WEST OF ENGLAND RAPID TRANSIT

Technology Review

Final Report

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1. INTRODUCTION

Background

1.1 The four Unitary Authorities of the West of England, Bath and North East Somerset, the City of Bristol, North Somerset and South Gloucestershire, are currently undertaking a programme of work to develop a Rapid Transit System for the Greater Bristol area.

1.2 In 2006 the Greater Bristol Strategic Transport Study (GBSTS) identified the need to progress a rapid transit network for the sub-region, as part of a package to successfully and appropriately accommodate additional transport movements arising from predicted residential and employment development over the next 20 years. The study concluded that:

"*further work is required to identify the type of vehicle used to operate the service but modern, low-floor, articulated buses are likely to be the most appropriate, flexible and cost effective vehicles to satisfy the requirements of the service*"[4].

1.3 GBSTS identified four Bus Rapid Transit (BRT) corridors, three of which have been included in the Joint Local Transport Plan (JLTP) and have a current financial allocation in the South West Regional Funding programme to 2016 totalling £71 million (2006 prices) with operation of the first route targeted to commence in 2013.

1.4 To obtain this funding, the West of England Authorities are required to submit a Major Scheme Bid for the first part of this network at the end of 2008. The route identified for this application is from Ashton Vale to Temple Meads via Bristol City Centre.

1.5 As part of the programme of work to develop a Rapid Transit System, the West of England Authorities have considered different rapid transit technologies. A review of technologies was first undertaken in 2007, this looked at a range of options from monorail and light rail through to conventional buses. Work from this review has been incorporated in to this report.

1.6 The West of England Authorities wish to ensure that the most appropriate technology is identified for its rapid transit network and further work is being undertaken specifically to look at the opportunities provided by newer rapid transit technologies. As a result, Steer Davies Gleave has been commissioned to undertake a further review of appropriate technologies that could be used to deliver the Ashton Vale to Temple Meads via Bristol City Centre route but also the wider identified rapid transit network. The brief for this assessment is included in Appendix A.

Proposed Rapid Transit Network

1.7 This technology review has been undertaken against the background of the proposed network of rapid transit routes being developed. The first three lines of the network

4 *Greater Bristol Strategic Transport Study*, Atkins, June 2006

identified in the JLTP are cross-city, sub-regional routes:

- Ashton Vale to Emerson's Green.
- Hengrive/Hartcliffe to North Fringe.
- Bath to Cribbs Causeway.

Ashton Vale to Temple Meads Route

1.8 For the purposes of this report and the comparison of different technologies, the following details on the Ashton Vale to Temple Meads route were used:

- The Ashton Vale to Temple Meads route is approximately 7km long, with around 3km of this being proposed as a segregated corridor and 4km running on-street in Bristol City Centre.
- The route is proposed to run from the existing Long Ashton Park and Ride site via an alignment through the proposed development at Ashton Park, crossing the Portishead railway line at Ashton Gate, to run alongside the Portishead railway line until it crosses the existing Ashton Avenue Bridge to connect with the alignment of the Bristol Harbour Railway line. The route continues running along the south side of the Floating Harbour adjacent to Cumberland Road to connect through to the proposed development at Wapping Wharf and the Bristol Industrial Museum.
- There are still options for the on-street sections in Bristol City Centre but the route will connect Broad Quay, The Centre, Broadmead, Cabots Circus, Old Market and Bristol Temple Meads Railway Station.
- The system will be required to provide a maximum capacity in the order of 3,000 passengers per direction per hour.

Study Process

1.9 In undertaking assessments of the appropriateness of different technologies for the development of a public transport scheme different guidance documents[5] and accepted professional practices advocate a similar approach in that they propose assessment of a range of different technologies against a set of criteria which usually include:

- Goals and objectives including policy objectives,
- Current problems and future challenges, including issues of local context within which the transit system will be implemented and operated,
- Physical opportunities and constraints that will influence the design or technology choice,
- Deliverability.

1.10 Good practice also advocates a process of increasing levels of detail in a step-wise or iterative manner to progressively eliminate those options that are not likely to provide

[5] For example:

Affordable Mass Transit Guidance: Helping you choose the best technology for your Area, Commission for Integrated Transport, 2005

Bus Rapid Transit – Planning Guide 2007, Institute for Transportation and Development Policy, June 2007 an appropriate or affordable solution to the identified need and objectives. To this end a staged process of firstly looking at a high level strategic assessment of the alternative technology options followed by a more detailed review of the most appropriate technologies is advised.

1.11 The process undertaken in this review has been:

- **High Level Strategic Review** of technology options – consideration of all the different public transport options for a transit network in the West of England has previously been undertaken firstly by GBSTS and further as part of the development of the rapid transit proposals. This review has briefly reviewed the range of different public transport options and has taken a high level look at system capacities and costs.
- **A Technical Review** of the individual technologies – looking at their application, operation, opportunities and constraints of the vehicle technologies and infrastructure.
- **A Comparative Assessment** of the individual technologies – looking at:
  - The application of the technology to the Ashton Vale to Temple Meads via Bristol City Centre to provide in particular a cost comparison of the technologies when applied to a specific route.
  - The application of the technology on the wider rapid transit network to assess the appropriateness of the technologies and the possible issues raised.
  - The different technologies are then assessed against the objectives of the proposed rapid transit network.

1.12 This report also includes a section on fuel technology, Section 6.

Steer Davies Gleave

1.13 Steer Davies Gleave is an independent consultancy working worldwide across the transport sector, providing advice to government, local government, transport bodies, operators, financiers, regulators, developers and other interest groups.

1.14 Over the last decade, Steer Davies Gleave has worked on over 30 rapid transit schemes worldwide. Our expertise extends from pre-feasibility and scheme development to securing powers, implementation and funding. Projects include:

- Barcelona Baix Llobregat Tramway, Spain
- Blackpool / Fleetwood Tramway Upgrading
- Cambridgeshire Guided Busway
- Cancún LRT, Mexico
- CentreLink, Tyne and Wear
- Cross River Tram, London
- Croydon Tramlink
- Docklands Light Railway (DLR) Extensions
- Dublin LRT (LUAS), Ireland
- Edinburgh Tram Line One
- East Leeds Quality Bus
- Greenwich Waterfront Transit
- Leigh-Salford-Manchester Quality Bus
- Luton-Dunstable Translink
- Manchester Metrolink
- Merseytram
- Midland Metro Network Development
- Santiago Guided Busway, Chile
- Sunderland Direct Metro Extension
- Transmilenio Busway, Bogotá, Colombia
- Tyne and Wear Metro Project Orpheus
- West London Tram

1.15 Steer Davies Gleave also has extensive experience of the UK railway market where our clients include, Network Rail, Office of the Rail Regulator, Department of Transport, and the majority of the UK operators. We are currently involved in the development of Tees Valley Metro, which may include either Tramtrain or conventional rail modes.

2. PUBLIC TRANSPORT TECHNOLOGIES

2.1 There is a wide range of public transport technologies that provide different benefits, operational characteristics and have different capital and operating costs.

Mass Transit

2.2 Metro or Light Metro such as LUL or Tyne and Wear Metro, which use either single or multiple high capacity units through large urban conurbations often utilising tunnelled infrastructure. Provide high levels of capacity between 25,000 and 45,000 passengers per hour per direction (PPHPD). As a result these are very expensive to deliver and only represent value for money if adopted on very high demand single corridor routes. Current estimates for extensions to metro systems for example are in the order of +£100 million per km. Mass Transit would provide way in excess of the capacity required for the rapid transit network and is very unlikely to make a case for this level of investment.

Heavy Rail

2.3 Heavy Rail systems usually provide local and regional commuter and long distance higher speed services. Heavy Rail services can carry between 10,000 and 30,000 PPHPD and again requires significant capital investment. Therefore, as with mass transit it is very unlikely to make a case for this level of investment.

2.4 A heavy rail solution would also be very difficult to develop in the urban corridors required and connect directly in to the local or city centre as required by the rapid transit network. More likely, any possible extensions to the local heavy rail network would connect in to existing termini which are or with current proposals will be capacity constrained. An interchange to bus or rapid transit to reach Bristol city centre would be required.

Light Rail / Tram[6]

2.5 Light Rail (LRT) or electric trams, similar to those operating in places such as Nottingham and Dublin, provide medium capacity systems on dedicated routes and can provide improved city centre connectivity. Typically LRT systems provide for between 4,000 and 10,000 PPHPD.

2.6 Several British Cities have re-introduced light rail systems with modern trams providing level boarding. The systems are provided with a high level of information and quality facilities integrated to provide a significant increase in passenger benefits compared to the bus or rail services.

2.7 Electric power provides light rail systems with a significantly improved performance compared to heavy rail, in terms of acceleration and deceleration, due to their lighter weight as they are not designed to withstand the same impact forces as traditional rail

[6] Text in this section takes information provided in the report *West of England Partnership: Greater Bristol Bus Rapid Transit (BRT) Technology Review of Systems*, Halcrow Group Limited, September 2007

vehicles.

2.8 Rails in conjunction with the tram vehicles provide a smooth ride for passenger comfort and the rails add to passenger perception and confidence in the certainty and stability of the system. The lower forces exerted by the light rail vehicle on track and structures results in lower capital costs and the shorter, usually articulated, vehicles enable sharp bends and steep gradients (compared to conventional railways) to be incorporated into the route, including elements of street running.

2.9 The capacity of light rail systems varies. In the UK the Midland Metro trams can carry 152 passengers each of which 56 can be seated. Each tram also has space for two wheelchairs. They have a maximum speed of 80kph. In Nottingham, UK, the five section tram has a passenger carrying capacity of 191 with a maximum speed of 80kph and radius capability equivalent to conventional buses.

FIGURE 2.1 NET LINE 1, NOTTINGHAM

2.10 LRT schemes have proved relatively expensive, currently costing in the order of £10m to £15m per km, and have proved difficult to fund and deliver in the UK. The Department for Transport (DfT) also requires a local funding contribution of around 25% (meaning the Local Authorities would need to provide funding in the order of £25m for the Ashton Vale to Temple Meads route). The corridor would also need to have a much higher demand/catchment than currently assessed in order to make a case for this level of investment to DfT.

Tramtrain

2.11 Tramtrain vehicles are capable of operating on both a heavy rail network and on urban low floor tram networks enabling light rail style services to be developed over a wider suburban heavy rail network and making use of improved proximity and connectivity of existing tram networks within urban centres.

2.12 Tramtrain is a developing technology, with a trial is planned in the UK. This technology has not been considered in detail previously and therefore this technology review has chosen to look at this option in more detail, see Section 4.

Ultra Light or Light Weight Transit

2.13 The cost of light rail systems are considered prohibitive for many conurbations, particularly where passenger demand is lower, and a number of "ultra-light rail" or light weight rail based transport systems are being developed, targeting this potential market.

2.14 Ultra Light or Light Weight Transit is also an emerging mode which is proposed to use lighter weight, lower capacity vehicles on lower cost rail infrastructure. The Parry People Mover (PPM) system, involving small vehicles with a driver, has been developed on narrow gauge railway track with a charged flywheel automotive system. Bristol Electric Railbus Ltd (BER) also operated a demonstration service along the Bristol Harbourside on existing standard gauge rail for 30 months between 1998 to 2000.

2.15 The mode is promoted as providing improved benefits to that of bus rapid transit (BRT) for similar cost. This technology review has chosen to look at this option in more detail, see Section 4.

Bus Rapid Transit

2.16 Bus Rapid Transit systems use high specification buses and a variety of physical, operating and system elements to provide a permanently integrated system. Bus Rapid Transit systems provide for between 2,000 and 4,000 PPHPD. The technology is generally promoted as being flexible, easier to implement and integrate within city centres than other transit options. Bus rapid transit is considered in more detail in Section 4.

Guided Light Transit

2.17 Guided Light Transit encompasses a number of different vehicles all with different characteristics, and includes Civis, Guided Light Transit, Phileas and Translohr. The vehicles are rubber tyred, use differing forms of guidance system, and can operate on overhead line. They are all currently proprietary systems and all continue to have deliverability, reliability and operational issues. In addition due to the high development costs and low numbers of vehicles in production these vehicles are very expensive (in the range of £0.5m to £1m per unit). Guided Light Transit has therefore not been considered further in this technology review.

Buses

2.18 Conventional bus technology can provide a variety of capacities and the vehicle can be the same as those used for BRT. Improvements to existing bus services are already included as part of the Greater Bristol Bus Network programme of works. As identified in GBSTS and JLTP, the proposed rapid transit network needs to deliver something over and above the benefits that GBBN will deliver so therefore conventional buses have not been furthered considered in this technology review.

Automated People Movers

2.19 Automated People Movers are generally used or promoted to be used in two forms, at airports for inter-terminal or satellite boarding gate connections, or as driverless Metro style systems. Examples are the VAL system and the ULTRA system currently being developed for Heathrow Terminal 5.

2.20 Véhicule Automatique Léger (VAL) is an automated system that uses rubber-tyred vehicles on a segregated guideway. It is used in Lille, Paris, Toulouse, Rennes, Chicago and Taipei. This style of system provides similar levels of capacity to Light Metro but due to the automation are generally more expensive. This mode is not considered further in this review.

FIGURE 2.2 VÉHICULE AUTOMATIQUE LÉGER (VAL)

2.21 APM also includes Personal Rapid Transit of which the ULTRA system is one example. Vehicles are described as driverless taxis operating on segregated often elevated tracks made from concrete. The reduced need to make lots of stops means that faster journeys are possible. The driverless pods are able to carry a maximum of four people. Even though they are driverless the cars have an automatic protection system, which acts as a safety net around the vehicle and prevents potential collisions. They have a car type chassis and rubber tyres and are guided electronically with battery power, fully loaded each vehicle weighs 800 kg.

2.22 ULTra’s first application in the UK will be to serve the long term executive parking at Heathrow Terminal 5, although other systems are under consideration (such as at Dunsfold Park in Surrey).

2.23 Both systems currently need dedicated, completely segregated infrastructure generally underground or elevated.

FIGURE 2.3 ULTRA

2.24 Personal Rapid Transit technology is new, innovative but largely untested and not currently available on the scale that would be required to deliver the proposed rapid transit system. As such it has not been considered further by this technology review.

Summary

2.25 The consideration of all the different public transport options for a transit network in the West of England has previously been undertaken firstly in GBSTS and further as part of the rapid transit scheme development. This, and a high level review of capacities and costs, has identified that mass rapid transit, heavy rail, light rail automated people movers and personal rapid transit are, in our opinion, not appropriate technologies for the proposed rapid transit network. This does not mean that these technologies are not appropriate in specific circumstances but that they fit less well with the proposed objectives of the rapid transit scheme and they are less likely to provide a successful case for government funding for this particular scheme.

2.26 This technology review therefore now concentrates on the rapid transit technologies of Tramtrain, Light Weight Rail and Bus Rapid Transit.

3. OBJECTIVES OF THE RAPID TRANSIT NETWORK AND TECHNICAL ASSESSMENT CRITERIA

Objectives of the Rapid Transit Network

3.1 In reviewing the three transport technologies covered by this report it is important to identify the objective any new transport provision is required to meet and the ability of the technologies to meet these requirements.

3.2 The Greater Bristol Strategic Transport Study (GBSTS) set out the objectives of future transport improvements for the Greater Bristol area. The GBSTS states the aim of the Second Generation Public Transport Improvements in Greater Bristol is "to provide high quality alternatives to the private car".

