnets for guidance.

There are key benefits of the guided bus-ways when compared to light rail systems (Barry, 1991):

- Relatively high speeds can be attained, up to 100km/h
- Systems are generally cheaper to implement than light rail equivalents
- Resources (buses and drivers) are available to use the new system with minor modification to the bus and little additional training required
- Once clear of the guided area the bus can be driven wherever required

Barry (1991) also points out the downsides: LRV generally attracts greater patronage and another disadvantage is derived from one of the advantages: whilst the bus can travel where required once out of the guided section, this does mean it is liable to be caught in road congestion. Guided bus-ways now use articulated vehicles giving passenger capacity similar to current LRVs, e.g. PHILEAS and Civis. This overcomes a once disadvantage of a lower capacity single carriage bus.

Leeds has built a business case on the guided-bus route as there are now plans to develop this Leeds network into a light rail system with advance road works already commencing. However, there is not a contract in place as yet to build and operate the system. It is not surprising that one consortium was ‘dropped’ on the basis that Leeds Tramlink (Amey, Bechtel and Egis Sealy) required full government compensation in the event of a lack of financial sustainability; i.e. a zero-risk option for the consortium (Anon 2002c).

Non-diesel Buses
Closely linked with the guided-buses are standard non-diesel buses as there have been recent developments in fuel sources for conventional buses used in conjunction with guidance technology. Examples include PHILEAS that has a number of fuel source options; for example LPG ICE, constant speed diesel ICE (both with electrical transmission) with options for fly-wheel and battery energy storage facilities. These developments have been made to combat the perception that

diesel buses are dirty in spite of recent developments made in diesel engine technology and ever-tightening emissions standards. Buses provide a 'test-bed' for transferable technology to LRVs.

Daimler-Benz developed a fuel cell bus, the Nebus, as being commercially viable in 1998. A rollout of fuel-cell buses is gathering pace across the Europe with 30 buses in place in 10 European cities. Daimler-Benz is involved with the 'Clean Urban Transport for Europe (CUTE)' project – an EU public/private partnership launched in 2001. Another German manufacturer, MAN, have a well-documented service running at Munich airport following work by a consortium of companies each bringing expertise to different facets of the fuel delivery, control and use. The U.S. Australia, Japan and Iceland to name a few also have many test-bed schemes now in place using fuel cell buses.

Definition of 'Light Rail' for this Research

There are different definitions of light rail provided as a subset of light rapid transit with no unambiguous, consistent statements apparent. A view can be formed on the definition of light rail in respect of segregation, power supplies and guidance systems.

Barry (1991) provides his own view and that of others in defining light rail. Barry is specific to determine 'light rail' as rail-based with electric traction powered via an OLE system. The LRTC confirms the use of electric traction but does not specify rails, only that it is an urban form of transport. The UITP states that the system is rail borne but the DoT is less specific, referring only 'guided transit'. Vuchic uses the general term of technologies to include 'support' (vehicle to running surface), 'guidance', 'propulsion' and 'control' (regulation of travel of one or all vehicles).

In terms of rights of way there are a number of variants. Barry and the LRTC include street running but qualify this by stating it will be principally reserved, i.e. segregated. The LRTC definition is broadened to include high-speed subways, elevated structures, and private rights of way, with or without grade crossings. Vuchic (1981 and 1999) developed different classifications of rights of way and limited these to 3 key areas.

- Category A: fully controlled right of way without grade crossings – referred to as grade separated, segregated, private or exclusive.
- Category B: rights of way that are longitudinally physically separated (e.g. concrete barriers) but with grade crossings
- Category C: surface streets with mixed traffic, transit systems may be given preferential treatment

Barry (1991) defines the vehicles as being high capacity, articulated and suited to street running. The LRTC states a 'wide range of capacities'.

