



West of England Combined Authority - Underground Metro

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Project

WECA Underground Metro pre-feasibility study

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Acronyms and Abbreviations

AV	Autonomous Vehicles
AVRT	Advanced Very Rapid Transit
AWBP	Aztec West Business Park
BCR	Benefit Cost Ratio
CPNN	Cribbs Patchway New Neighbourhood
PRT	Personal Rapid Transit
TBM	Tunnel Boring Machine
ULR	Ultra Light Rail
VAL	Véhicule Automatique Léger
WECA	West of England Combined Authority (excluding North Somerset Council)
WOE	West of England (including North Somerset Council)



Executive Summary

This pre-feasibility study has been commissioned by Bristol City Council to explore the viability of a light underground system in the Greater Bristol area and where appropriate to provide sufficient evidence that partially or fully underground route options are worth pursuing further.

The study focuses on technology options, build costs, operational costs, and funding options. Key benefits of the proposal are also highlighted, along with the possible interventions.

A review of technology options currently available has identified a number of options that are currently available and have the ability to deliver the level of service and capacity required to operate the underground system, based on approximately 3,000 passengers per hour per direction. The options considered include both autonomous and operator based operation.

A review of existing ground investigations across Bristol has been undertaken which has been supplemented with historic boreholes information obtained from the British Geological Survey's database. The investigation has identified that tunnelling is generally expected to be through Mercia Mudstone, but is also likely to encounter Alluvium, Tidal Flat Deposits and Redcliff Sandstone, especially when tunnelling near the River Avon and in the centre of Bristol. There is also a likelihood that some sections of the route would need to be tunnelled through Coal Measures. Consideration has been given to the many listed buildings, scheduled Monuments, Listed parks and Gardens and Site of Special Scientific such as Pen Park Caves.

The study has concluded that the system has the potential to cover its operating costs, but that further work, including detailed financial modelling, will be required to confirm these initial assumptions. It has also concluded that it will likely result in significant enhanced public transport connectivity for areas currently poorly served by public transport.

Based on experience from other systems the Underground Metro is also likely to have an impact on land values along the route and lead to increased delivery of housing stock and/or acceleration of the delivery rate. This is also likely to positively impact on employment sites along the route which could be densified, as a result of better public transport accessibility for employees and thus need to provide lower levels of parking.

The study has assessed the funding potential to support WECA Underground Metro This assessment focuses on funding that can be generated locally from third parties (i.e. not local grant funding) and presents funding scenarios. The study presents a high level range of potential funding sources and notes that there is a reasonable chance that more than 50% of the capital requirement of the Metro (excl. financing costs or Optimism Bias for capital costs) could be generated from various combinations of these local funding options.

The outcome of the study provides sufficient evidence to recommend that a proposed underground option should be considered as part of the development of the West of England Rapid Transit Study.



SECTION 2

Introduction

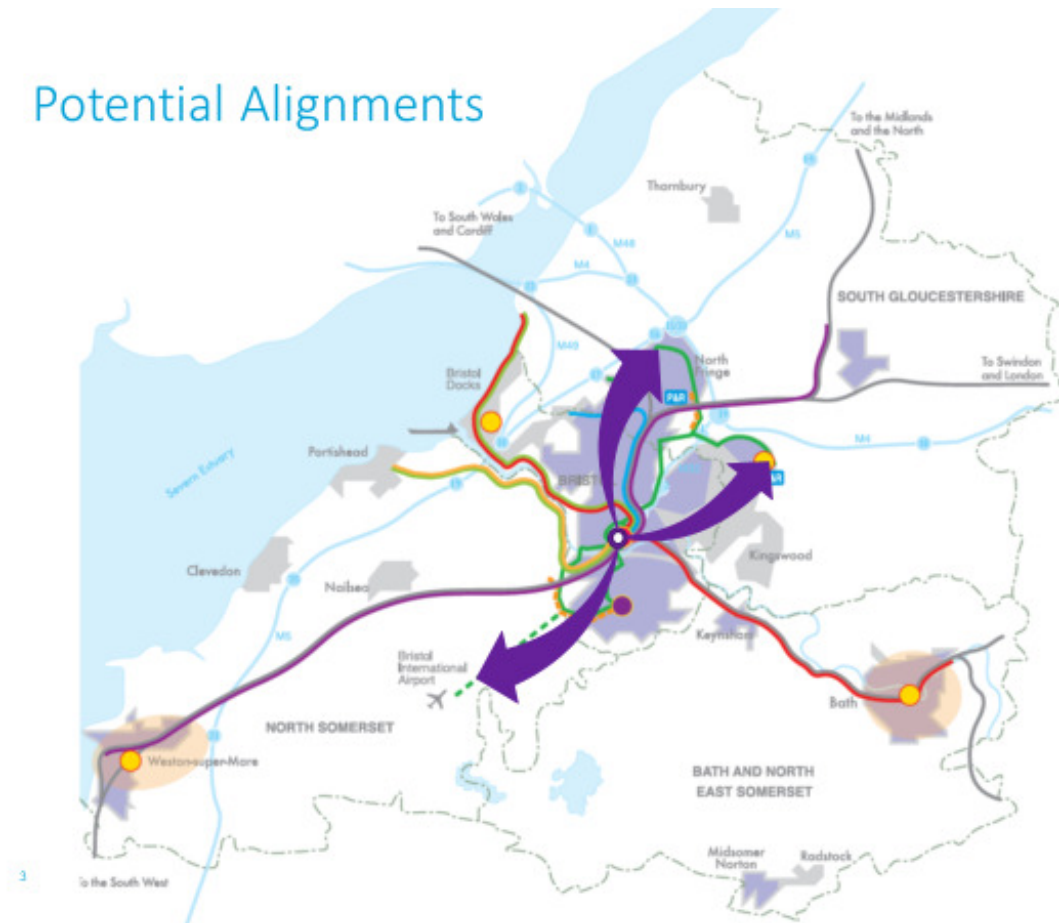
The Joint Transport Study recommends a number of rapid transit routes are needed to cater for existing and future transport demand. This includes routes between Bristol City Centre and:

- South Bristol and Bristol Airport;
- North Bristol and North Fringe;
- East Bristol and East Fringe; and
- Hicks Gate/Keynsham and potentially onwards to Bath.