3.3 GBSTS set out the rapid transit objectives as:

- Extending choice of transport modes for all, in particular for private car drivers to encourage a shift to public transport;
- Promoting sustainable development by providing high quality public transport links;
- Improving access to public transport in areas that currently have poor provision;
- Improving integration of the public transport network;
- Promoting social inclusion by improving access to employment, retail, community, leisure and education facilities;
- Improving safety along transport corridors by providing high quality public transport alternatives to the private car.

3.4 Rapid Transit is therefore designed to result in:

- Mode Shift – Providing a step change in the provision of public transport, which results in people shift from the private car to public transport.
- Reduced Congestion – A measure of reduced congestion is the overall network capacity, the number of people transported within a corridor.
- Economic Growth – Supporting the economic development of the area by improving access to employment, retail and leisure and through reduced congestion.

Technical Assessment Criteria

3.5 To provide the greatest level of confidence and robustness in this review a detailed set of technical assessment criteria has been identified. This is to ensure that individual aspect of each technology are identified and evaluated across the three technologies. These criteria are :

Vehicle Characteristics

- Step free – Provide a nominal boarding distance between the vehicle and the stop.
- Gap Free – Provides level access from the stop to the vehicle.
- Vehicle Capacity -Provides a sufficient passenger carrying capacity capable of meeting the identified demand with an appropriate service frequency.

- Seating – Provides an appropriate number of seats within the vehicles capacity.
- Route Capacity – The hourly capacity of the service on the route.
- Speed – The speed characteristics are appropriate to provide a form of rapid transport.
- Doors – The vehicle is equipped with sufficient doors to minimise boarding and alighting times.
- Runtime – Time taken to run the length of a route.
- Road Junctions – Can take advantage of priority at signalled junction and minimise the impact on other traffic.
- Gradients – Has the vehicle performance to cope with gradients.
- Perception of quality – Provides a perception of quality, and a high quality modern image.
- Axle Load – Weight of the vehicle on each axle.
- Maintenance and depots – Requirements for dedicated / possible connected depot and maintenance facilities.

Environmental

- Visual – Visual intrusion within the proposed corridor.
- Maintains existing facilities – Maintains cycle and pedestrian facilities.
- Severance (guidance, rails etc.) – Does the system create severance, rails, fencing etc.
- Land take – Width of land required.
- Noise – Vehicle and operational noise.
- Emissions – Vehicle emissions.

Operation

- Vehicle Recovery –Complexity and impact of recovering failed vehicles.
- Integration with Heritage Railway – Enables the Heritage railway to be retained.
- Service competition – Would the proposed route potentially suffer from competing modes on parallel corridors.

Local Context Issues and Deliverability

3.6 As well as these technical issues the following criteria were also reviewed:

- Segregation usable by other modes – In the case of rail modes the track would need to be grooved rail within a surfaced finish to allow other modes to operate along its length.
- Penetration of City Centre – Provides good connectivity to interchange, shopping, commercial and leisure facilities.
- Sub-regional accessibility - Ability to deliver benefits to the wider sub-region.
- Complements showcase bus scheme – Complements the priority improvement measure currently and to be provided on the Bus Showcase routes.
- Maintains road network capacity – ensures sufficient road network capacity is maintained.
- Restricts access to segregation – Can provide a barrier to entry by none

authorised vehicles.

- Provision to access alignments – Provide the ability for other public transport modes to access and gain advantage of the segregation provided on the rapid transit routes.
- Capital cost – Cost of the scheme and current funding available.
- Vehicle cost – Cost of the vehicle, this also includes the issue of fleet size, a lower cost vehicle with lower capacity can work out the same as a higher cost vehicle
- Technology maturity – Length in commercial service, the state of the market i.e. proprietary or competitive market exists for purchasers.
- Risk – Risk of deliverability, procurement, operation, maintenance etc.
- Funding – available funding levels and likelihood of securing funding.

4. TECHNICAL REVIEW

Tramtrain

4.1 Tramtrain was developed in Germany to enable tram style services to be developed over the wider suburban heavy rail network, making use of improved proximity and connectivity of existing tram networks within urban centres. The original impetus to develop Tramtrain in Germany came from a wish to make greater use of existing tram and rail infrastructure, with only generally minimal infrastructure works undertaken to connect the two networks.

4.2 Tramtrain in the simplest of terms is a vehicle solution not an independent mode such as bus or tram. The vehicles are capable of operating on both the heavy rail network and on urban low floor tram networks, which depending on the location and application requires the ability to work on differing overhead line power supplies and possibly independently through the use of onboard diesel generators. The vehicles are built to provide greater crash protection due to their interoperation with heavy rail vehicles.

4.3 The Tramtrain technology has been developed and operating in Germany for over 15 years with the first route developed between Karlsruhe and Bretten. Further routes have been developed in Germany, France and the Netherlands, with the maturity of the vehicle technology improving and becoming more standard in mainland Europe.

Tramtrain in the UK

4.4 There are currently no Tramtrain schemes within the UK. The Tyne and Wear Metro extension to Sunderland does incorporate some aspects of Tramtrain in that it runs on the heavy rail network in conjunction with freight, regional and long distance rail services. The development of the extension has in part assisted the development of Tramtrain in the UK in that Network Rail has developed Railway Group Standards for the operation of light rail vehicles[7] and acceptance of light rail vehicle for shared running[8] on their network.

4.5 The Tyne and Wear system has high floor vehicles, which operate on the original network under signalled operation, with a train protection system (Indusi train-stop), and as such has not addressed the issues of operating low floor vehicles, running on line of sight on Network Rail infrastructure. The system does however provide some insight into the complexities of shared running. The connection between the two systems needed to provide sufficient space to stand a train between the two networks to enable the service regulation on the separately controlled networks. The shared running section is fitted with both TPWS and the Indusi Train stop system, the Metro train detection and passenger information system is overlaid on the route, the in cab radio was modified to automatically facilitate communication with the Network Rail

[7] Railway Group Standard GE/GN8502 Operation of Trams and Light Rail or Metro Vehicles Over Network Rail Controlled Infrastructure

[8] Railway Group Standard GM/RT2452 Acceptance of Trams and Light Rail or Metro vehicles for shared Running on Network Rail controlled Infrastructure

control centre and Metro control respectively when operating on the different infrastructure, two telephones system are provided to connect to the respective control and operating organisations and cameras, public address and station SCADA[9] systems were directed to the respective station operator. This highlights the possible requirements and complexity of developing a shared running system across two sets of infrastructure.

4.6 In operation the system was initially difficult to regulate resulting in significant disruption to the Metro service pattern and schedule on both networks, this was resolved by reducing the Metro and regional train frequencies on the shared section of the network.

4.7 The focus on Tramtrain in the UK is slightly different from mainland Europe, as few cities have existing tram networks which could be connected to the wider rail network to provide improved connectivity and services. Hence the focus in part appears to be the development and the use of Tramtrain to convert branch line services, with an aim to cut the cost of provision and operation.

4.8 A trial of Tramtrain in the UK is to be undertaken by Northern Rail on the 37-mile Penistone Line between Huddersfield and Sheffield see Figure 4.1. The current service will be replaced using five Tramtrain vehicles between 2010 and 2012 and will look at the environmental, operational, passenger and lifecycle benefits along with the technical suitability of the technology. The vehicles may then be trialled on the Sheffield Supertram network to assess the operation and suitability of the technology on a UK tram network.

4.9 It is currently unclear if the vehicles will be dual mode to operate on a 750v dc overhead line network and under diesel power and will be provided with the operational systems to operate both on Network Rail and Supertram infrastructure.

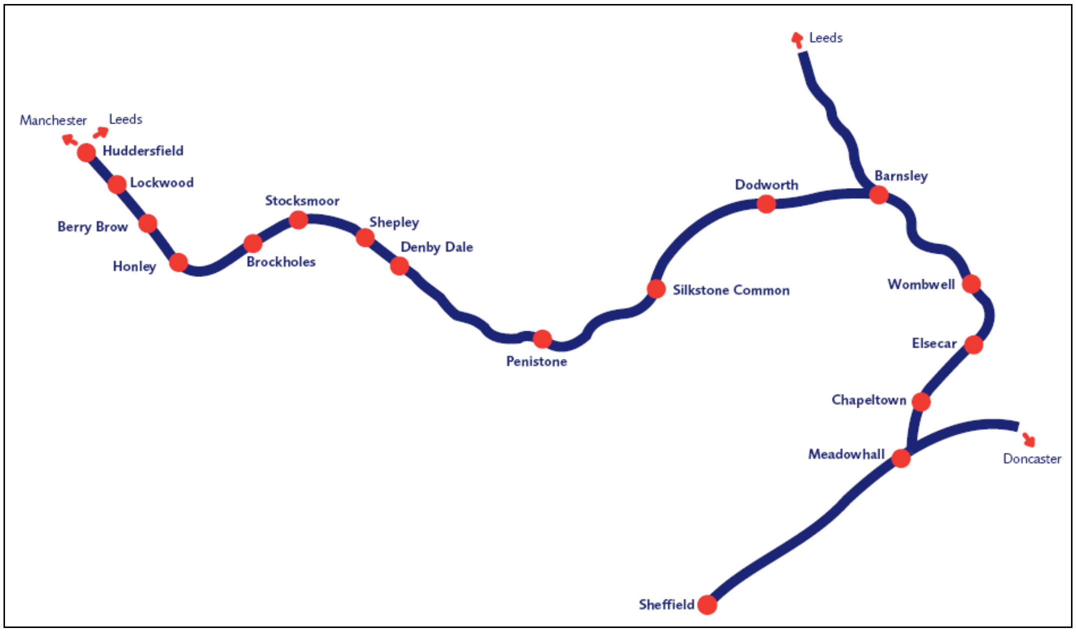
Operation

4.10 The current requirements for the operation of light rail vehicles relates to the running of vehicles from other administrations[10] onto Network Rail infrastructure. A service or vehicle operating wholly on Network Rail infrastructure would have to comply with the normal standards relating to the rail network. It is unclear if this requirement will be revised prior to, or following the Penistone trial.

[9] SCADA – Supervisory Control and Data Acquisition used for fire alarms, escalators, lifts, power, ticketing etc.

[10] Separately owned and operated networks, potentially operated under different safety arrangements, and potentially different infrastructure standards.

FIGURE 4.1 ROUTE OF PENISTONE TRAMTRAIN TRIAL



4.11 Operators of trains and stations on Network Rail infrastructure are normally required to have a safety case accepted by Network Rail in accordance with the "Railway (Safety Case) Regulations 1994" and amendments thereafter. The Railway Safety Case describes the operation proposed, identifies the risks which it presents and the control measures used to mitigate these so far as is practically possible. All the other operators utilising the proposed mixed running route or routes would also need to update and reissue for acceptance a revised safety case.

4.12 The primary issue in assessing the impact of light rail on the heavy rail network is the level of interaction with Network Rail and heavy rail operations. This might include one or a combination of the following:

- **Exclusive Running** in which light and heavy rail vehicles are separated by time of day. For example, light rail may use a section of the route during the day with heavy rail freight trains using it at night when all light rail services are finished or suspended. Although there may need to be some changes to the signalling system, this mainly relies on procedural measures to ensure that all vehicles of one type are clear of the route section before another type is allowed to enter it.
- **Limited Exclusive Running** in which light and heavy rail vehicles have exclusive use of the section of the route for limited periods during the day. This requires positive signalling measures to prove that all vehicles of one type have cleared the section before those of another type are allowed to enter it. A light rail route crossing a heavy rail could form this type of operation.
- **Mixed Running** in which vehicles of both types use the section of route at the same time. Because of the potential severe consequences of a collision between heavy and light rail vehicles, relying on drivers to observe line-side signalling is not felt to provide adequate protection or to reduce the risk as far as practicable. Additional measures are required to ensure that all vehicles (light and heavy) stop at a signal at danger (or within the overlap) by the automatic application of the brakes to reduce speed prior to and to bring the vehicle to stop at a red signal.

These measures have to be applied to all signals capable of displaying a stop aspect and to all vehicles using the route, light and heavy.

- **Parallel Running** in which the light rail operation take over a line or runs alongside an existing heavy rail route. This form of operation significantly differs from those above and is not covered by the same network Rail standards, this form of operation would need to be agreed with Network Rail and the Railway Inspectorate and is likely to result in the segregation of the two systems. An example is the parallel running on Nottingham Tram alongside the Robin Hood line, where to minimise operational and maintenance issues the two lines are separated by a fence.

4.13 In the case of Parallel or Limited Exclusive Running HMRI / ORR are likely to allow an exemption from the requirements for the operator to hold a heavy rail Railway Safety Case. This in turn means that compliance with Railway Group Standards is not required, but operating rules and agreements may need to be put in place to provide the levels of safety required for the operation and maintenance of both systems.

4.14 Where Tramtrain operation in conjunction with other heavy rail would result in increased service frequencies a route may need to be re-signalled, which would be a significant cost to any proposed scheme, particularly if the existing signalling system technology is old and requires complete replacement as part of any improvements.

4.15 The Penistone trial will hopefully facilitate setting the vehicle standards for Tramtrain vehicles, which if the manufacturers are able and willing to provide a suitable vehicle depending upon the market demand could significantly de-risk future Tramtrain projects and potentially provide a competitive market.

Vehicles

4.16 Three main vehicle suppliers offer Tramtrain vehicles, Alstom, Bombardier and Siemens. To date the current vehicles on offer have not been produced for any significant length of time and have not been produced in significant numbers (around 70 units in service of 125 ordered).

4.17 Alstom currently lead the field with orders although all the manufactures have a similar number of vehicles in service.

4.18 As mentioned above the Light Rail vehicles need to meet minimum structural requirements set out in Railway Group Standards to operate under shared running. Tramtrains developed to date for mainland European markets have been developed to meet improved structural requirements and significantly exceed that of tram vehicles. It is not currently clear if these vehicles would comply with Railway Group Standards for Light Rail vehicles.

4.19 The vehicle performance is similar to that of trams with a slightly higher top speed of 100km/hr.

4.20 **Alstom – Regio Citadis**, is based upon the multi-modular Citadis tram range adapted to provide improved crash protection for operation on heavy rail networks. The vehicle is low floor with three sections supported on four bogies. The vehicle has been produced to operate on two voltages 750V dc for tramway operation and differing ac traction voltages for heavy rail operation, the vehicle has also been provided with a diesel generator package, operating on 750V dc on the tram network and independently through the use of the diesel generator on none electrified suburban routes.

FIGURE 4.2 ALSTOM - REGIO CITADIS

TABLE 4.1 REGIO CITADIS DATA

Key Figures	
Length	36,762 mm
Width	2,659 mm
Seats	93
Standing	130
Doors	4 double per side 5 double doors available but reduces seating
Ordered / Supplied	82 / 28

4.21 **Bombardier – Flexity Link** has been supplied to Saarbrucken and is based on the range of Flexity vehicles supplied to Croydon, Stockholm and Instanbul. The vehicle has been produced to operate on both the 750V dc tram network and the AC traction voltage used on the heavy rail network.

FIGURE 4.3 BOMBARDIER - FLEXITY LINK

TABLE 4.2 FLEXITY LINK

Key Figures	
Length	37,000 mm
Width	2,650 mm
Seats	96
Standing	147
Doors	4 double per side
Ordered / Supplied	28 / 28

4.22 **Siemens – Avanto Tramtrain**, was based upon the S70 vehicle mainly produced for the American market. The Avanto Tramtrain version has been supplied to SNCF for operation in Paris. The vehicle is a five section low floor vehicle supplied to operate on both a 750V dc light rail network and the 25KV ac regional rail network. This vehicle is no longer available.