Having considered specific examples of LRT system it is relevant to consider these systems with respect the definitions indicated above to classify light rail for this research in order to:

- Ensure that the proposed OLE alternative is considered equivalent
- Bound the study area; to enable focus, and,
- The definitions discussed previously are inconsistent

The definition of that is to be applied in the development of this model is based on three key criteria from the earlier definitions. To fit within the model as an alternative option to OLE supplied vehicles, the vehicle must:

- Be laterally guided by non-discretionary means whilst in non-segregated areas
- Be capable of segregated running and non-segregated, at grade on-street – a key driver of the systems will be the capacity to integrate with the existing environment
- Have a minimum passenger capacity of 50 – so as to exclude ultra-light rail (no requirement for upper limit capacity as 'inappropriate larger scale systems are likely to be excluded by virtue of segregation – i.e. metro or heavy rail)

The vehicle travel control can be fully interlocked, partially controlled or discretionarily controlled by the driver and hence does not form part of the defining criteria. Also of note, rather obviously is that there is no specific requirement for a particular mode of power supply.

Table 2 indicates known combinations of power supply and guidance system and together with the 'right of way' and passenger capacity determines whether an equivalent system would be within the definition for this research.

ID	Power Supply	Guidance System	Right of Way	Cap. >50	Included/ Excluded	Example Systems
A	750vd.c. 3rd Rail	Steel Running Rail	A	Yes	Excluded	DLR Beijing Light Rail
B	750vd.c. OLE	Steel Running Rail	C	Yes	Included	Manchester Metro NET
C	Diesel ICE & Electrical Final Drive	Steel Running Rail	C	Yes	Included	Camden – Trenton Zwickau
D	750vd.c. 4th Rail	Steel Running Rail	A	Yes	Excluded	London Tube
E	Diesel ICE & Mechanical Final Drive	Raised Kerb & Discretionary	B	Yes	Potential to be Included	Leeds & Adelaide Guided Bus-ways
F	1.5kvd.c. OLE	Steel Running Rail	A	Yes	Excluded	Tyne & Wear Metro
G	750vd.c. 3rd Rail/OLE/ Battery	Steel Running Rail	C	Yes	Included	Bordeaux Tram
H	750vd.c. 3rd Rail	Raised Kerb	A	Yes	Excluded	Lille VAL
I	Alt Fuel ICE & Flywheel	Steel Running Rail	A	No	Potential to be Included	Parry People Mover
J	750vd.c. OLE	Guide Rail	C	Yes	Included	Caens Twisto Nancy
K	Diesel ICE & Electrical Final Drive	Optical White Line & Discretionary	C	Yes	Potential to be Included	Rouen Civis Guided Bus
L	750vd.c. OLE & 15kV d.c. OLE	Steel Running Rail	C	Yes	Included	Karlesruhe
M	600/750vd.c & 15kV 16⅔ Hz a.c.	Steel Running Rail	B	Yes	Included	Kassel
N	600/750vd.c. & Diesel ICE & Electrical Final Drive					
O	Diesel or LPG ICE & Electrical Final Drive & Flywheel or Battery	Magnetic & Discretionary	B	Yes	Potential to be Included	Eindhoven PHILEAS

Table 2 – Examples of Light Rail systems defined

Each item in Table 2 forms a different combination of power supply and guidance system. Note the similarities between B, F and J - these systems have d.c. OLE (750v or 1.5kV) but differences in guidance and segregation mean that one system (T&W Metro) is excluded and two (Manchester Metro and Caens Twisto) are included. The shaded areas indicate the rationale for exclusion or areas of doubt if inclusion is supported as incremental system development stages.

Review and Analysis

When considering the definition of 'light rail', for the purposes of this research, a boundary needs to be established that the definition will provide. The definition applied will then include or exclude different LRT modes from consideration in the model as an alternative to OLE. This will have implications for both vehicle and infrastructure.

The proposed definition is for a system that can

- Be laterally guided by non-discretionary means;

- Be capable of segregated running and non-segregated, at grade on-street;
- Have a minimum passenger carrying capacity of 50.