Parts of these routes, particularly to the north and east fringes, are likely to be very challenging to deliver on existing carriageways due to narrow highway width, kerb-side servicing requirements and impact of through traffic on journey times and reliability. In these cases, a potential alternative is to go underground on some sections of route.

The indicative route alignment is shown in figure 1 below.

Potential Alignments





SECTION 2 – INTRODUCTION

This study is exploring the viability of underground mass transit systems in this context. The JTS has specifically identified three of the corridors identified above for further investigation but this does not mean that underground running would not be considered for the A4 in the future. The potential underground sections considered in this study are:

- Line A A38 North, including approximately 9km of tunnel and 11 underground stations
- Line B A420 Emerson's Green, including approximately 10km of tunnel and 11 underground stations
- Line C South Bristol to Airport, including approximately 9.5km of tunnel and 7 underground stations

CH2M and Steer Davies Gleave have been commissioned to undertake a pre-feasibility study to explore the viability of light underground Metro options, such as light rail systems, in the Bristol region. The study is intended to capture the expected costs, benefits and funding opportunities for the WECA region. This high-level report is intended to inform Bristol City Council, as the Lead Authority, of whether this form of transport is a viable option to be considered further as part of a wider and more detailed assessment of rapid transit route options for the various corridors. Any new rapid transit system will need to align with the developing MetroBus network to ensure connectivity between modes.

The report has been divided into four main chapters covering the required subject matter, as follows:

Chapter 2- Assessment of Technology Options

Chapter 3 - Capex Including Ground Conditions and Route Alignment

Chapter 4 - Demand, Benefits and Outline Value for Money Assessment

Chapter 5 - Funding Assessment



SECTION 3

Assessment of Technology Options

3.1 Introduction

An assessment of technology options for the proposed WECA Metro has been undertaken. This has focussed on the use of various technologies for the underground sections of the potential underground routes, in the inner and central districts of Bristol.

The potential routes are:

- Line A A38 North, including approximately 9km of tunnel and 11 underground stations
- Line B A420 Emerson's Green, including approximately 10km of tunnel and 11 underground stations
- Line C South Bristol to Airport, including approximately 9.5km of tunnel and 7 underground stations

The routes would share a common alignment in the centre, with two stations common to both lines. The brief for this study has suggested that the review should include the following technologies:

- Light rail underground options (e.g. Seattle, San Francisco)
- VAL
- Cambridge system – Advanced Very Rapid Transit (AVRT)
- Emerging technologies/driverless vehicles
- Any others

3.2 System Characteristics

This review provides an overview of the characteristics of mass transit modes. It sets out the key issues pertinent to each characteristic. These characteristics are then mapped against the potential mass transit modes mentioned below.

The characteristics considered in the review include:

- Vehicle Capacity, Train Capacity, Frequency and Line Capacity
- Speed, Acceleration, Braking and Journey Time
- Single or Double Track / Shuttle or Line Haul Working
- Vehicle Size and Shape, Implications for Tunnels
- Vehicle Support
- Vehicle Guidance to include Central Rail, Electronic, Optical and emerging guidance
- Flanged running wheels and Lateral Guide Wheels
- Signalling and Control
- Energy Source, including External Power, Overhead Line, Third Rail, Ground Level Pickup systems, On Board Power, Internal Combustion Engine, Battery, Fuel Cell and Flywheel



- Alignment Characteristics such as Gradient, Curvature and Segregation

3.3 Examples of System Technologies in use or Proposed elsewhere

This section sets out mass transit systems and technologies which may be applicable to the WECA Metro. The systems and technologies range from generic systems widely used across the world, to proprietary systems with much less coverage. Consideration is also given to systems recently or currently proposed.

There is widespread interest in the development of fully autonomous vehicles (AVs), able to operate on existing roads. Such vehicles need a comprehensive capability to navigate safely on streets, shared with other vehicles (autonomous and manually driven), together with pedestrians, cyclists and a range of other hazards. Numerous organisations are developing the technologies required for AVs, and giving consideration to the legal, regulatory, insurance etc. issues arising. AVs have the potential to radically alter the way that public and private transport is provided. However, while trials of AVs are taking place, their full deployment on the public road system is clearly some way off.

This study is looking at options for mass transit on identified corridors, and so the technologies considered are based on the use of fixed alignments. However, there are emerging technologies being incorporated into these systems, as set out in the following descriptions.

In Table 3.1 the various technologies are mapped against the system characteristics.

3.3.1 Rail Based Metro

Rail Based Metro encompasses systems ranging from conventional urban railways, such as London Underground, to fully automated driverless systems, such as London's Docklands Light Railway. The common features of these systems are the use of steel wheels and steel rails, a fully segregated right of way, and being electrically powered from a low-level power rail or overhead line. Rail Based Metro offers a high capacity, frequent service that operates completely segregated from other traffic to provide fast, reliable journey times.

Urban rail-based metro systems exist in many cities worldwide. Some operate as the urban/suburban services of a wider rail network, others are more self-contained, but use conventional railway technology and operating practices. The London Underground system and Tyne and Wear Metro are UK examples of the latter.

A number of systems are fully separate from other transit networks, often using proprietary technologies. Examples include London's Docklands Light Railway and the Canada Line and SkyTrain systems in Vancouver, Canada. There have been concerns that the proprietary nature of many of the products and technologies available may affect the availability and cost of spare parts later, or may inhibit system expansion - both in terms of the capacity of existing lines and the development of new lines.