FIGURE 4.4 SIEMENS - AVANTO TRAMTRAIN

TABLE 4.3 SIEMENS AVANTO TRAMTRAIN DATA

Key Figures	
Length	36,965 mm
Width	2,650 mm
Seats	86
Standing	154
Doors	5 double per side
Ordered / Supplied	15 / 15

Diesel Trams

4.23 **Siemens – Combino,** a small low floor diesel powered tram vehicle was developed and supplied to Nordhausen. This is the only tram style vehicle to be diesel powered with the diesel generation package contained within the central passenger module. The vehicle is no longer available from Siemens following the replacement of the Combino model with Combino-Plus. The Combino plus is based on 9 metre body sections each of which are supported on a central bogie, this arrangement could limit the ability to include a diesel generator package within the vehicle.

4.24 The inclusion of a diesel generator on the roof of a low floor tram may be possible similar to the arrangement used on Tramtrains, although the available space would be limited and there could be a significant issue with the weight of the equipment.

FIGURE 4.5 NORDHAUSEN DIESEL COMBINO TRAM

4.25 If a manufacture were able to provide a diesel tram a 30 metre vehicle would provide a capacity of about 200 and could cost in the order of £2.5 to £3.0 million.

4.26 The infrastructure costs for a tram scheme mainly on a old rail alignment with a reduced length of on-street trackwork in the city centre could be comparable to the Nottingham Tram scheme, approximately £12 million per kilometre.

4.27 The efficiency of the individual vehicles can be a factor in the choice of mode, this can be influenced by:

- The fuel and efficiency of the propulsion system.
- The rolling resistance.
- The weight of the vehicle.
- The distance between stops.
- The speed profile due to stops, junctions etc.

4.28 Tramtrain vehicles are equipped with an electrical traction system which incorporates regenerative braking and can include energy stores such as high speed flywheels, capacitor or batteries. The efficiency of these systems is good, and could be improved significantly through the use of an energy store facility, which would significantly improve the reuse of the regenerated energy under braking and smooth the power demand under acceleration.

4.29 A diesel powered vehicle, utilises the diesel engine in conjunction with a generator package to provide the power for the electrical traction system. In this configuration the regenerative braking energy is not captured and is dissipated as heat, it could be reused in conjunction with an energy store if it were to be included within the traction package. Operation under diesel power would be less efficient than the electric overhead line, due to the losses in the generation system and the need for the generator package to operate at high revs while the vehicle accelerates, potentially a significant part of the time on a frequent stop urban network. The system is more efficient when operating to provide the vehicle with the constant speed power where the diesel arrangement can run at a more efficient speed.

4.30 The Rolling Resistance Coefficient of a Tramtrain vehicle is of the order of 0.005, much less than that of a rubber tyred vehicle which could improve the energy efficiency of the vehicle when compared to rubber tyred vehicles. This is however reduced by a number of factors:

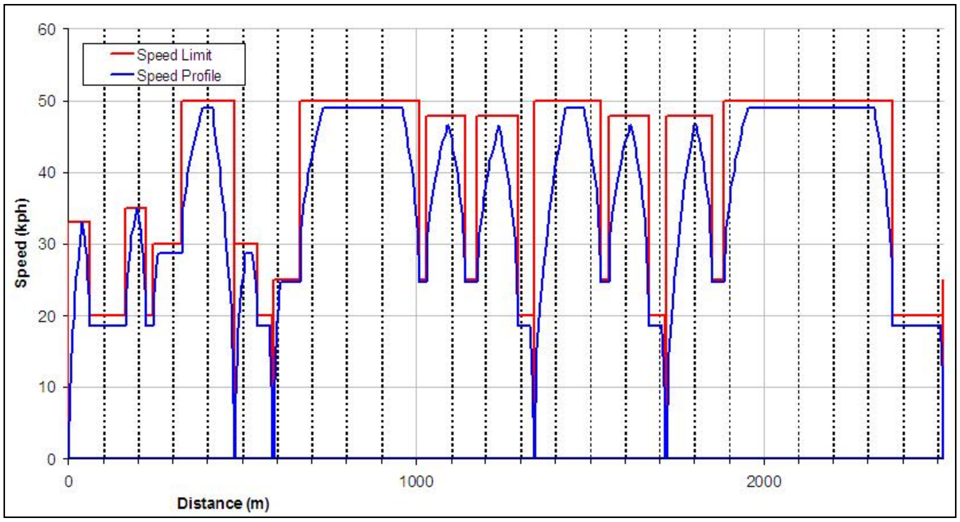
- **Reduced tractive adhesion -** which impacts on the ability of the vehicle to accelerate, this is somewhat mitigated by the much heavier weight of the vehicle and the more complex traction systems to reduce wheel slip. It is worth noting to increase the acceleration and deceleration characteristics of metro vehicles a number of systems, Val, Paris Metro, and the Paris Meteor Line use rubber tyred metro vehicles.
- **Vehicle weight** – Rail vehicles tend to be heavy due to the bogies, body structure, and traction packages, and the passenger capacity.
- **Short stopping distances -** on urban systems result in the vehicle either accelerating or braking over a significant element of a journey profile with limited sections of steady speed operation. A typical speed distance profile is shown in Figure 4.5

4.31 Lower Rolling Resistance Coefficient becomes a more significant advantage where a vehicle is running at a constant speed where the power input required to maintain the vehicle speed can be significantly lower than that of a rubber tyred vehicle.

Infrastructure

4.32 Tramtrain's key benefit is the ability to use existing rail infrastructure to operate on and provide connection in to city centres. In the case of the Greater Bristol area a city centre tram style network could be constructed plus connections to identified existing rail routes. The city centre network wouldn't necessarily need to be electrified as a Tramtrain option for the area would need to be diesel powered to operate on the current heavy rail network in the area.

FIGURE 4.6 TYPICAL SPEED DISTANCE PROFILE FOR AN URBAN TRANPORT SYSTEM



4.33 Operation under diesel power could in part be mitigated if the vehicle where fitted with an energy store, storing the energy created under braking (similar to the Parry People Mover). The energy store would provide power for acceleration in conjunction with the diesel generator allowing the engine to run at a more optimal speed reducing noise and emissions. Three types of energy store are potentially possible battery, capacitor or high speed flywheel. The inclusion of an energy store system would increase the cost of the vehicle.

4.34 Within the city centre track could be constructed utilising the latest ORR guidance[11] potentially reducing the depth of construction compared to tram schemes constructed to date, with the potential to mitigate some of the utility diversion works required. Utilities would though need to be moved where they would be impacted upon by the construction of the running rails and where access and continued serviceability would be affected. Local utility connections, water, gas, electricity, telecoms would need to be moved if the routes run parallel to and within the swept path of any proposed route to enable utility companies to access, maintain and provide connections to their equipment.

4.35 Tracks on connecting routes could utilise more conventional ballasted track where these are segregated from public areas.

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11 ORR Tramway Technical Guidance Note 1, Design Requirements for Street Track, May 2008

4.36 Stops would need to be provided along the route to provide a level boarding height of approximately 330mm to 350mm, their length would be dependant on the vehicle length and the door position. However the length of all three current vehicles is in the order of 37 metres. This would take considerable kerb space in Bristol city centre.

4.37 Stop width would need to be of the order of three metres, possibly wider where they are included within busy footways.

4.38 Deliverability is currently a significant issue with Tramtrain in the UK; this may improve following the completion of the Penistone trial in 2012. The development of standalone systems utilising Tramtrain technology will be more expensive than more standard tram technology and run a significant risk of not being compatible with Tramtrain requirements set in the future. The development of Tramtrain route on the heavy rail network are likely to continue to be high risk in terms of costs due to the unknown level of signalling and infrastructure works required to facilitate their operation on the existing heavy rail routes.

Application to the Ashton Vale to Temple Meads Route

4.39 To provide a comparison of cost we have developed a cost for each of the technologies based on the development of the route from Temple Meads through the City Centre to Ashton Vale Park and Ride. The route in the city centre is based upon running on Victoria Street, Counterslip, Lower Castle Street, with a single track loop on Horse Fair Nelson Street and Newgate continuing to Wapping Wharf via Broad Quay and Prince Street. We have not carried out any evaluation of the technical feasibility of using this route for the individual technologies.

4.40 We have not included for shared running on the short section of existing rail infrastructure at Ashton Gate (Portishead Freight Line) as this could be prohibitively expensive due to the signalling costs associated with this section. We have priced for a parallel route and bridge over the line at this stage.

4.41 The capacity provided for comparison is up to 3000 passengers in the peak hour as this would provide for some growth in passengers on the route, and initially provide a more comfortable vehicle loading. The journey time is assumed to be approximately 20 minutes, resulting in a requirement for a five minute service providing a capacity of approximately 2940. 10 vehicles with a vehicle capacity of approximately 245 would be required to provide the service with spares.

4.42 The intensity of the service would require the route to be double track other than under Cumberland Road, where it would be beneficial to retain the existing bridge, minimise the section of single operation and operate the route bi-directionally over this short section.

Costs

4.43 Indicative capital cost estimates for Tramtrain vehicles and infrastructure costs for the Aston Vale route are shown in Table 4.4. The vehicle cost is based on a pricing received from both suppliers and operators for a dual powered low floor vehicle. The cost estimate for a single power source vehicle is likely to be at the lower end of the cost range supplied. The vehicle cost is both higher than that of a tram and a heavy rail vehicle. This is in part due to the dual mode traction system, but more down to the requirement to meet the required crashworthiness, with a low floor vehicle which is inherently less rigid than a high floor rail vehicle. There is also the issue of the low numbers of vehicle produced to date compared to both tram and rail products, which are either more standard products or substantively based upon them.

TABLE 4.4 TRAMTRAIN CAPITAL COSTS ESTIMATE (2007 PRICES) LOWER COST INFASTRUCTURE AND VEHICLES

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles dual Power			£2.8 to 3.2 million [12] each
Vehicle cost for 5 minute service (10 vehicles)			£28 million
Passenger Capacity			2960 / hr
Infrastructure (Lower Track Cost)	£49.6	£40.4	£90.0 million (£12.7 / Km)
Infrastructure with Electrification (Lower Track Cost)	£54.6	£44.4	£99.0 million (£13.9 / Km)
TOTAL COST (Infrastructure (Lower Track Cost))			£118 million

TABLE 4.5 TRAMTRAIN CAPITAL COSTS ESTIMATE (2007 PRICES) TRAM INFRASTRUCTURE AND HIGHER COST VEHICLES

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles dual Power			£2.8 to 3.2 million [12] each
Vehicle cost for 4 minute service (10 vehicles)			£32 million
Passenger Capacity			2960 / hr
Infrastructure (Conventional UK Tram cost)	£60.4	£50.2	£110.6 million (£15.6 / Km)
Infrastructure with Electrification (Conventional UK Tram cost)	£66.4	£55.2	£121.6 million (£17.1 / Km)
TOTAL COST (Tram Infrastructure Cost))			£142 million

[12] *Diesel Trams: A New Way forward*, Modern Railways March 2007 quotes a figure of £1.9 million per vehicle. Contact with manufacturers and German operators suggest a much higher figure of between 2.8 and 3.2 million.

4.44 The costs show that a Tramtrain scheme including vehicles could be of the order of £120 to £142 million, it is important to note this is an initial estimate based on the Ashton Vale to Temple Meads route with no site inspection or engineering review of the feasibility. These costs are comparable to the outturn costs for tram schemes including vehicles of an average of approximately £12 million per km (see Table 4.6) with the on-street element costing up to £20 million per km excluding vehicles.

4.45 The developed costs do not include for land or optimism bias.

TABLE 4.6 CONSTRUCTED TRAM SYSTEM INFASTRUCTURE COSTS

System	2007 Price	Length /km	£m / km
Midland Metro	£144	20.4	£7.04
Croydon	£181	28	£6.46
Sheffield	£225	29	£7.75
Manchester	£251	37	£6.78
Nottingham	£142	14.3	£9.91
Merseytram (cost estimate)	£334	16.8	£19.89
Edinburgh	£423	18.0	£23.50
Average Cost			**£11.62**

4.46 The cost of off-street track construction on either disused rail alignments or similar open space would be of the order of £5 million to £7 million.

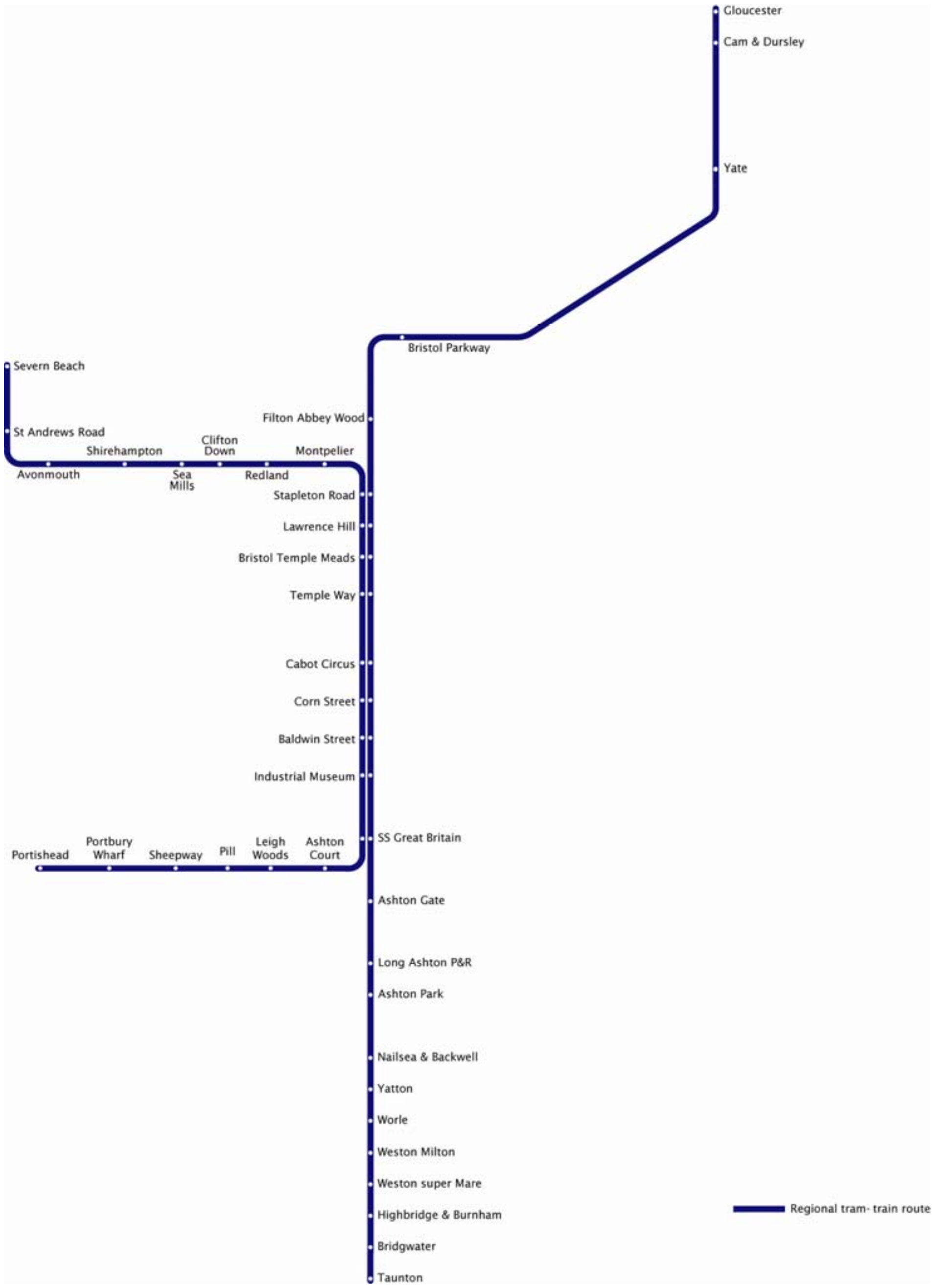
4.47 It is notable, from Table 4.6, that the cost of tram schemes in the UK has been rising significantly.