However, this definition would appear to exclude systems such as Leeds and Rouen. As seen the Leeds bus-way is to be a forerunner to a full light rail system, so is it appropriate to include such a system as a viable alternative? By definition a system proposed to use OLE will have a fixed guide-way system. Electrical current collection requirements mean this cannot be compromised so an alternative fuel source equivalent should also have fixed guidance. It follows that Leeds and Rouen are potentially included on the basis that over time incremental development of system complexity will likely mean less discretionary guidance. A rubber-tyre LRV that still meets the above criteria can be permitted; for example, Caens.

As seen in the U.K., the competition for public finance funding is growing, against increasingly risk averse consortia seeking to limit their investment. These considerable issues provide further rationale for looking at (more cost effective) alternatives to OLE; but the sources and mechanisms of finance for light rail systems per se will not be considered to be significant in this research.

There appears to be a trade-off in the cost of system implementation (based on the level of integration and penetration) and the likely patronage of the system:

- High cost on-street running that penetrates in to the recreational and commercial districts of a city, integrated in to existing transport networks will be relatively expensive but likely to attract relatively high passenger numbers

- Lower cost systems with peripheral routes and limited integration will be likely to attract relatively fewer passenger numbers.

By implementing the Civis in Rouen an attempt is being made to introduce new, passenger-attractive technology without the cost of full light rail implementation; justification why the Civis system may be considered if this introduces the benefits of light rail without the headline cost. Other examples of options for implementing a ‘cost efficient’ alternative prior to OLE LRVs allowing for incremental growth:

- Incremental technology growth, e.g. Leeds: from guided bus-way to light rail
- Incremental route growth, e.g. NET: build one route, establish precedent: expand the system
- Incremental technology and route growth together, e.g. Kassel: expand system needing hybrid vehicles to grow the network

The environmental considerations for any proposed system can involve complex arguments that are difficult to quantify. Electric traction is generally considered ‘clean’ due to the lack of emissions at the point of use and ICE vehicles are considered as polluters even though overall they may be no more damaging on the environment. Notwithstanding public perception, the alternative to the OLE solution could be a price worth paying to avoid visual and potentially electromagnetic and stray current intrusion of OLE. The local populace (via an elected mayor) in Bordeaux considered the implementation of a novel system viable to avoid OLE associated ‘pollution’.

There are key issues facing the continued re-deployment of light rail in the U.K. It is possible to see that given the constraints on finance and the accuracy of passenger forecasts any system promoted will need to exercise the most cost effective solution. This must be whilst generating the revenues required to drive financial sustainability in to operation and being at least as environmentally sound as the OLE option, i.e. economic and environmental performance.

Research Proposal

There are a number of solutions (see examples in Table 2) that can be used as an alternative to the OLE option. To provide validation of the alternatives a model needs to be developed that will assess life cycle LRV and infrastructure costs and emissions. The proposed model to address this is illustrated in Figure 2.