3.3.2 Light Rail Transit/Tram

The key components of high quality LRT are:

- Flexible alignment types – can incorporate a mix of segregated and shared running operation with traffic or in pedestrianised areas (with track flush with road surface)



- Alignments can be at grade, elevated or in tunnel
- Modern systems feature low floor vehicles with multiple double doors for easy level boarding and alighting
- Platforms are 300-350mm high - “raised kerbs” easily designed into urban areas
- Vehicles electrically powered via overhead lines supported by poles or building fittings. Alternative designs with no wires are being developed
- Modern LRT vehicles are articulated, typically 30 metres and 50-80 seats and an overall passenger capacity of around 200
- Driver operated and controlled on line of sight, using the traffic signals at junctions.

Figure 3.1: SkyTrain, Vancouver, Canada



Source: Steer Davies Gleave

Figure 3.2: Shared Running LRT – Croydon, UK



Source: Steer Davies Gleave

3.3.3 Ultra Light Rail (ULR)

Lighter weight versions of LRT have been proposed for use where the level of patronage is lower than for many urban mass transit systems. Smaller vehicles can be used, which in turn will be lighter and impose lower loads on the track structure. ULR vehicle proponents often aim to use components developed for the road vehicle industry, available at lower cost.

Lighter weight track solutions have been put forward, some based on existing road pavements as part of the track foundation, negating or reducing the need for extensive excavation and reinforced concrete trackbed.

It is claimed that the combined effect of these changes is a significant reduction in the cost of implementing light rail, making it affordable in situations where a conventional solution would be too costly.

Early ULR proposals were based on the use of manually driven vehicles, powered from an overhead line. More recent proposals focus on the potential for driverless, battery -powered operation.



SECTION 3 – ASSESSMENT OF TECHNOLOGY OPTIONS

No mass transit ULR systems have yet been implemented in the UK, although a system is currently being developed by Warwick University's Warwick Manufacturing Group, with a demonstrator vehicle planned for 2019, and longer-term aspirations to use ULR to link Coventry to the Birmingham HS2 station.

3.3.4 Personal Rapid Transit (PRT)

Personal Rapid Transit is a system in which small, lightweight, driverless electric vehicles provide on-demand, direct (non-stop) trips between origin and destination. In concept, such systems could operate on existing road networks as fully autonomous vehicles, but with the technology currently available vehicles are limited to a specific guideway. Vehicles are rubber tyred and battery powered.

PRT vehicles or 'pods' run under the control of a central control system, which ensures that vehicles are appropriately deployed around the network to meet system demands, with the individual vehicles fitted with autonomous systems to follow the guideway and automatic vehicle protection (i.e. avoiding vehicle to vehicle contact).

The guideway is fully segregated, and can be at grade, elevated or underground.

On boarding, passengers select their destination, and the control system routes the vehicle by the quickest route to the chosen destination.

An Ultra PRT system has been in operation at London's Heathrow Airport Terminal 5 since 2011 and comprises 21 vehicles serving 3 stations, and operating over 3.8 km of unidirectional guideway. The system is claimed to be able to dispatch the 4-person pods at a rate of 100-120 per hour, giving a system capacity of 800 passengers per hour per direction.

Figure 3.3 Ultra PRT at Heathrow



Source: Ultra Global PRT
<http://www.ultraglobalprt.com/photos-videos/photos/>

Figure 3.4: VAL on Lille Metro Line 1



Jérémy-Günther-Heinz Jähnck / Ligne 1 du métro de Lille Métropole - Interstation CHR Oscar-Lambret ↔ CHR B-Calmette (02A) / Wikimedia Commons / GFDL-1.2

3.3.5 VAL

VAL (Véhicule Automatique Léger) is an automated transit system, developed by Matra in France and first used for the Lille Metro, the first section of which opened in 1983. The technology is now owned by Siemens.

The VAL system has a segregated guideway. VAL vehicles run on rubber tyres with separate twin horizontal wheels running on vertical guiderails either side providing guidance. It uses relatively light cars, which can operate singly or in trains of up to six vehicles. VAL cars are 11.2m long and either 2.65m



or 2.80m wide with up to 24 seats and space for up to 100 standees per car. The cars are electrically powered at 750v DC, with power collected by shoes from a separate power rail.

VAL systems are operated from a central control room. The control system automatically speeds up or slows down vehicles/trains in order to maintain timetabled operation, and is also able to insert or remove vehicles or trains into service as required to meet demand. It is stated that the system can operate with headways as low as 60 seconds.

VAL systems have been implemented both as Urban Mass Transit Systems and as shorter shuttle operations at airports.

Urban systems operate in Lille (2 lines), Toulouse (2 lines) and Rennes in France, with other systems in Taipei (Taiwan), Turin (Italy) and Uijeongbu (South Korea). A second line in Rennes is due to open in 2019. The existing urban VAL routes total 117km, with 755 vehicles serving 155 stations. Rennes Line B will add a further 12 km, 51 vehicles and 17 stations.

Airport systems have been implemented at Paris Charles De Gaulle (2 lines) and Orly, with a system also in operation at Chicago O'Hare Airport. The Orly route, which connects the Antony RER station to the airport's west and south terminals, is 7.2km long – much longer than most airport people mover systems. The airport VAL routes total 15km with 38 vehicles serving 15 stations.

3.3.6 Cambridge System – Advanced Very Rapid Transit (AVRT)

AVRT is intended to represent a creative approach to use new and future technologies to transform the local transport system, make better connections between Cambridge and the surrounding towns and villages, within a capital and operating budget that is affordable for a small but growing city region. The promoters believe it may, in future, also serve the needs of many other small, vibrant, cities across the UK and abroad – with Oxford and Milton Keynes identified as early candidate cities. The current AVRT concept is intended to illustrate the nature of what might be, to contribute to a debate, rather than proposing a definitive solution.