4.48 In developing the costs for the route it suggests that it would be as cost effective to provide a more convention tram system in place of the Tramtrain technology with its more expensive vehicle and the potential risks of its possible wider operation on other dedicated routes or the wider heavy rail network.

Wider Route Network

4.49 A possible Tramtrain network is shown in Figure 4.6. This identifies two route corridors utilising both current freight only and passenger rail routes. The proposed routes would potentially raise a significant number of issues. The routes are in the main two tracks and would require Tramtrains to operate in conjunction with freight, local, longer distance and high speed services. The current rail network in the area is also capacity constrained, particularly given the short to medium term proposals for the rail network. Some of proposed Tramtrain routes are also proposed to operating on the mainlines and the diversionary routes for the mainlines, which could be difficult to achieve at any frequency and regularity in conjunction with high speed services. Having said this, the introduction of Tramtrains on local services would be likely to remove the conflicting heavy rail service in any event in order to provide the proposed objectives of Tramtrain, that being, higher frequencies at lower maintenance and operating costs.

FIGURE 4.7 POSSIBLE TRAMTRAIN NETWORK



4.50 The following issues would need to be addressed to assess the feasibility of these routes:

- Low platforms on heavy rail network (freight and heavy rail vehicle operation through them).
- Available capacity.
- Operation in conjunction with high speed services, issue of differential speeds
- Frequency on single sections / Improvement works.

- Length of the proposed routes.
- Runtime, headway and timetable issues.
- Weekend working (Network Rail closures for maintenance).
- Service diversion routing.
- Rail operators delay penalty arrangements.
- Mix of train operation.
- Impact on existing operators.
- Impact on franchise arrangements.

4.51 A particular issue is the operation of a tram style service through the city centre and dedicated routes which would operate in the main on a headway basis and not a timetable and the need to operate to a timetable on the heavy rail network. This is a difficult arrangement to manage and can result in vehicles being held to regulate their access to the rail network, increasing runtimes.

4.52 The adoption of the same technology in place of some of the other proposed rapid transit routes would result in the need to revise the routes. For example the proposed route using the M32 would need to review the issues of completely segregated running from other road traffic or consider alternative routes altogether. The cost of dedicated, segregated infrastructure for such services would be comparable to tram system costs, which could be a more appropriate, cost effective mode in place of Tramtrain technology.

4.53 The ability to serve the wider West of England area would require the development of dedicated Tramtrain corridors requiring more extensive expensive infrastructure. The developing network would need to be integrated with bus services requiring additional infrastructure and potentially creating significant interchange penalties for multi mode journeys.

Fit with Objectives

4.54 **Mode shift – Extend choice / encourage shift to public transport**, the provision of Tramtrain within the corridors would if not replacing an existing mode, would extend choice, improve the quality, reliability and potentially the frequency. Rail based modes are proven to encourage a higher shift to public transport than bus based modes.

4.55 **Mode shift - Improve access to public transport,** the development of Tramtrain routes would be within dedicated corridors, which would improve the access within the particular corridor. Mode shift from the wider network would be dependant on the integration of the routes with other public transport modes and could suffer from an in interchange penalty. Routes developed on the heavy rail network would only serve the existing station catchments as additional stations would be difficult to insert due to the interoperation with other services. The benefits to the wider region could therefore be limited.

4.56 **Mode shift - Improve integration,** the integration of Tramtrain operating on the existing rail or dedicated networks could improve integration and improve the number of seamless journey possibilities. The development of Tramtrain on the existing rail network in the short to medium term look extremely limited, and are likely to be reliant on the results of the Penistone Trial.

4.57 **Help reduce traffic congestion - Improve safety along transport routes,** Tram and Tramtrains are inherently safe Public transport modes. Tramtrain has not been applied in the UK to date, but would not be progressed if the hazards of operating low floor vehicles are not removed or mitigated on the heavy rail network. The Penistone trial will hopefully resolve the potential issue of low platforms and low floor operation.

4.58 **Help reduce traffic congestion - Increase network capacity,** Tramtrain vehicle are high capacity and as such would significantly improve the network capacity within their corridors of operation.

4.59 **Contribute towards economic growth – Promote Sustainable Development**, The provision of another transport mode within the network would contribute towards the growth of the local economy. With the mode focused within a dedicated corridor the wider benefits of the system may be reduced, although the development of a wider Tramtrain network utilising the existing heavy rail network could provide wider benefits. This would be dependant on the development of Tramtrain in the UK.

4.60 **Contribute towards economic growth – Promote social inclusion**, the development of additional transport corridors would improve overall access to transport and their integrated with existing public transport modes would improve journey opportunities. Peoples would therefore have improved connectivity and ability to access employment and services.

4.61 In terms of **affordability/deliverability**, the capital costs for Tramtrain are likely to be far in excess of the funding currently identified in the Regional Funding Allocation (RFA).

4.62 Tramtrain trials on the heavy rail network are planned to conclude in 2012 with trials on LRT network potentially after that. Prior to understanding the results trials being undertaken by the rail industry, Tramtrain is likely to remain high cost and high risk. The Penistone trial will hopefully facilitate setting the vehicle standards for Tramtrain vehicles, which if the manufacturers are able and willing to provide a suitable vehicle depending upon the market demand could significantly de-risk future Tramtrain projects and potentially provide a competitive market. Operation of the first rapid transit route is programmed for 2013. Tramtrain is highly unlikely to happen before 2016 and therefore is outside the current regional funding allocation programme.

4.63 The local contribution required by Central Government from the West of England Authorities could be 25% for Tramtrain as it is with tram schemes. If this was the case the four local authorities would be looking at a local contribution in the order of £30 to £36 million.

Light Weight Rail / Ultra Light Rail

4.64 Light Weight Rail / Ultra Light Rail (LWR/ULR) has been developed by Parry People Movers (PPM) as an intermediate mode between bus and tram and is being promoted by Sustraco/Ultra Light Rail as Hybrid Ultra Light Transit System (HULTS). The concept is to provide a lower cost intermediate mode which could run in place of existing branch line services on the national rail network or a low cost alternative to tram technology.

4.65 PPM uses a flywheel, which is accelerated up to approximately 2500 rpm as the main drive for the vehicle, this provides the torque needed to accelerate. The flywheel is accelerated up to speed with a small petrol engine converted to LPG, which is also used to propel the vehicle over longer distances once it is up to speed. The braking action of the vehicle is also utilised to recharge the flywheel, effectively a form of regenerative braking.

4.66 The system has been trialled on a number of routes and recently won its first order to supply two vehicles to operate the Stourbridge branch line service in place of the single diesel car used on the line currently and the PPM trial vehicle operated on Sundays, the two vehicles will enter service in December 2008 and will be operated by Pre Metro Operations Ltd part of the Parry Group for Midland Rail.

4.67 A site visit to Stourbridge was undertaken to review the PPM trial vehicle and discuss the Light Weight Rail concept with Parry People Movers.

4.68 ULR is reported by the promoters to require significantly lower cost infrastructure to that of a tram system, as it doesn't require overhead power systems and potentially would not require the same level of utility diversions.

4.69 Information on HULTS has been provided by Scott Wilson on behalf of Bristol Electric Bus Ltd. Their report sets out proposals for Light Weight Rail from Bristol to Long Ashton Park and Ride[13]. This report is provided in Appendix B.

Operation

4.70 The current operation of the Parry People Mover demonstration vehicle on the Stourbridge Branch line has a number of dispensations from Railway Group Standards, these have been achieved by the vehicle operating under exclusive running with physical measures employed to segregate the service from the heavy rail network, in effect being classed as physically separate from the heavy rail network while in operation (see levels of interaction discussed under Tramtrain from Paragraph 4.12).

4.71 The PPM vehicle would not meet the Railway Group Standard for light rail vehicles operating on Network Rail infrastructure and as such is unlikely to be able to operate under limited exclusive running and would not be able to run under mixed running.

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13 *The Hybrid Ultra Light Transit System (HULTS): An Alternative Proposal to Bus Rapid Transit from Bristol City Centre to Long Ashton Park and Ride*, Scott Wilson, June 2008

The PPM vehicle could be used on a Parallel Running route (a dedicated new corridor alongside a rail route) although the level of segregation may need to be reviewed due to the light weight construction of the vehicle and possible risk identified from either systems' operation.

Vehicles

4.72 The Parry People Mover vehicle has been developed from the idea of providing a low cost environmentally friendly vehicle, utilising a slow speed flywheel to provide the vehicles tractive power. The vehicle utilises a small LPG powered engine to charge the flywheel and supplement the tractive power to maintain the vehicles constant speed over longer distances. The LPG engine also provides the vehicles auxiliary supplies in conjunction with batteries. The vehicles are light weight, approximately 10 tonnes with two fixed axles, one of which is powered. The design and manufacture of the vehicle attempts to utilises standard parts and equipment such as a Ford engine, bus windows and equipments etc, to both reduce cost and to ensure the maintainability of the vehicle.

FIGURE 4.8 PARRY PEOPLE MOVER

4.73 The vehicle is RVAR[14] compliant and is wheelchair accessible, the vehicle being equipped with single passenger access per side at opposite ends of the vehicle results in the need to provide sufficient space within the interior for a wheelchair to be able to negotiate the length of the vehicle between the doors. This results in a significant amount of floor space and minimal seating approximately 16 seats for a 50 passenger vehicle.

4.74 At the Stourbridge site visit the vehicle was operating over a short section of track, approximately 50 metres. The vehicle offered good acceleration and deceleration although the speed achieved was low and the vehicle was only laden with 6 people. It was notable that the vehicle suffered wheel slip when starting with the light laden

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[14] Rail Vehicle Accessibility Regulations

weight.

4.75 The vehicles appeared relatively simple to operate although the speed of the LPG engine was manually controlled to increase the charging of the flywheel as required. The flywheel was noticeably recharged under braking and the vehicle was quiet both under acceleration and deceleration. The vehicle data provided suggest the vehicle is capable of similar performance levels to that of a tram, although the top speed of the vehicle is limited to 60kph.

4.76 The vehicle is not equipped with secondary suspension and with a fixed axle arrangement will rely on the quality of the track infrastructure for ride quality. Even with quality trackwork the ride quality at higher speeds is likely to suffer from the current single fixed axle arrangement as apposed to a vehicle equipped with bogies.

4.77 The vehicle can be produced as a medium floor height version achieving a boarding height of 450mm (this was used as the Bristol Electric Trial vehicle on the heritage railway route, as shown in Figure 4.8), this compares to a tram boarding height of approximately 330 mm and of approximately 340 mm without kneeling for a bus. A kneeling bus which is now a standard product would achieve a boarding height of approximately 150mm.

FIGURE 4.9 BRISTOL ELECTRIC BUS VEHICLE (DEMONSTRATION PROJECT)

4.78 HULTS proposes a 60 passenger PPM low floor vehicle utilising two bogies, Figure 4.9. The PPM bogie technology upon which the vehicle would rely is also currently a concept and has not been developed. The development of this vehicle would require a radical redesign of the current PPM vehicles and we understand this is proposed. The promoters propose the vehicles to have a high quality appearance/finish, Figure 4.10.

FIGURE 4.10 SCHEMATIC HYBRID ULTRA LIGHT TRAM SYSTEM – HULTS [13]

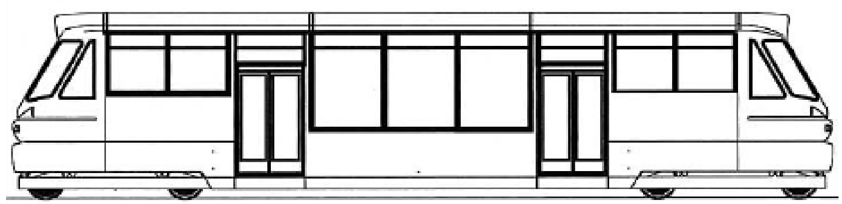

Figure 3 – Schematic Hybrid Ultra Light Tram System - HULTS
Source: Parry People Movers (PPM)

FIGURE 4.11 PROPOSED HULTS [13]

4.79 Operation of the vehicle with general traffic in an on-street environment has not been tested to date; it is therefore unclear how the vehicle will perform in this arrangement. It is also unclear if the current vehicle complies with the requirements of the Road Traffic Act to facilitate its operation on street.

4.80 Deliverability is a significant issue with this technology as to date only development vehicles have been produced and trialled on a number of short rail routes, where the vehicles operation can be segregated from other uses. The first two production vehicles are currently being built for the Stourbridge route and will go into service in December 2008 and are high floor vehicles with a boarding height of approximately 900mm. The vehicle is also one of a kind which would raise the issue of sole provider and long term product support.

4.81 PPM proposes that a double vehicle could be produced to accommodate 100 passengers, effectively based upon the joining of two PPM 50 vehicles. The joining of two vehicles is inherently complex. It is unclear how an articulated join of two vehicles would be achieved and the affect such an arrangement would have on ride quality and vehicle performance. The control of the vehicle would also become significantly more complex, requiring the vehicle to have a traction control package to monitor and control the two drive and brake systems, within the two sections.

4.82 The durability of the vehicle under continuous operation has also yet to be proved. The life of a Tramtrain or tram would be 30 years, it is not clear that the PPM vehicles could operate reliably over this timescale.

TABLE 4.7 PARRY PEOPLE MOVER VEHICLE DATA

Key Figures	
Length	8,700 mm
Width	2,400 mm
Seats	20-25
Standing	30-35
Doors	1 double per side
Ordered / Supplied	2 / 0

4.83 The efficiency of the vehicle as described under Tramtrain is influenced by a number of factors. The fuel efficiency of the PPM vehicle benefits form the use of the flywheel technology to provide the accelerating torque for the vehicle, and store the vehicle braking energy, this has the potential to allow the supplementary LPG engine to run at more optimum speed to supplement the vehicle power and assist in recharging the flywheel while the vehicle is stationary. A full day service is expected to utilise approximately 150kg of propane (current vehicle fuel) though this would depend on the stopping distance and speed of the vehicle.

4.84 The vehicle could be operated with other engine packages using bio-fuels if required, to date this has not been provided or tested, although the same technologies are employed on buses around the world, which demonstrate the potential.

4.85 The PPM vehicle has the advantage of lower Rolling Resistance Coefficient which would be similar to light rail /Tramtrain at approximately 0.005. The advantages of this as with Tramtrain could be reduced by:

- **Reduced tractive adhesion** – the overall weight (including passengers) of the vehicle is slightly lower at approximately 78% than that of a tram / Tramtrain. It was though noticeable with a small load that the vehicle suffered from wheel slip. Unlike a tram or Tramtrain the vehicle does not have a wheel slip / traction control package to mitigate this issue, this is controlled by the driver of the vehicle. On gradients the wheel slip issue could be an issue particularly if the vehicle stopped for junction, stops etc. This could be a significant issue particularly for potential routes to south and northwest in the Bristol urban area where there are significant gradients.
- **Vehicle Weight –** including the weight of passengers is slightly lower than that of a tram but slightly higher per passenger than that of an articulated bus.