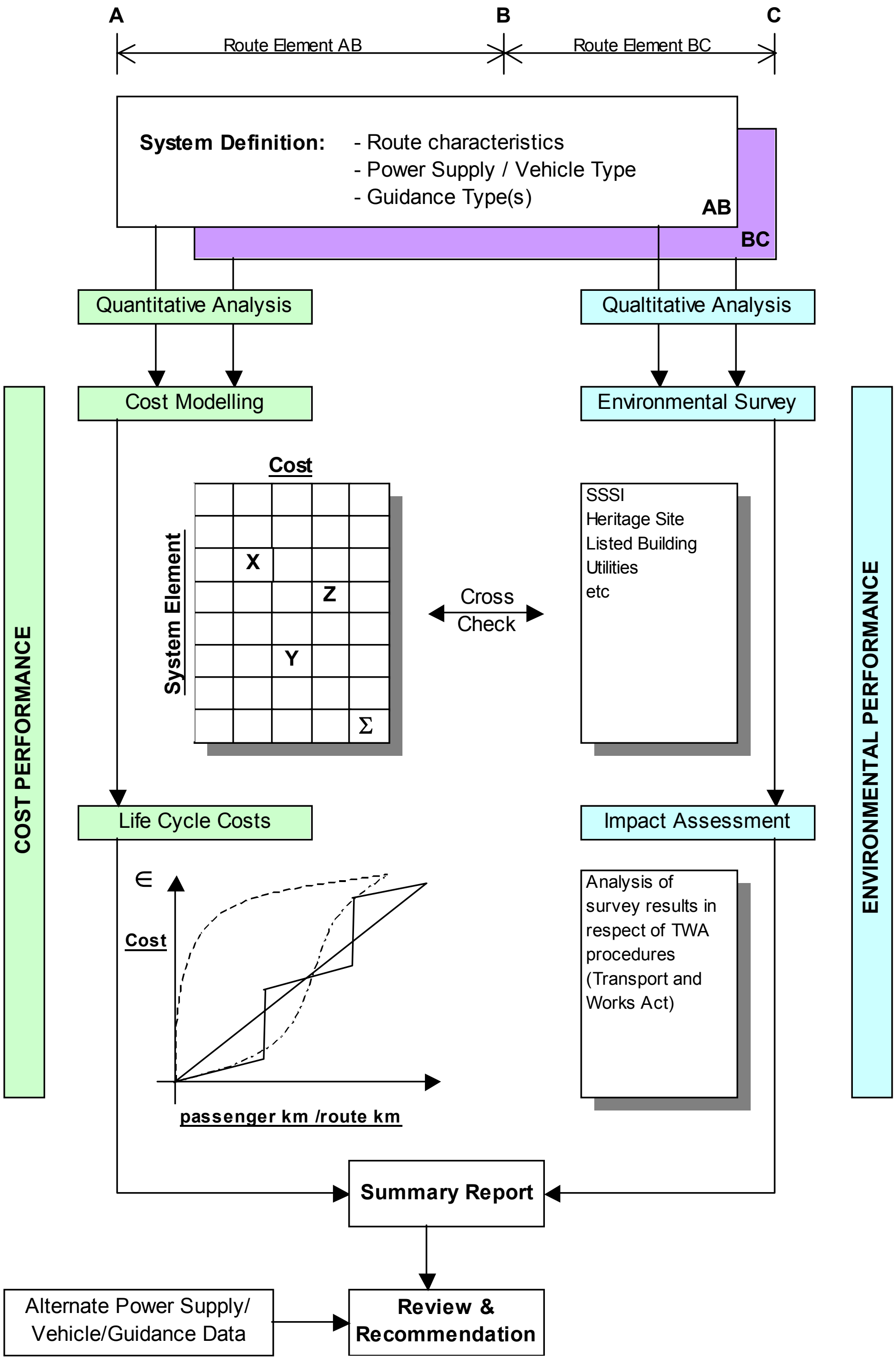

Figure 2 – Proposed Model for Life-Cycle Costing of LRT Systems

There are two key factors that determine the vehicle and infrastructure design, build and hence 'cost' and 'environmental performance', for a given pre-determined route:

- Power supply mode – single or hybrid
- Guidance system – single or hybrid

There is no interdependency between power supply and guidance system; each power supply mode (or combination) could be implemented with each guidance system (or combination). The proposal for this research is to develop a suite of reports based upon the cost and environmental data that will provide the basis for the modelling data to be presented.

Model Construction
The model will be built on a detailed schedule of light rail system architecture, systems and sub-systems. This schedule will form the basis for identifying the costs and environmental impact for each option.

It will be necessary to provide a robust, transportable measure between light rail system and sub-system elements if the model is to be baselined, otherwise comparison between systems will be meaningless. Clearly this will require careful consideration to be given to the measure. Typically, this may be of €/km or €/passenger space 1000km, for example. By using a measuring of available space as opposed to the actual numbers of passengers forecasted to use any given system, this will allow like-for-like comparisons to be made.