The AVRT promoters have recognised that cities the size of Cambridge do not have the volumes of movement necessary to justify a conventional underground metro system, and the AVRT project aims to address this by reducing the costs by a range of measures including:

- Use of fully autonomous vehicles, of smaller dimensions than typical rail-based transit vehicles, with a capacity of approximately 40 passengers. They would be capable of operating singly or in platoons, avoiding the cost of drivers
- Rubber-tyred, running on a flat paved surface to avoid the costs and spatial requirements of conventional steel rail trackform
- Battery powered, to avoid the costs of overhead line infrastructure, with rapid recharging provided at each of the stations
- Smaller diameter tunnels to reduce tunnel construction costs
- Operation as a series of simple single-track end to end shuttles, to avoid the need for a complex railway-type signalling system
- Shuttle routes connecting four hub stations on the edge of the city and to a single central Cambridge station



SECTION 3 – ASSESSMENT OF TECHNOLOGY OPTIONS

- Outer radial routes, 8-15km in length, connecting remote park and ride sites to the hubs. These would use similar vehicle and systems technology to the underground shuttle routes, but would operate at grade/partially elevated and use conventional twin-track operation
- High speed running (192 km/hr) and high acceleration and braking rates (2.6 m/s^2) to achieve fast journey times (necessary to achieve high frequency service with the shuttle operation)

Figure 3.5 shows the overall concept and Figure 3.6 shows a typical 'city ring' station. The proposed central Cambridge station would be similar in general form, but located underground. For the latter option, an alternative layout, with two underground levels each serving two shuttle routes, has also been considered.

Figure 3.5: Cambridge AVRT Concept

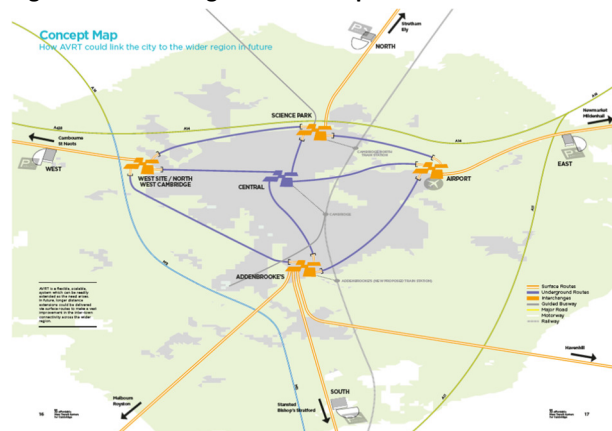
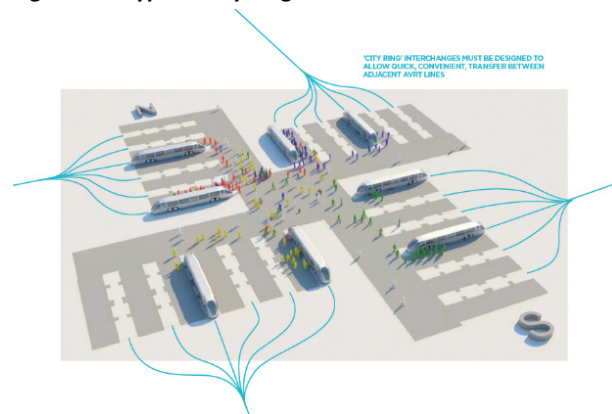


Figure 3.6: Typical 'City Ring' Station



Source: Affordable Mass Transit for Cambridge and the Wider Region

The AVRT concept relies on the use of new and emerging technologies. The promoters view is that these are all either proven in use or under active development. They also note the level of worldwide investment in these technologies from industry and UK Government support for the necessary changes to legislation, approvals processes and regulatory regimes to facilitate their widespread adoption. The promoters view is that use of these technologies for a public transport system is entirely feasible, and suggest that a demonstration vehicle could be designed and built within a period of 2-3 years.

From the passenger perspective, the key difference between AVRT and other mass transit systems is that there are no through-services, and passengers need to transfer from one service to another at each of the stations for most journeys. The limited number of stations in the system mean that the onward connection from the station to the final destination may be longer than with other systems. This may require separate 'last mile' solutions to be adopted for those destinations further from the stations. The promoters view is that while passengers are required to make transfers, the interchange times will be relatively short due to the high service frequency, and the additional interchange times will be balanced by the very rapid journey times on each shuttle leg.

The other technologies reviewed in this document have all been used elsewhere, and so there is some experience and understanding of their strengths and weaknesses. AVRT involves some novel concepts for a mass transit system.

3.3.7 Bus Rapid Transit

Bus Rapid Transit (BRT) is an umbrella term that encompasses a wide range of bus-based transit systems. At the lowest, it can amount to little more than use of modern high-quality buses, upgraded



bus stops and a specific route or system branding. At the other end of the scale it can comprise extensive fully segregated busways (guided or unguided) operating high frequency high capacity bus services. The developing MetroBus system in the West of England is a form of BRT.

Most BRT systems aim to emulate LRT levels of capacity, speed and service quality, but at lower cost, by using bus technology. Improvements in the level of service and capacity over conventional bus services are achieved by adding a series of measures to improve the performance and quality of service, offering faster and more reliable journey times and improved facilities for passengers. BRT is usually implemented on higher demand corridors where conventional bus services cannot meet the passenger demand or where the interactions between buses and other traffic result in poor reliability and variable bus journey times.