- **Short stopping distances –** the vehicle as with the Tramtrain would benefit from lower rolling resistance on longer routes, countering this would be the need for the vehicle to utilise more energy from the supplementary LPG engine. On an urban route the vehicle would though mainly be accelerating or braking, reducing the benefit of the lower rolling resistance.

Infrastructure

4.86 Track infrastructure is generally designed and procured separately from the vehicles and as such the development of the proposed track infrastructure for light weight rail has not been developed to the same level as the vehicle. Promoters of light weight rail propose a vastly reduced cost (70% lower) quoting a figure of below £3 million[15] per single track kilometre, proposing this is due to the removal of the electrification system and reduced impact on utilities due to the removal of stray current issues. Clarification of the cost estimate has identified that the cost does not include for stop furniture and systems such as CCTV, help point or ticketing.

4.87 Table 4.8 shows a typical breakdown of a conventional tram scheme, with an average cost of £12m per km. Removing both the electrification and all the utilities cost would only account for a possible reduction of 33% in the cost of construction producing a track cost of approximately £8.04 million. The removal of all but the Site Preparation, Highway and Trackwork costs results in a cost of £4.8 million compared to the proposed £3 million rate.

4.88 The ORR has recently released guidance on track construction for tram systems, which could reduce the cost of construction (this is provided in Appendix C). Shallow rail profiles are also available which could also reduce the depth further although these are more expensive and more difficult to procure. Importantly the track construction within a highway needs to maintain the durability and loading required for the highway vehicles (40 tonnes) as well as LWR/ULR.

TABLE 4.8 TYPICAL COST BREAKDOWN FOR A TRAM SYSTEM

Description	Percentage	Cost Based on £12 Million per km
Site Preparation	13%	£1.56
Highway Works	7%	£0.84
Utilities	20%	£2.40
Trackwork	22%	£2.64
Stops	7%	£0.84
Traction Power	13%	£1.56
Signalling and Telecommunications	18%	£2.16
Total	100%	£12.00

15 *Hybrid Ultra Light Transit System*, Scott Wilson for Bristol Electric Railbus Ltd, June 2008

4.89 The need to divert utilities is a function of the depth of construction and also, importantly, continued access and serviceability to utility companies. To our knowledge there has not been a fixed rail system in the UK where utilities have not been moved. Local utility connections, water, gas, electricity, telecoms would need to be moved if the routes run parallel to and within the swept path of any proposed route to enable utility companies to access, maintain and provide connections to their equipment. The majority of access chambers would also need to be moved clear of the swept path of any system.

4.90 The proposed ULR track was discussed with local Utility providers at a meeting in July 2008. The representatives of the Utility Companies were not in principle against the concept of a track which could run on top of their assets within the highway but raised a number of issues:

- Services would need to be diverted or suspended when access or work were required. This would need to be taken in to consideration in the development of the track solution.
- Different consideration would need to be given in terms of access to utilities in cases of planned and emergency requirements. By its nature planned works would be easier to co-ordinate in terms of changes to services.
- Different consideration would need to be given to different types of assets i.e. access to water and sewer systems has very different issues to telecommunications equipment for example.
- Utility Companies would be looking to the owner of the track, the Local Authorities, to be responsible for the reinstatement of the highway where this was for example dug up for utility works to insure the risk of damage to the track rested with the Local Authority.
- Utility Companies would be looking to the owner of the track, the Local Authorities, to be responsible for paying for any reinstatement works.

4.91 The representatives of the HULTS technology at the meeting noted that they want to develop a track for ULR which meets the requirements of the Utility Companies without having to move their assets. The intention was to have ongoing engagement with the Utility Companies in this process.

4.92 Stray current is an issue for electrified systems but this is mitigated in the main by the use of encapsulated rails, floating earth systems and ensuring the quality of the traction return. The Scott Wilson report on Hybrid Ultra Light Rail comments that they would retain the use of encapsulated rail due to its properties in reducing noise and vibration. In relation to the overall cost electrification accounts for approximately 13% of tram system costs.

4.93 Therefore a number of cost estimates for the development of the different technologies for the Ashton Vale route have been developed to provide a comparison against £3 million per kilometre cost proposed by HULTS and the Scott Wilson Report.

Application to the Ashton Vale Route

4.94 To provide a comparison of cost we have developed a cost for each of the technologies based on the development of the route from Temple Meads through the

City Centre to Ashton Vale Park and Ride. The route is the same as detailed under Tramtrain. We have not carried out any evaluation of the technical feasibility of using this route for the individual technologies.

4.95 We have based the cost on the vehicle information provided and the lower track cost developed for the Tramtrain costs. We believe this to be reasonable assumption based on our knowledge of track construction.

4.96 The capacity provided for comparison is based on 3000 passengers in the peak hour as this would provide for some growth in passengers on the route, and initially provide a more comfortable vehicle loading. Although the journey time could be greater than 20 minutes due to the vehicles lower top speed, for this review we have assumed the vehicle can match the Tramtrain and BRT performance. This results in a requirement for a 2.5 minute service frequency providing a capacity of approximately 2880. 18 vehicles would be required to provide the service with spares. (Not withstanding previous commentary on the feasibility of linking two units). In our opinion, a service level of two minutes on a technology untested in passenger operations has considerable risks.

Costs

4.97 Indicative capital cost estimates for Light Weight Rail vehicles and infrastructure costs for the Aston Vale route are shown in Table 4.8. The costs show that a (HULTS) Light Weight Rail Scheme could be of the order of £38 million (2007 prices), it is important to note this is an initial estimate based on the Ashton Vale to Temple Meads route with no site inspection or engineering review of the feasibility.

4.98 The deliverability of trackwork at such a low cost would need to be established, for comparison the capital cost when including an allowance for city centre highway and signalling costs would be £45 million. The capital cost based on a low cost tram style track would be of the order of £103 million this include the lower cost associated with ballasted track were this would be possible. A significant element of the route is on-street at approximately 4.5km of the 7.2km route.

TABLE 4.9 LIGHT WEIGHT RAIL CAPITAL COST ESTIMATE 1 HULTS (2007 PRICES)

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles 60 passengers			£350,000 each
Vehicle 120 Passengers			£700,000 each
Vehicle cost for 2.5 minute service (18 vehicles)			£12.6 million
Passenger Capacity			2880 / hr
Infrastructure (HULTS) £3m/km +Structures	£12.5m	£13.0m	£25.5 million (£3.6 / Km)
TOTAL COST (HULTS)			£38.1 million

4.99 The HULTS track estimate (£3 million /km) for the city centre section of the route significantly underestimates the costs involved, as a minimum we believe the city centre section would require a similar highway costs to that of the BRT scheme. These are included in Table 4.10.

TABLE 4.10 LIGHT WEIGHT RAIL CAPITAL COST ESTIMATE 2 REVISED HULTS (2007 PRICES)

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles			£350,000 each
Vehicle 120 Passengers			£700,000 each
Vehicle cost for 2.5 minute service (18 vehicles)			£12.6 million
Passenger Capacity			2880 / hr
Infrastructure (HULTS) £3m/km +Structures	£12.5m	£13.0m	£25.5 million (£3.6 / Km)
Highway and signalling costs	£7.0m		£32.5 million (£4.6 / Km)
TOTAL COST			£45.1 million

4.100 For comparison a capital cost for the HULTS scheme including an infrastructure cost based on a low cost tram track without electrification is shown in Table 4.11.

TABLE 4.11 LIGHT WEIGHT RAIL CAPITAL COST ESTIMATE 3 LOW COST TRAM STYLE INFRASTRUCTURE(2007 PRICES)

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles			£350,000 each
Vehicle 120 Passengers			£700,000 each
Vehicle cost for 2.5 minute service (18 vehicles)			£12.6 million
Passenger Capacity			2880 / hr
Infrastructure (Low Cost Tram not electrified)	£49.6m	£40.4m	£90.0 (£12.7 / Km)
TOTAL COST			£102.6m

Wider Route Network

4.101 The operation of a rail based vehicle on some of the proposed rapid transit would result in the need to revise the routes as operation of elements such as on the M32 , out to Bristol Airport etc. would need to be reviewed. Dedicated corridors would have to be developed, alongside or on alternative routes depending on land and feasibility. Routes developed would require infrastructure along their full length to be constructed to enable operation of this mode.

4.102 The ability to service the wider West of England area would require interchange with bus services.

Fit with Objectives

4.103 **Mode Shift – Extend choice / encourage shift to public transport,** as an additional mode within the transport network Light Weight Rail would generate mode shift, this will though depend on the reliability, quality and image of the system, and its integration with the wider network. With a larger vehicle and a service frequency providing similar capacity to that of a tram the technology could achieve a mode shift close to that of a tram system. The interchange penalty could significantly affect the level of mode shift generated from integration of the route with the wider bus network.

4.104 **Mode Shift – Improve access to public transport,** as standalone routes the technology would improve access to public transport in the corridors developed. Mode shift and access in the wider network would be dependant on the integration of the corridors with the existing public transport modes, which could suffer from an interchange penalty.

4.105 **Mode Shift – Improve Integration,** it is likely the technology would be provided within dedicated corridors. Integration with the city centre destinations, other bus services and Bristol temple Meads station is likely to be very expensive. Integration would be dependant on the routes developed and as such would need to be a key objective when developing routes. If a city centre network was to be progressed integrated with rail and bus stations, integration could be good.

4.106 **Help reduce traffic congestion - Improve safety along transport routes**, the mode to date has been trialled on segregated sections of rail alignments, none of which have been on street with traffic. It has operated safely on these routes and there is nothing to suggest that the technology would not improve safety in the transport network. Although when running on-street it would mix with other traffic and would be unable to avoid other vehicles or obstructions on a route, delaying services.

4.107 **Help reduce traffic congestion - Increase network capacity**, the current low capacity of the vehicle against other modes significantly affects the performance of the technology in relation to the overall network capacity. This in part can be improved through increased service frequency although this will increase the capital and more importantly operating costs for the routes. There also becomes a point where increased frequency impacts upon the operation of the system with vehicles being delayed by other vehicles increasing the journey time and potentially increasing the infrastructure required to operate and regulate the service.

4.108 **Contribute towards economic growth – Promote sustainable development**, the provision of another transport mode within the network would contribute towards the growth of the local economy. With the mode focused within a dedicated corridor the wider benefits of the system may be reduced and would be reliant on its integration with other modes. The vehicles limited capacity could also limit the modes ability to deliver a long term increasing contribution, as the capacity of the route or network is reached.

4.109 **Contribute towards economic growth – Promote social inclusion**, the development and integration of an additional mode would improve journey opportunities, which would improve peoples connectivity and their ability to access employment and services.

4.110 In terms of **affordability/deliverability**, the capital costs for LWR/ULR are likely to be in excess of the funding currently identified in the Regional Funding Allocation (RFA). The risks of the technology will be better understood once there is some operational experience after the Stourbridge vehicles go in to service in December 2008. Operation of the first rapid transit route is programmed for 2013. Development of a ULR vehicle and track is in our opinion likely to be outside these timescales.

4.111 The local contribution required from Central Government from the West of England Authorities could be 25% as it is with tram schemes. If this was the case the four local authorities would be looking at a local contribution in the range from £10 to £26 million.

Bus Rapid Transit

4.112 Bus Rapid Transit (BRT) aims to deliver the characteristics of fixed rail systems but with bus-based technology. It consists of a variety of physical measures in conjunction with operational and system elements such as a segregated alignment, high quality dedicated vehicles, improved stop infrastructure, on-street priority, improved passenger information and high frequency services. The BRT concept benefits significantly from its flexibility and is both adaptable at inception and over time to meet the changing needs of urban conurbations.

Different Types of Bus Rapid Systems

4.113 The application of BRT system design has been applied to a number of different schemes with differing bus technologies. Some of these systems are guided and some are unguided systems. Guided systems come in three main types:

- Mechanical or physical guidance – kerb guided or slot guided.
- Optical guidance – CIVIS optical system.
- Electronic guidance – inductive buried wire (no longer promoted), magnets.

4.114 Table 4.9 summarises the different types of BRT systems.

Kerb Guided Bus Systems

4.115 Kerb Guidance **-** After the initial development of guided bus ways in Essen (Germany) and Adelaide in the early 1980s, the first application in the UK was introduced in Birmingham in 1984 on the Short Heath guided busway demonstration project (TracLine 65). Although later abandoned, this was only ever intended as a demonstration of the technology. It led to other, commercial applications in the UK and these are currently in successful operation in Leeds (two corridors), Bradford, Ipswich, Crawley and Edinburgh, with a further schemes planned for Cambridgeshire, Luton and Leigh. There also schemes under development in London.

4.116 Kerb guided bus systems operate in a number of locations across the world. A trial system was created in Essen, Germany, and a full-scale system was built in a corridor of Adelaide, Australia.

4.117 In the UK, there are currently four examples in operation:

- West Yorkshire; three separate alignments, 2 in Leeds, 1 in Bradford;
- A 200m section at Ipswich;
- Gatwick Fastway in Crawley; and the
- Edinburgh WEBS system (this will be replaced this Autumn by the Edinburgh Tram Line 1).

4.118 The Crawley Fastway system sells itself as being 'intelligent integrated transport'. The vehicles are equipped with automatic vehicle location systems that help maintain schedules and provide on-board real-time information. In addition, on Phase 1, there are 2,200m of segregated bus lane, 650m of guided busway and seven modified bus friendly junctions to enhance the attractiveness of the service. Once all phases are completed there will be 2.5km of guided busway within a route length of 24km.

4.119 Both phases one and two of the Crawley Fastway are now complete and the system has been more successful than anticipated, with patronage 40% higher than forecast[16].

4.120 The first guided busway in Leeds was constructed over a four year period but the second scheme, in the east of the city, was built in one phase in approximately 18 months.

4.121 The construction quality of a number of these systems has resulted in a requirement for remedial works and poor ride quality particularly when double deck buses are employed due the induced sway of the vehicle.

'Slot' Guided Bus Systems

4.122 Central Rail guided systems are rubber-tyred systems, which are held in place by a single central guiderail fitted into the roadway. Power can be distributed by overhead wires or by battery (diesel is also a possibility). Referred to as "trams on tyres", the original intention was for vehicles to operate on or off the guideway, however technical issues with engaging and disengaging with the central rail have meant that all the systems are only operating in guided mode.

4.123 Rubber-tyred systems which use a single, central guiderail have been developed by two known suppliers: Bombardier and Lohr Industries.

4.124 Bombardier's Guided Light Transit (GLT) has been developed as a hybrid of Light Rapid Transit and conventional buses. An LRT-style body is carried on normal rubber tyres and guided by means of a single, central, retractable guide-wheel running in a metal groove mounted flush with the road surface, similar to a tram rail. As such, GLT

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[16] *Study of High Quality Buses in Leeds*, Atkins, 2005

has the same advantages and disadvantages as a tram when in guided mode. Bombardier systems are currently being operated in Caen and Nancy. The vehicles and system is currently not being offered to new clients.

4.125 The Translohr system is the newer of the two systems and was developed by Lohr Industrie and Fiat-ferrovia,. The general principles of operation are similar to GLT and the Translohr is currently being tested on the Trans Val-de-Marne commercial busway in Paris. It differs from the GLT primarily in the way that the vehicle grips the rail - Translohr claim that their less direct gripping mechanism (two guidewheels grip the central rail at a 45% inclination) results in better performance characteristics. The GLT system imposes all the load downwards, resulting in greater friction and force onto the guideway. Hence, the rail needs to be fixed more than the Translohr, which is simply glued to the road surface. The Translohr system claims that the rail load is 25% less than the GLT (1 tonne) and this causes less friction that can result in better braking and acceleration.