Anomalies of specific system configurations will need the most careful consideration, as these will be the key differentiators between the systems. Small degrees of change (more of/less of) will not be as critical as step-change (requirement/non-requirement) elements between light rail systems.

As key outputs to the model it will be necessary first to identify stakeholder groups and the metrics (KPIs) that they will be interested in. Likely stakeholders are local and national government; local and national transport companies, construction consortia, and pro and anti-light rail pressure groups and the potential customers of the system.

Data Population
As discussed there are some obvious discrete case studies that will provide data, for example the NET system. The statistical significance of this data will need to be clearly demonstrated.

The baseline model will be the OLE LRV without energy storage. There will be much data available for this. The other data-sets will be populated based on combinations of traction power supply mode (including energy storage) and guidance system. Energy storage is energy that is retained on-board the vehicle for traction power. This excludes retained energy for auxiliary power and energy storage where this is exported to the OLE system, for example through regenerative braking. (The electrical distribution network is a pseudo-energy storage system.)

To limit the types of system that can be considered prior to populating the entire model with excessively detailed data it will be first practicable to conduct a series of outline first pass go/no-go tests, as detailed below:

- The system provides non-discretionary guidance capability
- The system can be utilised on non-segregated routes
- The vehicle has a capacity of >50 passengers
- The system technology has been used in a transferable mode (proven, system data available)
- The system is viable in the environment being studied (e.g. a diesel LRV in covered areas)

All systems will need to be considered in terms of the vehicle and infrastructure separately although there is likely to be extensive areas of overlap. For example, the non-electrified system infrastructure will be similar in each case (e.g. diesel vs. alternative fuel ICE) except for fuelling facilities and the relative emissions.

The population of emission data for each system will have to be precise and consistent in how this is applied for cost purposes. Clear rules must be established and applied to indicate how far up the energy supply-chain and for which elements of the system the analysis will seek to demonstrate in the measures. This will need to be at common critical point across all systems where the reliable and valid emission costs can be collated.

Model Output

To be valid the model proposed should be able to be applied to any given system in its unique environment to produce a suite of reports tailored to the previously identified KPIs. This data may be used to allow an informed decision to be made on the best-fit selection of traction power and supporting infrastructure for future U.K. light rail systems depending on the viewpoint of the 'decision-maker' – which will dictate which metric is the most appropriate to their particular case. In terms of recommendations arising from the model it will only be possible to make relative statements, regarding different aspects of the results that may suit different stakeholder agendas. The recommendations will take the form of an objective report and commentary on the findings.

Research Focus

This paper has identified a rationale for researching light rail systems to model alternative fuel traction power supplies:

Application	The U.K. light rail sector is expanding, so this research has the potential for real-world application. U.K. metro and heavy rail on the other hand is consolidating
Challenge	Although 'in vogue' for environmental and transport planning agendas, light rail systems are not without issues. A key issue being financial viability based on passenger revenues. The financial viability defined pre-implementation will be affected by projected build and operate costs offset by the forecast passenger numbers.
Relevance	With the pre-requisite to demonstrate financial viability this is exacerbated as more systems are being proposed against a back-drop of increasingly scarce finance. There is a need for flexible adaptable designs that may be more cost-effective than OLE. Also the alternative needs to demonstrate environmental performance; i.e. are there more cost-effective and flexible means to achieve an environmentally friendly, self-powered, non-OLE system? These alternatives need to be studied for feasibility and ultimately modelled.
Method	As stand-alone systems there are clear boundaries to light rail systems, not apparent in metro and heavy rail applications. This will make focus easier.
Data	There should be sufficient empirical data from U.K. and overseas systems to support each variation of power supply.
Technology	An implication of the data availability is that the technology for each variation exists either directly in a light rail application or is transferable from an equivalent mode, e.g. bus

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