Typical key components of high quality BRT are:

- Dedicated right-of-way, bus only streets and bus only designated lanes within existing highway
- Priority at junctions
- Modern, low floor vehicles
- Multiple door boarding
- Off-bus ticketing
- Distinctive branding
- High quality stops/shelters
- ITS/Real-time information

A number of different BRT design approaches can be used. Wider stop spacing and the implementation of greater segregation and priority over general traffic are designed to provide faster and more reliable services. Segregation from other road users can take the form of dedicated lanes on existing roadway, dedicated unguided roadway and dedicated guided roadway.

BRT systems can operate with a range of vehicle types, usually based on standard buses, although some BRT vehicles aim to adopt elements of LRT styling to differentiate them from conventional bus services. Vehicles may be rigid, or single or double articulated to suit the proposed style of service and the passenger capacities required. Double deck rigid buses are also used.

BRT systems are operated by drivers on line of sight and controlled by conventional traffic signals. They are generally powered by internal combustion engines.

BRT systems have been developed worldwide, with the majority being implemented in Europe, Australia, South and North America. Systems featuring extensive segregation include the Transmillenio in Bogota, the Ottawa Busway system and the O-Bahn Guided Busways in Essen and Adelaide. More recent examples featuring a mix of BRT components include Eugene (Oregon), Los Angeles (California) and Cleveland (Ohio) in the USA and Nantes in France.

BRT systems (and kerb-guided buses – see next section) generally do not operate extensively underground, but there are examples of limited use (such as Essen and Seattle). Extensive underground use of BRT (or kerb-guided bus) would require appropriate propulsion system, potentially including direct electric power and/or batteries as well as (or instead of) diesel power.



Figure 3.7 BRT, Nantes, France



Source: Steer Davies Gleave

Figure 3.8 Cambridge Kerb Guided Busway



Photo © David P Howard (CC-BY-SA/2.0)

3.3.8 Kerb Guided Bus

Kerb guided bus is a mode which uses conventional bus vehicles, which have small lateral guidewheels fitted to the front steering, enabling them to be steered automatically when operating on a busway with vertical guide rails either side, but also capable of operating conventionally with manual steering, used when operating in shared space with general traffic. Acceleration and braking are controlled by the driver in the usual way at all times. The advantages claimed for the use of guidance are:

- A narrower right of way can be used
- Better ride quality can be achieved
- Close tolerance ‘docking’ can be provided at stops to give easy level boarding, comparable to that achieved on many light rail systems.
- A kerb guided busway can be largely self-enforcing, whereas a bus-only road is more open to use by non-permitted vehicles.

Kerb guided busways have operated in Essen, Germany and Adelaide, Australia since 1980 and 1986 respectively. In the UK, a short experimental system was trialled in Birmingham in 1984. Current UK bus services including sections of kerb guided busway include Kesgrave, Ipswich (opened 1995, regauged for full size buses 2005), Leeds (from 1995), Bradford (2001), Crawley (2003, 2004), Cambridge Guided Busway (2011), Luton-Dunstable Translink (2013) and Leigh-Salford Busway (2016). Trials of the Bristol AVTM Guided Bus system have commenced.

3.3.9 Other Guidance Systems

Other guided bus systems have been proposed in recent years. Some of these have been based on the use of reasonably conventional bus vehicles, fitted with a guidance system. Others, which have aimed to replicate some of the characteristics of rail-based modes but at lower cost, have used a bespoke (rubber tyred) vehicle to give a distinct system image, albeit that these largely incorporate conventional road vehicle technology.

Some systems are no longer being promoted by the system suppliers. Optical guidance systems, in which the vehicle path is determined by markings painted on the road surface, have been more successful, but are being supplanted by the more sophisticated guidance systems now being developed for autonomous vehicles (e.g. LIDAR).



3.3.10 Mapping of System Characteristics and System Technologies

Table 3.1 maps the system characteristics to the systems described above.

3.4 Passenger Capacity and Service Levels

The available data on vehicle and system capacities is not necessarily consistent across modes. Table 3.2 illustrates the capacities of selected mass transit vehicle types, to help inform decisions on the size of vehicle which might be needed for the WECA Underground Metro. Information is based on manufacturers' data where available. Some manufacturers quote standing capacities without giving the floor area or standee density on which this is based. This is noted in the table.

The outliers in the table are VAL, AVRT and Articulated Bus. The manufacturer's data for VAL in Turin gives an overall train length and capacity, but no indication of the number of seats or the standee density. It is therefore not clear whether this data is comparable with the other modes. For other VAL lines, the manufacturer provides very limited information, and direct contact would be required to determine the figures on a comparable basis.

The Articulated Bus example also does not give the basis of the numbers quoted.

AVRT is specified as carrying seated passengers only (which may be appropriate given the speeds and acceleration/braking proposed). Nevertheless, this results in a much lower capacity, meaning that an AVRT solution would require some 2-3 times the number of vehicles of equivalent length compared with other modes.


Table 3.1: Mapping of System Characteristics

	Conventional Rail Based Metro	Automated Rail Based Metro	Light Rail Transit/Tram	PRT ¹	VAL	Cambridge AVRT	Bus Rapid Transit	Kerb Guided Bus	Other Guided Bus
System Capacity (pphpd)	14,000 typical ²	6,000 - 30,000	1,200 - 15,000	800	16,800	1,000	500 – 3,500	500 – 3,500	500 – 3,500
Maximum Speed (km/hr)	80	80	80 or road speed limit	40	80	120	80 or road speed limit	80 or road speed limit	80 or road speed limit
Minimum Headway (min)	2 - 3	1.5	2	0.5	1	3.5	2	2	2
Single or Double Track / Shuttle or Line Haul	Double track	Double track	Double track	Double track	Double track	Shuttle	Double track	Double track	Double track
Tunnel Diameter ³	4.4 – 6.2	4.4 – 6.2	-	-	-	3.7	-	-	-
Vehicle Support	Steel wheel / rail	Steel wheel / rail	Steel wheel / rail	Rubber tyre / concrete rail, fibreglass grid or road pavement	Rubber tyre / steel or concrete rail	Rubber tyre / Road pavement	Rubber tyre / Road pavement	Rubber tyre / steel or concrete rail	Road pavement
Vehicle Guidance	Steel wheel / rail	Steel wheel / rail	Steel wheel / rail	Optical / vertical kerb face	Rubber tyre / vertical guide rail	Automatic – System not stated	Unguided	Rubber tyre / vertical guide rail	Central steel rail / optical / electronic / LIDAR
Signalling and Control	Driver, Fixed block signalling	Automatic, Moving block signalling	Driver, Line of sight	Automatic – Central System Control + Autonomous Systems	Automatic Central control system	Autonomous Local control systems only	Driver, Line of sight	Driver, Line of sight	Driver, Line of sight
Energy Source	Electric, Third rail	Electric, Third rail	Electric, Overhead Line	Battery	Electric, Third rail	Battery	Diesel	Diesel	Diesel