4.126 There is also a difference in the design of the vehicles themselves, with the wheels for the Translohr being housed in hidden bogies to allow maximum interior space. The vehicles are lighter than GLT and, generally, the specification is more sophisticated.

4.127 The tramway in Nancy derailed several times. It suffered serious problems and as a result, the service was interrupted several times then suspended for several months.

4.128 There are concerns that translor system suffers too from safety concerns. It seems that there is an inherent instability to the rear section of a Central Rail guided vehicle particularly when moving from guided to non-guided mode.

Optical Guidance

4.129 The CiViS vehicle system is based on optical guidance and has been developed by a partnership between Matra (95% owned by Siemens) and IrisBus (created by the merger of the bus and coach divisions of Iveco and Renault).

4.130 The optical guidance system includes a camera mounted in front of the steering wheel, which can read coded markings painted on the road indicating the path to be followed, and an image processor that detects and corrects. The optical guidance system can in theory be built into any type of vehicle.

4.131 The CiViS vehicle system has been implemented in several French cities, including Lyon, Rouen, Clermond-Ferrand and Grenoble and in Las Vegas, USA. The bespoke vehicles are due to be replaced on the Las Vegas system due to their poor reliability.

Electronic guidance – Wire Guidance

4.132 The “ELTRAC” system was developed by Cegelec/AEG systems; this is now Alstom. Two wires 300mm apart are laid 50-150 mm below the road surface. These carry audio frequency, low-intensity currents derived from wayside frequency generators. The currents produce a magnetic field and an antenna mounted on the bus behind the front bumper senses the magnetic field. If the bus deviates from the centreline of the path, horizontal components of the magnetic field are also sensed. The steering is operated to bring the bus back onto the required path.

4.133 From 1983 to 1985, the system was in use on a standard articulated city bus in Fürth, Germany, in a regular public service along a two-lane, 1.5km route. From 1989, the Eurotunnel Transmanch link service tunnel used this system on a total of 100km of guideway, allowing vehicles passing in less than 100 mm side by side. The system has less success in less enclosed environments.

4.134 This technology was demonstrated on a bus in trials in Newcastle in 1996 and was selected for use on the Millennium Transit system, but was abandoned when the technology proved unreliable on the prototype vehicle. Following the Millennium transit problems, Alstom has deemed that the business case for wire guidance is not strong enough for further development and, thus, has no longer offer this product.

4.135 In 2000, GEC Alstrom and London Transport sought HMRI certification to operate the bus service to the Dome, but failed because of their electronic guidance system. Meanwhile, TDI has been developing an alternative form of electronic guidance called 'Safeguide'.

TABLE 4.12 DIFFERENT TYPES OF BRT SYSTEMS

Bus / Busway

Buses are the most common form of high-density public transport worldwide. They can serve a wide range of needs from low frequency or demand-responsive routes in low-density areas to high frequency trunk services on major corridors. Busways are continuous bus lanes providing a completely segregated but not physically constrained alignment.

Kerb-Guided

A kerb-guided system requires the construction of a segregated guide-way with vertical guiderails (kerbs) on either side, which allows conventional buses fitted with guidewheels to be guided along the route.

Central Rail Guidance

Central Rail guided systems are rubber-tyred systems, which are held in place by a single central guiderail fitted into the roadway. Power can be distributed by overhead wires or by battery (diesel is also a possibility. Two central guiderail systems have been developed by two known suppliers: Bombardier and Lohr Industries.

Optical Guidance (CiViS)

The CiViS system includes a camera mounted in front of the steering wheel, which can read coded markings painted on the road indicating the path to be followed, and an image processor that detects and corrects to ensure vehicles maintain their alignment. The optical guidance system can in theory be built into any type of vehicle.

Wire Guidance

Wire guidance systems have two wires 300mm apart, laid 50-150 mm below the road surface which carry audio frequency, low-intensity currents derived from wayside frequency generators. The currents produce a magnetic field that is sensed via an antenna. If the bus deviates from the centreline of the path, horizontal components of the magnetic field are also sensed. The steering is then operated to bring the bus back onto the required path.

Phileas

The Phileas system is based on magnetic plugs in the road surface that provide and correct the vehicle route information via a GPS device. Phileas vehicles are currently double-articulated with rear wheel steering which reduces the swept-path of the vehicle compared with regular articulated vehicles.

STREAM

The STREAM system combines guidance and electrical power pickup from a buried power strip set into the road surface. The power strip comprises an assembly with a series of electrical contact points which are energised only when the vehicle is directly above. They are earthed at other times and pose no hazard to pedestrians and other road users. A shoe on the vehicle connects to the live contacts with a feed back to the steering mechanism.

Electronic guidance – Phileas

4.136 Phileas vehicles have an electronic lane assistance and precision docking system with all-wheel steering vehicles. The system is based on magnetic plugs in the road surface that provide and correct the routing information. Phileas works with speeds up to 80 km/hr and under most weather conditions, even with snow on the road surface. While driving in automatic mode, the Phileas automatically follows a predetermined trajectory, so that the lane-width required is small, only 6.4 m for two-way dedicated lanes at 70 km/h. The system is still at the development stage and is not in full commercial operations.

Electronic guidance – STREAM

4.137 Ansaldo Breda has developed a system which combines guidance and electrical power pickup from a buried power strip set into the road surface. This system is seen primarily as a means of providing continuous electric power without the need for a visually intrusive overhead line. As with all the other systems, it has the ability to detach itself from the guideway, but there are no specific details of how quickly the vehicle can re-connect to the contact line.

4.138 The power strip comprises an assembly with a series of electrical contact points which are energised only when the vehicle is directly above. They are earthed at other times and pose no hazard to pedestrians and other road users. A shoe on the vehicle connects to the live contacts and the adjacent earthed return contacts. The system which maintains the alignment of the shoe relative to the power strip can feed back guidance signals to the steering system in a similar manner to the other systems described.

4.139 Although initial test systems have been implemented in Naples and Trieste (3km), the system is not in full commercial operation and is still at the testing stage. Therefore, it is impossible to understand how it performs in an urban commercial environment, and the only information available is from the supplier.

BRT System Attributes

Operation

4.140 Segregation from other traffic can be through the provision and use of dedicated infrastructure, or the provision of lanes within or alongside the existing highway network. The level of segregation can be provided incrementally over time, potentially in conjunction with other transport or highway improvements, though it is usually important to ensure that the BRT routes are provided with sufficient segregation at the outset to enable them to bypass congestion and attain consistent journey times in operation.

4.141 Signal priority systems at junctions can used to allow vehicles to the front of traffic or through the provision of a dedicated BRT routes across junctions. Signal priority is often controlled through the use of on vehicle system which monitor the vehicles performance to timetable or headway to provide varying priority based on the vehicles progress on an individual route.

4.142 High quality stop infrastructure similar to that utilised on tram schemes are often provided in conjunction with on stop ticket, passenger information, help points and CCTV to provide a significant differentiator to normal service and reinforce the image, quality and performance of a route.

4.143 Low floor vehicles in conjunction with a raised platforms can provide step free, gap free vehicle boarding, improve accessibility and improve boarding and alighting times. In combination with the stop furniture it also aids the differentiation of the system. The location and orientation of the stop platforms needs to provide straight entry to enable vehicles to consistently dock accurately with the stop infrastructure similar to rail based systems.

4.144 BRT systems in utilising more standard vehicle technology, which can be more readily purchased, with shorter delivery times. Vehicles, other than BRT services, can utilise BRT infrastructure. The quality of vehicles and services can be ensured the setting of services or quality standards as a requirements to access the BRT infrastructure.

Vehicles

4.145 A variety of vehicles are capable of being used on BRT systems, some of these are shown in Figure 4.12. The quality of vehicles continues to improve and develop due the scale of the market. hybrid diesel electric vehicles and zero emission vehicles are becoming more prevalent with more manufactures bringing products to the market. BRT systems such as the Las Vegas MAX system promoting these newer technologies through the adoption of Wright Bus hybrid vehicles, replacing the existing Civis vehicles. Different fuel options are further discussed in Section 6.

4.146 The choice of vehicle will be governed by the type of infrastructure, the required capacity of the network and the environmental consideration. The choice of vehicle needs to take note of the overarching requirements of BRT systems such as emission standards, low floor and accessible, sufficient door width and capacity to minimise dwell times at stops and operational reliability.

4.147 A good example of vehicle choice, it the Mercedes Citaro vehicle on Nantes Line 4, in France see Figure 4.11. The vehicle is a standard Citaro 18-metre articulated vehicle with 4 double doors, the first three of which provide level boarding. The vehicle has been adapted very slightly from the standard vehicle to provide roofline cowling to hide the air-conditioning units and provide a more streamlined profile and with a drivers screen provided within the vehicle as the fare collection system is off vehicle. The vehicle has then been branded to provide a differentiating image from the local services.

4.148 To provide gap free, step free boarding the choice of vehicle will need to be considered in relation to the stop location and design as longer vehicles may need a greater length of straight road or alignment prior to the stop to ensure accurate vehicle docking.

FIGURE 4.12 DIFFERENT TYPES OF POTENTIAL BRT VEHICLES

4.149 The fuel efficiency of the vehicle is influenced by a number of factors. In relation to bus technology this will be influenced more by the choice of propulsion, which would generally be down to the environmental requirements, which in turn would affect the price of the vehicle. Technologies such as hydrogen vehicles would be similar to electric trams in that there would be no detrimental emissions at the point of use.

4.150 Bus technology has greater rolling resistance than rail based technologies with a Rolling Resistance Coefficient of approximately 0.03. Again this is affected by a number of factors.

FIGURE 4.13 NANTES LINE 4 CITARO VEHICLE

- **Improved tractive adhesion –** Unlike the rail based mode rubber tyred vehicle have a higher rolling resistance allowing the vehicle to deliver more tractive effort to the wheels potentially improving the performance of the vehicles acceleration and deceleration. This is limited by the acceptable jerk rate imposed on passenger, a passenger comfort issue.
- **Vehicle weight –** The vehicle weight per passenger for an articulated bus is slightly lower than that of a PPM vehicle and 75% of that of a Tramtrain.
- **Short stopping distances –** The vehicle again would be operating in an urban network and would mainly be accelerating or braking, the same as the other modes considered, and issue would be whether the vehicle made use of braking energy which is not the case for standard diesel bus packages currently.

4.151 In relation to all the modes considered the operating cost are more affected by personnel costs which vary with the differing requirements and levels of responsibility.

Infrastructure

4.152 BRT schemes benefit from their flexibility to utilise the existing highway network in conjunction with dedicated or segregated provision. The infrastructure requirements will vary depending on the aim, objectives and constraints on each route. It can include on street operation, both with traffic and on dedicated corridors or within bus lanes, dedicated unguided highway and guided routes to minimise land take and maximise operational speed.

4.153 BRT systems successfully operating are either busways (unguided) or kerb guided busways. The latter has been constructed using either standard kerb components, slipform guide-ways or concrete beam guideways. The selection of construction type depends on cost, physical constraints of geometry/topography and desired ride quality. Quality of BRT infrastructure has been variable depending on the type of construction.

4.154 Busways use standard road construction. Access to the busway on corridors can restricted to the BRT vehicles. On-street systems can utilise dedicated bus lane or operate with traffic such as with tram or LWR/ULR. ON the on-street sections, vehicles can steer around obstructions such as utility works, parked vehicles etc.

Ashton Vale Proposals

4.155 We have utilised the Ashton Vale proposals for the corridor, utilising the city centre arrangement set out under the Tramtrains section. The route would run on street within the city centre running in part alongside and on street on Cumberland Road before running on a dedicated alignment through to Ashton Vale. We have not carried out a review of these proposals or any evaluation of the technical feasibility of using this route for the individual technologies.

Costs

4.156 The cost estimates for the Aston Vale to Temple Meads BRT route have been provided and are included with the cost of standard articulated vehicles in Table 4.10. The costs show that a BRT Scheme could be of the order of £24 million (2007 prices) when utilising an 18 metre articulated diesel powered vehicle . We have not reviewed the cost estimate provided other than to compare the cost per kilometre based on other schemes and the scope of works involved, we have not carried out a site inspection or engineering review of the feasibility.

TABLE 4.13 BUS RAPID TRANSIT CAPITAL COST ESTIMATE (2007 PRICES) DIESEL ARTICULATED VEHICLE

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles (18 metre Articulated diesel vehicle)			£220,000 each
Vehicle cost for 2.5 minute service (18 vehicles)			£3.96 Million
Passenger Capacity			2880 / hr
Infrastructure	7	13	£20 Million (£2.8 / Km)
TOTAL COST			£24 million

4.157 For comparison the cost associated with the a BRT scheme utilising a hybrid vehicle are shown in Table 4.14.

TABLE 4.14 BUS RAPID TRANSIT CAPITAL COST ESTIMATE (2007 PRICES) HYBRID ARTICULATED VEHICLE

Element	City Centre	Industrial Museum to Ashton Vale	Cost (Million)
Vehicles (18 metre Articulated hybrid vehicle)			£350,000 each
Vehicle cost for 2.5 minute service (18 vehicles)			£6.30 Million
Passenger Capacity			2880 / hr
Infrastructure (Lower Track Cost)	7	13	£20 Million (£2.8 / Km)
TOTAL COST			£26 million

Wider Route Network

4.158 BRT has the benefit over rail based modes that it can be more flexible, with BRT routes making use of segregation out of the city and then continuing to cover elements of the wider network, leveraging greater benefits from capital investment. It is also possible to provide the priority for both the core and wider network incrementally to either counter the effects of congestion or improve the journey time and reliability of the routes.

4.159 BRT, in able to operate on the existing road network without infrastructure works, could operate on the M32, A38 to Bristol International Airport and A4 to Bath where other rail based modes would need additional infrastructure built, significantly increasing the cost.

4.160 Capacity can be a constraint on BRT schemes with a vehicle capacity of an articulated bus based vehicle approximately half that of a tram. The capital cost difference between the two modes though is also significant.

Fit with Objectives

4.161 **Mode Shift – Extend choice / encourage shift to public transport**, the development of a BRT route within a corridor would both provide an additional mode and the potential for service from the wider network to join the corridor and benefit from the segregation and priority. Such an arrangement has the potential to provide greater mode shift due to the wider network although fixed rail systems do, to date, provide a greater mode shift than BRT systems.

4.162 **Mode Shift – Improve access to public transport**, the development of a new corridor in conjunction with the wider network access would provide both route specific and wider access.

4.163 **Mode Shift – Improve Integration**, the operation of both a dedicated core service and the wider route network would improve the level of integration on both the wider network at the points they connect with the route and provide improved integration where the routes connects with the exist public transport network.

4.164 **Help reduce traffic congestion - Improve safety along transport routes**, the development of a high capacity transport route on segregated alignments, encouraging mode shift would improve safety.

4.165 **Help reduce traffic congestion - Increase network capacity**, the operation of high capacity vehicle both on dedicated corridors and the wider network would significantly improve network capacity.

4.166 **Contribute towards economic growth – Promote sustainable development**, the provision of an additional mode within the network and the development of complimentary BRT services gaining advantage from the segregated BRT route, would provide improved connectivity over route specific modes and therefore have the potential to facilitate sustainable development over a wider area.

4.167 **Contribute towards economic growth – Promote social inclusion,** the improved connectivity of the dedicated routes and the wider connectivity would significantly improve peoples connectivity and their ability to access employment and services.

4.168 In terms of **affordability/deliverability**, the capital costs for BRT are within the funding currently identified in the Regional Funding Allocation (RFA), although it is fair to say that BRT has been costed historically for the RFA as it is identified as the technology in the Joint Local Transport Plan. The risks of the technology are more similar to other major highway schemes and therefore more familiar to Local Authorities in delivering the works required.

4.169 The local contribution required from Central Government for bus related schemes is usually 10%. The four local authorities would be looking at a local contribution in the order of £2 million to £2.5 million.

5. COMPARATIVE ASSESSMENT

5.1 The aspects and issues of individual technology have been review in terms of the general technology and its adoption and application in a UK context. Their application on the Ashton Vale route in terms of their cost and any specific issues identified and the wider implications and issues of the possible adoption on parts of a wider Bristol rapid transit network.

5.2 This section draws together the technology review section to provide a comparative assessment of the technologies against the main headings covered in each technology

Operation

Tramtrain

5.3 There are no operating Tramtrain systems in the UK, with the first trial due to start on the Penistone Line in 2010 through to 2012. The closest style of system to date in the UK is the shared running of Tyne and Wear Metro, which highlighted the complexities of mixed operation of light rail vehicles on the existing heavy rail network.

5.4 The adoption of the technology in the UK currently raises significant deliverability risks, particularly the operation of low floor platforms on heavy rail routes. In the West of England area the majority of the available rail routes are or will be capacity constrained which would significantly limit the potential for its adoption, without impacting upon existing suburban and inter-suburban services.

Light Weight Rail

5.5 The technology to date is in its infancy and has only been demonstrated on segregated sections of railway. The demonstration vehicle is operated under exclusive running on the Stourbridge branch line on Sundays. PPM's first order for 2 vehicles will replace the existing rail service from December 2008, again operating under exclusive running.

5.6 The vehicle is not suitable for Tramtrain style operation and would not be able to share trackwork with other rail vehicles.

5.7 The concept of Light Weight Rail operation similar to tram operation has not been trialled to date, and raises significant deliverability risks, there isn't currently a suitable low floor vehicle (300 to 350mm boarding height) and the cost estimates proposed for the track infrastructure and the associated assumptions are as yet untested.

Bus Rapid Transit

5.8 BRT is in operation in the UK and has been deliverable in a variety of formats, on street, guided, unguided and combinations of these. The mode is the most flexible of those reviewed due to its ability to both operate on dedicated corridors as well as operate on the wider road network, connecting with dedicated routes at point along their length to leverage wider benefits from any infrastructure provided.

5.9 A variety of vehicles are also available from a significant number of manufactures, with varying capacities. These are also available with a variety of engine / traction packages providing reducing levels of emissions through to zero emission vehicles at the point of operation, although this has to be balanced against the cost of the vehicle.

Vehicles

Tramtrain

5.10 A number of vehicle manufacturers have developed and supplied vehicles to systems in mainland Europe. No vehicles have been trialled or specifically developed for the UK market to date.

5.11 Competition does potentially exist in this market and the current vehicle standards that these comply with may well be adaptable for the UK rail network. The forthcoming procurement and trial of the technology on the Penistone route through to 2012, will hopefully resolve these issues.

Light Weight Rail

5.12 The PPM vehicle which the promoters of the technology have based their proposals on has been and continues to be developed by Parry People Movers with prototype high floor vehicles (currently being trialled on the Stourbridge route) and a medium floor height vehicle (450mm).

5.13 A true low floor vehicle has yet to be developed, it has been proposed that this would utilise two bogies in place of the existing fixed axle arrangement. The bogie technology for this style of vehicle is also yet to be developed. The capacity of the vehicle at between 50 and 60 people is low and reduced its potential market, a larger vehicle based on the joining of two vehicles is proposed. This is again undeveloped and would be significantly complex to develop due to the articulation of the body sections and more so the control of the two traction packages.

5.14 The deliverability of a suitable vehicle would be a significant risk to any project in the medium, along with the maturity of the technology. There is also the issue of PPM being the only supplier of this style of vehicle.

5.15 For ULR the vehicle uses the same principle as the Hybrid Bus, it uses a constant speed engine with a power store (the flywheel). A fully laden bus is 28 tonnes, a comparable PPM vehicle would be about 30 tonnes so it is likely that the emissions for a ULR are going to be close to that of a Hybrid Bus. (An important point is that if ULR were to use a vehicle with bogies which is what appears to be suggested the vehicle weight would be a lot heavier, which would impact on performance or emissions). ULR can use LPG, bio fuels etc. Buses could use the same fuels.

Bus Rapid Transit

5.16 A variety of vehicles are available from a significant number of manufactures, with varying capacities. These are also available with a variety of engine / traction packages providing reducing levels of emissions through to zero emission vehicles at the point of operation, although this has to be balanced against the cost of the vehicle.

Infrastructure

Tramtrain

5.17 The infrastructure required for Tramtrain on any dedicated infrastructure would be similar to that for a tram system. The recent ORR guidance on tram track construction could also provide an opportunity to reduce the cost of construction through the adoption of a slimmer form of track construction compared to those constructed to date in the UK.

5.18 The connection and operation of the technology on the heavy rail network raises a significant number of issues. The technology has not been implemented in the UK the use of low floor platforms on the heavy rail network raises significant risk where high floor vehicle would operate through them. Where capacity does not exist on existing route, significant infrastructure or signalling works may be required to facilitate their operation.

5.19 The deliverability of Tramtrain in the UK would be high risk other than on very low used routes.

Light Weight Rail

5.20 The promoters provide very little detailed information on how they propose to construct the trackwork for the £3 million per track km for on-street track. The suggestion is that the track slab would be a slimmer construction due to the vehicle weight and that they wouldn't need to move utilities as the system doesn't use overhead electrification and hence doesn't have any stray current issues.

5.21 The weight issue is related to axle weight and work out at about 70% of that of a tram at about 8 to 9 tonnes, a tram is between 10 and 12 tonnes. It would be advisable to construct track to the higher weight to allow for the possible implementation of trams in the future.

5.22 The need to move utilities is not particularly driven by electrification and stray current it is driven by the need for utilities to access their equipment to provide connection, maintain and repair. Access chambers for the majority of utilities would need to be moved clear of the swept path of the vehicle and in particular the rails to allow their construction.

5.23 A great deal of dialog with the utility companies has been undertaken on the Edinburgh system currently under construction and a risk based approach developed to try to minimise utility diversion. In practice when it came to getting agreement this has proved extremely difficult resulting in the majority of the utilities having to be moved to keep to programme.

5.24 If a significantly lower cost of track was achievable it is unclear why this wouldn't have already or a least in part been adopted on tram schemes. The deliverability of on-street trackwork within the proposed estimates therefore appears to be a high risk.

5.25 A more conventional tram style track construction would be achievable but would be significantly more expensive.

Bus Rapid Transit

5.26 The construction and cost of unguided BRT system is similar to that of highway construction, the associated costs are therefore well known and the associated construction risks greatly reduced.

5.27 The construction of guided BRT varies depending on the form of construction, a variety of solution exist, these include slipform, slab and kerb and concrete beam construction all of which have been utilised in the UK and have been proven to be constructed within the cost estimates.

5.28 The BRT routes also have the advantage of being able to be operated on the existing highway network.

Application to Ashton Vale

5.29 The individual technologies have been assessed against their adoption on the Ashton Vale route to identify any implementation or operational issues and cost estimates developed.

Comparison of cost for Aston Vale route

5.30 A comparison of the cost estimates developed is shown in Table 5.1. The lowest cost is the BRT scheme the highest cost is the Tramtrain option. The developed cost highlighted that it would potentially be as cost effective to develop an electrified tramway on the route in place of the Tramtrain option unless the service connected into the wider rail network.

TABLE 5.1 COMPARISION OF CAPITAL COSTS (2007 PRICES)

Element	Tramtrain	Tramtrain	LWR Promoters Costs	LWR Light Rail Costs	BRT Diesel	BRT Hybrid
Single Vehicle	£2.8M	£3.2 M	£700 K	£700 K	£220 K	£350 K
Number of Vehicles	10	10	18	18	18	18
Fleet Cost	£28 M	£32 M	£12.6 M	£12.6 M	£3.96 M	£6.3 M
Capacity Achieved	2960	2960	2880	2880	2880	2880
Service Frequency	5 min	5 min	2.5 min	2.5 min	2.5 min	2.5 min
Infrastructure Cost	£90 M	£110 M	£25.5 M	£90.0 M	£20 M	£20 M
Total Cost	£130 M	£132 M	£38.1 M	£102.6 M	£24 M	£26 M

5.31 In identifying the service frequency for the options to identify the vehicle costs it is evident that the light weight rail solution with the current vehicle capacity would not be an appropriate technology as it is not capable of delivering the required capacity with an operable vehicle frequency.

5.32 A vehicle would need to match the BRT vehicle capacity of 120 passengers to be a viable solution on this route. The promoters comment that this would be possible but as yet this vehicle has not been produced and would require equipments that have also not been developed.

Whole Life Costs

5.33 Over a 30 year period the whole life costs for a rail based system will differ to that of a bus based mode. Rail vehicle have an expected life of 30 years where a bus would need to be replaced at least every 8 to 10 years.

5.34 The infrastructure of rail based system will have higher operating and maintenance cost and will incur additional costs for the replacement of tight curves due to rail wear. If the numbers of curves are minimal (2 or 3) this could be covered by the general operating and maintenance costs over the 30 year period.

5.35 Bus based modes depending on the construction would, over a 30 year period require resurfacing of elements of dedicated routes due to rutting and surface deterioration.

5.36 The remainder of the operational, road signalling, stop, maintenance requirements will be similar for both modes.

5.37 Taking account of the differences in the capital costs and the replacement and renewal costs over thirty years, the whole life cost for a bus based system would be lower than that of a rail based mode.

Fit with Scheme Objectives

Detailed Criteria Assessment

5.38 The different technologies and their fit with the detailed criteria is shown in Table 5.2.

TABLE 5.2 CRITERIA ASSESSMENT FOR REVIEWED MODES

Assessment Criteria	Tramtrain	Light Weight Rail	Unguided BRT	Guided BRT	Comments
Key Measures					
Mode Shift	✓✓	✓✓	✓✓	✓✓	
Reduced Congestion	✓ Restricted Network	✓ Lower ultimate capacity	✓✓ Access to wider sub-region	✓✓ Access to wider sub-region	
Economic Growth	✓	✓	✓✓	✓✓	The greater the network capacity the greater the potential growth
General Criteria					
Penetration of City Centre	✓✓ very high cost	✓✓ high cost	✓✓ runs on existing streets	✓✓ runs on existing streets	

Assessment Criteria	Tramtrain	Light Weight Rail	Unguided BRT	Guided BRT	Comments
Accessibility to Sub-region	✓	✓	✓✓✓	✓✓✓	
Maintains road network capacity	✓	✓	✓✓	✓✓	
Restricts access to segregated alignment	✓✓	✓✓	✓	✓✓	
Provision to leave and join Alignments	×	×	✓✓	✓✓	
Vehicle Criteria					
Step Free	✓✓	✓✓	✓✓	✓✓	
Gap Free	✓✓	✓✓	✓	✓✓	
Vehicle Capacity	✓✓✓	✓	✓✓	✓✓	
Route Capacity	✓✓✓	✓	✓✓	✓✓	
Speed	✓✓	✓	✓✓	✓✓	ULR restricted to 60kph Other modes 100kph
Doors	✓✓✓	✓	✓✓	✓✓	
Runtime Excluding Interchange	✓✓	✓ unproven	✓✓	✓✓	BRT affords greater opportunity for seamless journeys from wider sub-region
Road Junctions	✓	✓	✓	✓	
Gradients	✓✓	✓ unproven	✓✓✓	✓✓✓	
Perception of Quality	✓✓✓	✓✓ unproven	✓✓	✓✓	
Maintenance and Depots	new facilities required	new facilities required	existing facilities could be used	existing facilities could be used	
Deliverability					
Capital Cost	×××	××	×	×	
Vehicle Costs	×××	××	×	×	

Assessment Criteria	Tramtrain	Light Weight Rail	Unguided BRT	Guided BRT	Comments
Technology Maturity	✓ but not in UK	×× still under development	✓✓	✓✓	
Risk	×× untested technology in the UK	××× untested technology new untested infrastructure construction	✓✓ Accepted technology standard highway construction	✓ Accepted technology standard highway construction	
Procedural Process	×× significant procedural issues to be resolved	×× procedural issues to be resolved	✓✓ well established	✓✓ well established	
Environmental					
Visual	similar impact	similar impact	similar impact	similar impact	
Maintains existing cycle and pedestrian facilities	✓✓	✓✓	✓✓	✓✓	
Severance	similar impact	similar impact	similar impact	similar impact	
Land Take	similar impact	similar impact	similar impact	similar impact	
Noise	×× diesel only	×	×	×	
Emissions	×× diesel only	×	×	×	Based on Hybrid bus
Operation					
Vehicle Recovery	××	××	✓	×	
Integration with Heritage Railway	✓✓✓	✓✓	✓	✓	BRT could operate on road network
Service Competition	×	×	✓	✓	

5.39 In overview the table shows that both Tramtrain and BRT perform comparatively well against a significant proportion of the criteria although there is a significant capital cost difference between the two modes. The Light Weight Rail mode performs comparatively less well against a number of the criteria mainly due to its lower vehicle capacity and the risks surrounding its deliverability, particularly in relation to the proposed costs and the deliverability of an appropriate low floor vehicle.

6. FUEL TECHNOLOGIES[17]

6.1 Diesel is the most common fuel used for public transport, and it dominates because, diesel fueled vehicles are operationally efficient, cost effective and have significant infrastructure to support their operation. More recently alternative fuels have become more popular, with growing concern for the impact on the environment.

Diesel

6.2 From October 2006 new buses and coaches must be powered by engines which meet the Euro IV standard. This is much tougher than the previous Euro III standard in respect of reduced particulate emissions, but effects reductions in permitted emission levels across all indicators. For the first time in many years, as emissions standards have become more stringent, the move from Euro III to Euro IV has been accompanied by an improvement in fuel consumption. Diesel powered vehicles are becoming cleaner and more fuel-efficient especially as a marketing tool for lowering user's carbon footprints.

6.3 The next level in the emissions standards will be Euro V, due to be introduced in 2008, further reducing the limits for emissions of oxides of nitrogen. A handful of operators have already placed Euro V standard vehicles into service. It is not anticipated that there will be any significant impact on fuel consumption with the change to Euro V.

6.4 Efficient combustion, modern engine management systems and good maintenance ensure that the emission of particulates, particularly PM10s that are regarded as carcinogenic and can contribute to respiratory problems, is kept to a minimum. It is also possible to fit a particulate trap to vehicles to further cut down on the emission of particulates or use other fuel additives or devices to the same end.

Liquefied Petroleum Gas

6.5 Liquefied Petroleum Gas is a low emission fuel, most commonly used for cars and often in a "dual fuel" application where the car can switch between LPG and petrol. LPG was also used for buses in the 1990s, as its emissions were then considerably lower than the prevailing Euro standard diesels.