¹ Data is for Heathrow ULTRA

² Based on LU Piccadilly Line – 6 car trains, 228 seats + 456 standees (@ 4 per square metre), 21 trains per hour

³ Minimum (circular) tunnel diameter not determined for most modes. Where underground operation exists, it is may be in rectangular section cut and cover tunnels or former heavy rail tunnels


Table 3.1: Mapping of System Characteristics

	Conventional Rail Based Metro	Automated Rail Based Metro	Light Rail Transit/Tram	PRT ¹	VAL	Cambridge AVRT	Bus Rapid Transit	Kerb Guided Bus	Other Guided Bus
Alignment – Minimum Horizontal Curve Radius (m)	100 (typical)	40 ⁴	25	5	22	n/a ⁵	12	≈ 60 (guided) 12 unguided	12
Alignment – Maximum Gradient	3%	6%	6-8% 10% ⁶	12% ⁷	12%	?	12%	12%	12%
Segregation	100% Segregated	100% Segregated	Segregated or Shared with priority	100% Segregated	100% Segregated	100% Segregated	Segregated or Shared with priority	100% segregated / Segregated or Shared ⁸	Segregated or Shared with priority
System proven in service? Other risks?	Many examples worldwide	Several examples Generally proprietary technology	Many examples worldwide	Very limited experience	Established system. Single supplier	Proposed system reliant on several new technologies	Many examples worldwide	Several examples worldwide	Limited experience

⁴ Absolute Minimum Radius for London's Docklands Light Railway – other systems vary

⁵ AVRT routes are straight between stations. Vehicles required to follow curved paths within stations – radius not specified.

⁶ Requires all axles motored and enhanced braking capability

⁷ Not stated. 12% is typical limit for a rubber-tyred system

⁸ 100% segregated on kerb guided sections. Segregated or shared running with priority elsewhere.



SECTION 3 – ASSESSMENT OF TECHNOLOGY OPTIONS

Table 3.2: Passenger Capacities of Typical Mass Transit Vehicles

Vehicle Type	Data Source	Overall Length over Couplers	No. of Seats (including perch and tip-up seats)	Floor area for Standees (m2)	Standee Density (per square metre)	No. of Standees	Total Capacity	Capacity per Metre Length
London Underground 2009 Tube Stock, Victoria Line	LUL Rolling Stock Information Sheet: 4th Edition	133.3	276	146	4	584	860	6.45
Bombardier Docklands Light Railway B07 Stock	Manufacturer's Drawing ⁹	28.8	56	36	4	144	200	6.94
Bombardier M5000 Tram, Manchester	Manufacturer's Data	29.2	60	36.5	4	146	206	7.05
Stadler Variobahn Croydon	Manufacturer's Data	32.4	72	33.5	4	134	206	6.36
CAF Urbos 3 Tram, Midland Metro	Manufacturer's Data	33	54	Not stated	?	156	210	6.36
VAL 208 Paired, Turin	Manufacturer's Data	52	Not stated	Not stated	?	Not stated	440	8.46
Cambridge AVRT	AVRT Report	16	40	n/a	0	0	40	2.50
Rigid Single Deck Bus - Wrightbus StreetLite Max	Manufacturer's Data	11.5	45	Not stated	?	25	70	6.09
Articulated Bus - Mercedes Citaro G 3 door	Manufacturer's Data	18.1	44	Not stated	?	111	155	8.55

⁹ Obtained from https://www.whatdotheyknow.com/request/dlr_rolling_stock_technical_draw



3.5 Conclusions – implications for WECA Underground Metro

Current indicative demand estimates for the proposed WECA Underground Metro suggest that the planning capacity for the system should be about 3,000 passengers per hour per direction. Table 3.1 shows that this fits within the capacity of bus-based systems but will require higher frequency or high capacity systems, but that many of the other modes considered have potentially much higher capacities. This is not entirely surprising – many of these modes have been developed in cities with much higher levels of demand than Bristol. The upper bound capacities given represent the maximum that can be achieved, using multiple vehicle trains and minimum headway operation. These modes can also operate at lower capacity.

Personal Rapid Transit is a mode which could ultimately operate across the general road network as a form of autonomous vehicle. But in its present form its capacity is too low to be appropriate for Bristol. There is also limited experience of it in use, albeit that the Heathrow operation reports high levels of reliability.

It is assumed that bus based systems (unless using an emission-free power source) are not appropriate for underground operation.

Cambridge AVRT is a proposed mode which is very different from the others. The proposed system of individual shuttles, with multiple enforced transfers, limited numbers of stations and longer ‘first/last mile’ links could make the system less attractive to passengers. In particular, the AVRT concept is not compatible with the indicative routes and station locations identified for the WECA Metro. There are significant risks in terms of technological development, approvals processes, cost and programme, which, together with potential broader public/political acceptability may make AVRT unattractive to those who would fund and own such a system.

The other technologies listed have some common features – all feature wheeled vehicles with mechanical guidance and capable of operation as single vehicles or in trains of coupled vehicles. Whilst these different modes have developed separately and have their own characteristics, most of these are not inherent to the mode. For example, modes intended to run on the surface have square vehicle body profiles, whereas systems intended to operate underground have rounded profiles to better fit the tunnel space.

For a given line capacity requirement there is a trade-off between the capacity of individual trains and the frequency of service. With driver-operated trains this has typically tended to favour the use of relatively high capacity trains running at relatively low frequency to reduce the driver costs – one of the largest components of a system’s operating costs. For underground systems, this effect is tempered by the need to provide more costly, larger underground stations to accommodate the longer trains. It should be noted that the rolling stock requirement is independent of this balance – it is simply a matter of whether there are many small trains or fewer large trains. The implications for the capital and non-staff operating costs of the trains are therefore small.

Automatic operation is already a feature of many mass transit systems which are fully segregated. With the use of automatic operation and unstaffed trains, these driver costs are avoided – customer service can be provided by station based staff, whose numbers are determined by the number of stations not by the operating pattern. This therefore favours the use of more frequent smaller trains on a new-build system.



SECTION 3 – ASSESSMENT OF TECHNOLOGY OPTIONS

The sizing of stations, particularly underground stations, is determined essentially by two conditions:

- Normal operation
- Emergency situations

For normal operation, the length of platforms required is determined by the longest trains using the system. The rest of the infrastructure is sized based on passenger throughput, subject to minimum requirements. For a typical underground station, the minimum requirement will comprise one set of up escalators, one set of down escalators and at least one lift from ground level to each platform. The capacity of this minimum provision will be sufficient to meet the demand at many (if not all) stations, and hence will determine the size of the station access infrastructure but this will be covered within the detailed design.

Note also that Building Regulations require that a firefighter's shaft (with stairs and lift) is provided at any station or intermediate access/ventilation shaft (if more than 10m deep, which most/all will be).

Use of more frequent, smaller trains also results in a more even flow of arriving passengers, compared with larger, less frequent trains where the arriving passenger flow will come in waves. This makes better use of the station access infrastructure, and reduces congestion in the station, providing better conditions for passengers.

Table 3.2 suggests that most mass transit modes have a passenger capacity of 6-7 passengers per metre length of vehicle. Thus, for a planning capacity of 3,000 passengers per hour, the system will need to deliver a service with an aggregate vehicle length of around 450m per hour. This could be supplied in a number of different ways. For example:

- 20m vehicles at 2.5 minute headway
- 30m vehicles at 4 minute headway
- 40m vehicles at 5 minute headway
- 60m vehicles at 8 minute headway

The 20m vehicles could be single cars, but the longer vehicles would be either articulated or coupled in trains.



SECTION 4

Capex Including Ground Conditions and Route Alignment

4.1 Tunnelling and ground conditions

4.1.1 Geology Review

From the Bristol Metro - Pre-Concept Stage Study Initial Tunnelling Review it is understood that tunnelling is expected to be through faulted rock of variable strength and there is also a risk of historical coal mining activities. A high-water table can be expected and Alluvium and Tidal Flat deposits containing clay and silt are likely in the city centre, River Avon and Temple Meads areas.

For this Pre-Feasibility study, a review of ground investigations across Bristol has been undertaken. This has been supplemented with historic boreholes obtained from the British Geological Survey's database. The locations are shown in Figure 4.1 and the recorded strata are noted in Table 4.1.