6.6 However, there are problems with the use of LPG. Initial vehicle capital cost is higher than that for diesel vehicles. LPG is incompatible with diesel fuel in that it requires significant changes to be made to the vehicle engine. This gives inflexibility of operation, as a separate spare pool of vehicles is required to cover the LPG fleet. Maintenance costs are also higher, in part due to the lack of economies of scale with manufacturers and skills required to maintain LPG engines. LPG also requires separate storage and fuelling facilities which take up depot space and are expensive to provide. LPG fuelling facilities are uncommon in the UK. There are also problems with variability in the calorific value of batches of fuels and a consequent impact on vehicle performance in particular with heavily loaded or on gradients.

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17 Information in this section has been sourced from the report *West of England Partnership: Greater Bristol Bus Rapid Transit (BRT) Technology Review of Systems*, Halcrow Group Limited, September 2007 and information provided by First Group.

6.7 Now that Euro standards have progressed such that diesel power is “cleaner” in its emissions than LPG there is no advantage in taking the LPG fuel route, and UK applications for buses have reduced or ceased altogether.

Compressed Natural Gas

6.8 CNG vehicles usually feature reinforced high pressure fuel tanks in the roof of the vehicle. Vehicle capital costs are higher than for LPG as the nature of the fuel requires larger volumes for storage.

6.9 Compressed natural gas is similar in nature to LPG. It too has now been somewhat superseded by events as its emissions can be bettered by the latest Euro diesels. It has similar drawbacks to LPG in respect of vehicle cost, reliability and maintenance, and due to its volatility, the need for special storage and fuelling equipment and comparatively long fill times makes it even less attractive.

6.10 Similarly to LPG, UK applications for buses are believed to have all ceased, but CNG remains comparatively popular in continental Europe, particularly France and Spain, where some major operators made significant investment in the 1990s and now need to persevere with CNG in order to make an appropriate return.

Bio Fuels

6.11 Bio fuels, including Bio Diesel and Bio Ethanol, are a more recent initiative. The emissions from the use of these fuels are almost identical to that of conventional diesel however the means by which the fuel is sourced are more sustainable as they are derived from crops or from waste cooking oil rather than from crude oil.

6.12 In some applications it is possible to combine bio fuels with conventional diesel and to run diesel-engined vehicles with little or no modification. However there is little evidence yet demonstrating what if any effect there is on vehicle life and on maintenance costs resulting from the use of bio fuels.

6.13 Interest in developing ethanol powered buses is building in mainland Europe with Scania in particular developing vehicles, but this technology is still in its infancy.

Hybrid

6.14 Hybrid vehicles employ an electrical traction package in conjunction with a constant speed engine generating electricity to operate the vehicle. An energy store (battery, capacitor, flywheel) is used to power the vehicle, regenerative braking energy is used to recharge the store. The vehicles constant speed generator is run at its optimal efficiency to minimise emissions and provide power.

6.15 The vehicle can operate on battery power alone for short lengths of route, thereby minimising noise and airborne emissions. The batteries are charged by the internal combustion engine which, as it can be run at constant (and optimal) power, is also capable of producing minimised emissions. It is also possible to operate using a “parallel” hybrid drive that can provide power from the internal combustion engine and batteries simultaneously in short bursts. Thus there is no solid drive train between the engine/generator and the wheels, connections being cable. This means that the compact engine and generator can be located more flexibly within the overall vehicle structure, enabling a low flat floor throughout the bus and the possibility of a level access door behind the rear axle of the bus.

6.16 The design also reduces the need for mechanical parts on the vehicle as the transmission system is replaced by electronic control of the motors. Quality of ride is significantly improved due to the elimination of jerking from gear changing.

6.17 The costs of maintenance remain high however, as a result of the need to replace the battery packs after a given period of use. Battery technology is continually improving and battery weight is falling and life is increasing.

6.18 Bus operators have undertaken experiments with hybrid vehicles powered by both conventional diesel engines and with turbine units. The former are generally more acceptable to the industry, being of tried and tested design and familiar to maintenance staff. Whilst turbines have lower emissions of nitrogen oxides, their carbon based emissions are higher than conventional diesels and these are now considered to be the most preferred power source, operating at their optimum efficiency.

6.19 The city of Christchurch in New Zealand has introduced electric hybrid buses into service – the Designline. A batch of ten of these vehicles is in service on the Quaylink in Newcastle-upon-Tyne in the UK. These vehicles were introduced as part of a campaign to reduce city pollution, especially from CO_2 emissions, and vehicle noise. The vehicles have ‘super low floor’ access with wide entry/exit doors and a capacity of 37 passengers (20 seated, 16 standing and one wheelchair). The vehicle’s electric motors are powered by solid gel, water-cooled batteries. An LPG powered turbine charges the vehicles batteries.

6.20 Since March 2006 diesel hybrid buses have been running on the Transport for London 360 route in London, between Kensington and Elephant and Castle. There are six hybrid vehicles currently operating this service showing reducing emissions of local pollutants and carbon dioxide by at least 30 per cent compared to a conventional diesel bus.

6.21 Hybrid vehicles are still currently expensive to purchase. Typically vehicles cost approximately £60k more than the same design would with a conventional diesel engine. Maintenance costs are also higher as there is a need to replace the battery packs after a certain period of time. But previous commitment by Transport for London to a programme of hybrid drive investment in London could see a reduction in prices due to competition between suppliers and the benefits of economies of scale, but with the move to replace articulated buses in London the focus may have been diverted.

Electric

6.22 Battery powered vehicles without an auxiliary power source are almost entirely ruled out of local bus service provision as a result of their limited range of operation without recharge. There are examples where a single electric motor is mounted at the rear of the bus and drives a conventional axle. These are usually adaptations of older designs of vehicles and do not offer the key advantage of a low floor throughout the vehicle.

6.23 Whilst two services remain in operation in Merseyside and experiments in the 1990s in Bristol and Oxford operated for some years, the improvements in battery design remain insufficient to make promotion of battery power for local bus services a realistic alternative at present.

6.24 Trolleybuses have not operated in the UK since 1972 (with the exception of an off-road experiment in Doncaster from 1985-1989). In mainland Europe their fortunes have varied, with many systems closing but others investing in low floor state of the art vehicles such as the Cristalis (Lyon in particular has invested heavily in these vehicles to replace its 1980s trolleybuses). The reason for abandonment in many cases is the high maintenance costs associated with the overhead power supply. This can also be controversial as a result of its visual impact on the environment.

6.25 One advantage of electric buses was thought to be quiet operation but it has been found necessary to introduce a mechanical noise or bell in pedestrian areas as a safety measure.

6.26 Whilst the capital costs of trolleybuses are very high (typically 2 to 3 times that of a conventional UK bus), they do have low mechanical maintenance costs and can be depreciated over a longer time period as they generally last longer (subject to obsolescence) being less prone to vibration etc.

6.27 To afford operational flexibility a trolleybus also requires an auxiliary power source, usually in the form of batteries or a small diesel generator, to provide a means of avoiding obstructions and otherwise moving vehicles without reliance on the overhead wires. This adds to the cost, weight and complexity of the vehicles.

Fuel Cell

6.28 The latest fuel technology is fuel cells. This is in its infancy and the first major experiment, a three-year trial, across several major European cities including London, Amsterdam, Hamburg and Madrid was concluded in January 2007. Most of the main bus manufacturers, MAN, Mercedes, Scania and Neoplan are developing fuel cell vehicles.

6.29 The fuel cell Mercedes Benz Citaro vehicles used in the European Cities trial can carry 70 passengers (the same as a conventional single deck bus) with a range of 200km. They are powered by roof mounted pressure cylinders that contain hydrogen compressed to 350 bar.

6.30 The fuel cells combine hydrogen and oxygen, the only emission being water vapour. Whilst operationally successful, the problem with fuel cell applications is the high cost due to there being as yet no economies of scale. The vehicles used by First in London cost over £1.5m each. Fuelling infrastructure is also very expensive.

6.31 It is highly likely that the use of fuel cells will increase, at least in those areas with the highest environmental sensitivity. But there will need to be dramatic reductions in the capital costs of vehicles and associated infrastructure if this technology is to have wider applications.

Bath & North East Somerset Council's CIVITAS Project

6.32 Bath & North East Somerset Council together with seven local partners has recently been awarded funding by the European Commission under the CIVITAS Plus initiative, 'Testing Innovative Strategies for Clean Urban Transport for Historic European Cities'.

6.33 The four year programme is a mixture of study work and demonstration projects which will be evaluated and compared with similar proposals in the partner cities. The initial phase, lasting around 18 months, is a study period to formulate concepts which are developed into a demonstration project, lasting at least 18 months.

6.34 As well as a number of other innovative transport measures the Bath initiative will include a study, with partner First Group, to identify and trial a 'green' fuel articulated bus suitable for operation in a historic environment.

6.35 The findings of this study will be an important consideration in the development of the rapid transit scheme.

Other Innovations

Shell Gas to Liquids (GTL) Transport Fuel

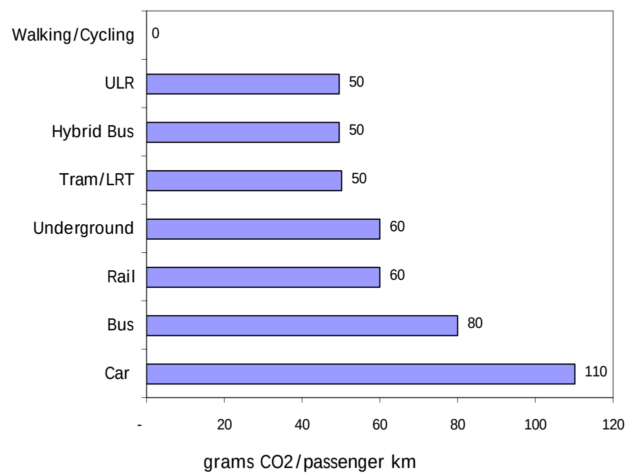
6.36 The fuel company Shell has developed a 'clean' diesel fuel. This is a natural gas transformed into a very clean form of diesel. It is a synthetic fuel product that is crystal clear, free of sulphur and can be used neat or blended with regular diesel. This 'gas to liquid' can be used in any vehicle without the need for complicated alternative engines and refuelling infrastructures. Another advantage is that it produces lower emissions. This is to be trialled on one of the articulated bus routes in London, UK.

Emissions

6.37 Vehicles emissions data will vary significantly depending on the passenger loading of the vehicle in conjunction with the means of propulsion and the fuel used. Figure 6.1 shows a comparison of the different CO_2 emissions for the different types of technologies[18].

[18] TfL Climate change Action Plan - Hybrid vehicles were shown to have a 38% reduction in carbon dioxide compared with standard buses. ULR calculated using hybrid estimate of reduced fuel usage of 40% when compared with standard bus (see page 25 of Scott Wilson report, Appendix B).

FIGURE 6.1 CO2 EMMISSIONS FOR DIFFERENT TYPES OF TECHNOLOGIES



6.38 The information for the ULR vehicle within Figure 6.1 is based upon the Scott Wilson HULTS report which states the vehicle reduces fuel usage by 40% when compared to a diesel bus. We have shown therefore a 40% reduction in CO2 emissions to provide a simple comparison. In reality the issue is more complex as the emissions of the vehicle will be dependant on the vehicles fuel efficiency and the optimum performance of the vehicles engine and in particular the passenger loading, all of which could impact upon the vehicles emissions performance.

6.39 The figure does show that ULR, Hybrid bus and LRT are comparable, with potentially little difference in the total emissions. Importantly the electric vehicle emissions would be zero at the point of use. The Tramtrain emissions are likely to be comparable to rail.

6.40 The choice of fuel in relation to ULR and Hybrid bus and the resulting emissions will not provide any significant difference between the technologies as both technologies could use the same fuels.

Summary

6.41 Alternative fuel technology is still in its infancy and is continuing to evolve. There are some encouraging developments and the outcomes of the work being undertaken by Bath & North East Somerset Council and First Group will be important.

6.42 A key issue is the operational feasibility of alternative technologies for a large scale network, including the infrastructure investment required, maintenance and reliability. There is also the capital cost consideration as small scale projects result in high vehicle costs due to limited sales opportunities over which to recover development costs.

6.43 For the present and short to medium term, diesel power is likely to remain the most appropriate fuel for local bus based vehicles. The ongoing development of hybrid drive systems is likely to reduce their cost and increase their capability and reliability. Therefore hybrid is likely to be a viable alternative in the next few years, subject particularly to reduction in capital cost.

7. CONCLUSIONS

Tramtrain

7.1 Tramtrain would only provide additional benefit over that of a tram scheme if it were able to be integrated with and operate on the existing rail network in the area. There are significant deliverability issues with the implementation of Tramtrain in the UK, and potential capacity issues on the existing rail network in the West of England area. A significant amount of work would need to be undertaken to identify the opportunities and constraints for the adoption of the technology in the area

7.2 Tramtrain vehicles provide the highest capacity of the modes reviewed. The mode is the most expensive and if it were deliverable only on dedicated routes separated from the existing rail network, light rail / tram technology could be more appropriate and more deliverable for a similar cost.

Light Weight Rail

7.3 The deliverability of Light Weight Rail is a significant risk, an appropriate vehicle has yet to be produced. This includes the bogie technology that it would need to be based upon. The capacity of the proposed vehicle is also lower at 60 passengers than that required to meet the identified demand. The proposed solution of either coupling or providing a double length vehicle would raise additional deliverability risks.

7.4 The cost estimates for the technology's infrastructure is based upon a very low cost for track infrastructure of £3 million / kilometre, 60% to 80% less than the costs of comparable on-street tram track construction. It is not clear within the HULTS information how this cost has been developed. The basis of cost would need to be developed further and the assumptions confirmed with all the influencing parties and market tested as a minimum to reduce the considerable delivery risk. In particular the assumptions on utilities would need to be developed and confirmed as the LRT industry has repeatedly failed to get utility companies to buy in to reduced utility diversions.

7.5 Currently the technology doesn't have a fully low floor vehicle; it doesn't have a vehicle with sufficient capacity; and the deliverability of the infrastructure required at the proposed cost would need to be validated. These issues would pose significant deliverability risk to any project, with the initial project effectively having to pay for the cost of developing all the required elements.

7.6 This mode would need to be developed further before it becomes a viable option for delivery of the proposed rapid transit system.

Bus Rapid Transit

7.7 The BRT mode is the most flexible of the modes considered and has the additional benefit of wider network services being able to utilise the infrastructure provided to gain runtime and operational benefits. The capacity of the vehicle is limited to approximately 120 passengers for an articulated bus. This sits between the capacity of the PPM vehicle and Tram / Tramtrain modes.

7.8 In undertaking the review, the vehicle has been assumed to be a diesel powered articulated vehicle meeting the latest emissions standards. A variety of other vehicle technologies are also available from vehicle manufacturers that could be employed to further reduce vehicle emissions, these include hybrid and hydrogen, although these would increase the cost of the fleet. Their adoption would therefore need to take account of the affordability to the project.

7.9 The BRT mode is the lowest cost mode and would have the lowest deliverability risk as the vehicles could, as proposed in the city centre, operate with minimal infrastructure works. On dedicated corridors the infrastructure could be either an exclusive highway or, for guided sections, utilise kerb guidance which can be constructed in a number of ways, all of which have been undertaken in the UK.

7.10 The infrastructure for BRT routes and networks can be developed incrementally over a period of time (unlike rail based modes) allowing BRT services to adapt and make use of segregation and priority as it is provided.

7.11 In our opinion, Bus Rapid Transit should be pursued for the Ashton Vale to Temple Meads rapid transit route as it best meets the rapid transit scheme objectives; is the most cost effective and flexible; and can be delivered within the current programme and available funding.

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