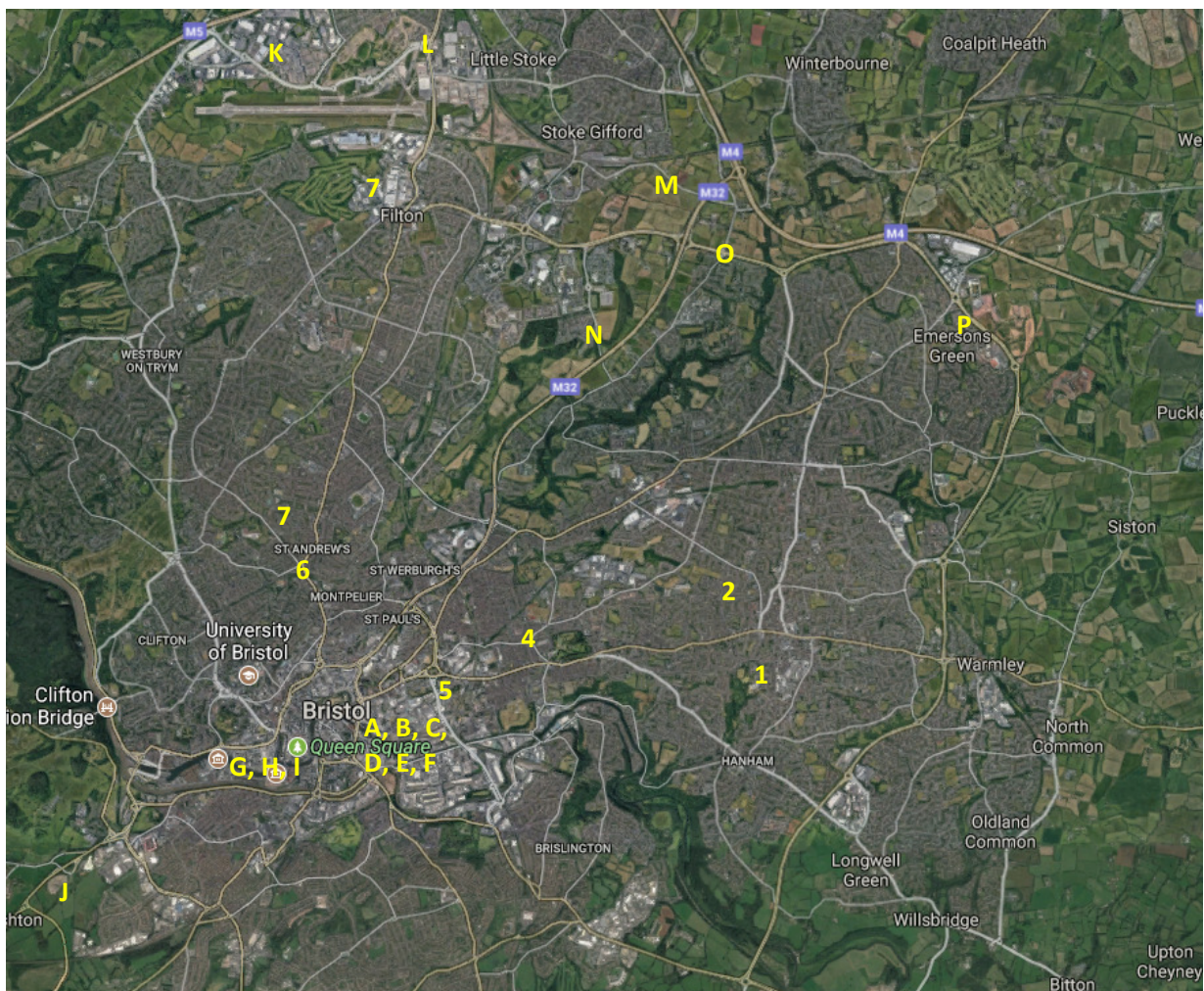


Figure 4.1: Plan showing the location of Ground Investigation Data



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

The table shows the expected main tunnelling strata, shown in red bold and underlined, with potential likely tunnelling strata shown in red. It is assumed that tunnelling will typically be at depths of 10m to 20m below ground level.

Table 4.1 Summary of Ground Investigation Data

Ref	Ground Investigation	Location	Main Strata
Geotechnical Investigations			
A	TQEZ Bristol Harbour Walkway	Central by Temple Meads St.	Alluvium River Terrace Gravels Redcliff Sandstone <u>Mercia Mudstone</u>
B	TQEZ Cattle Market Rd		Tidal Flat Deposits <u>Redcliff Sandstone</u> Mercia Mudstone
C	TQEZ Avon River Path	Central south of Temple Meads St.	<u>Alluvium</u> <u>Mercia Mudstone</u>
D	TQEZ St Phillip's Footbridge		Alluvium <u>Mercia Mudstone</u>
E	TQEZ Bristol Arena		Alluvium <u>Mercia Mudstone</u>
F	TQEZ Diesel Depot Access Road		<u>Mercia Mudstone</u>
G	Ashton Vale to Temple Meads (AVTM) Metrobus: Bathurst Basin Bridge	West of centre on river Avon	Tidal Flat Deposits Base of Redcliff Sandstone <u>Base of Mercia Mudstone</u>
H	Camden Rd Footbridge	West of centre	South Wales Middle Coal Measure
I	AVTM Metrobus	South West (Offline of tunnelling)	Alluvium Mercia Mudstone Coal Measures
J	South Bristol Link Rd	South West (Offline of tunnelling)	Alluvium Redcliff Sandstone Mercia Mudstone Coal Measures
K	North Fringe – Hengrove, Metrobus: Cribbs Patchway Metrobus Extension	Cribbs Causeway	<u>Mercia Mudstone</u>
L	Rolls Royce	North East of Filton Airport	<u>Mercia Mudstone</u>



Table 4.1 Summary of Ground Investigation Data

Ref	Ground Investigation	Location	Main Strata
M	NFHR: Stoke Gifford Transport Link (SGTL)	North East (offline)	Mercia Mudstone
N	NFHR: East Fringe		Coal Measures
O	Emersons Green Footbridge		
P	NFHR: M32 Bus Only Junction and Stoke Lane	East	Coal Measures
Historic BGS Boreholes			
1	ST67SW110	Kingswood	<u>Coal Measures</u>
2	ST67SW150	Kingswood	<u>Coal Measures</u>
3	ST67SW55	St George	<u>Coal Measures</u>
4	ST67SW55	St George's Park	<u>Coal Measures</u>
5	ST67SW77	Lawrence Hill	<u>Mercia Mudstone</u> Coal Measures
6	ST57SE23	Montpellier Station	<u>Mercia Mudstone</u>
7	ST57NE3	Ashley Down	<u>Mercia Mudstone</u>
8	ST67NW12	Filton	<u>Lower Lias</u> <u>Mercia Mudstone</u>

From reviewing previous work, ground investigation data and temporary boreholes, it is expected that in central Bristol, shafts, station boxes and portals will need to be excavated through water bearing made ground and Alluvial Deposits and River Terrace Gravels / Tidal Deposits. It is assumed station boxes and portals will be constructed using diaphragm wall techniques and that shafts should be constructed through water bearing gravel layers using secant piling techniques or as a caisson with segmental lining to prevent water ingress. In all areas, the base of the structures are expected to be within weak Sandstone, Mercia Mudstone or Coal Measures.

Tunnelling is generally expected to be through Mercia Mudstone, but is also likely to encounter Alluvium, Tidal Flat Deposits and Redcliff Sandstone, especially when tunnelling near the River Avon and in the centre of Bristol. Some sections of the route would need to be tunnelled through Coal Measures.

4.1.2 Coal Measures

Reports associated with the reviewed ground investigations and historic boreholes include evidence of potential shallow coal mine working in the South West and North East of Bristol, presenting a significant risk to tunnelling in these areas. In the South West, this would be mitigated where the Metro is proposed to run on the surface towards the airport. The Coal Authority map shows significant sections of the potential tunnelling route are within high risk areas and areas with mine entries present, see Figure 4.2.



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

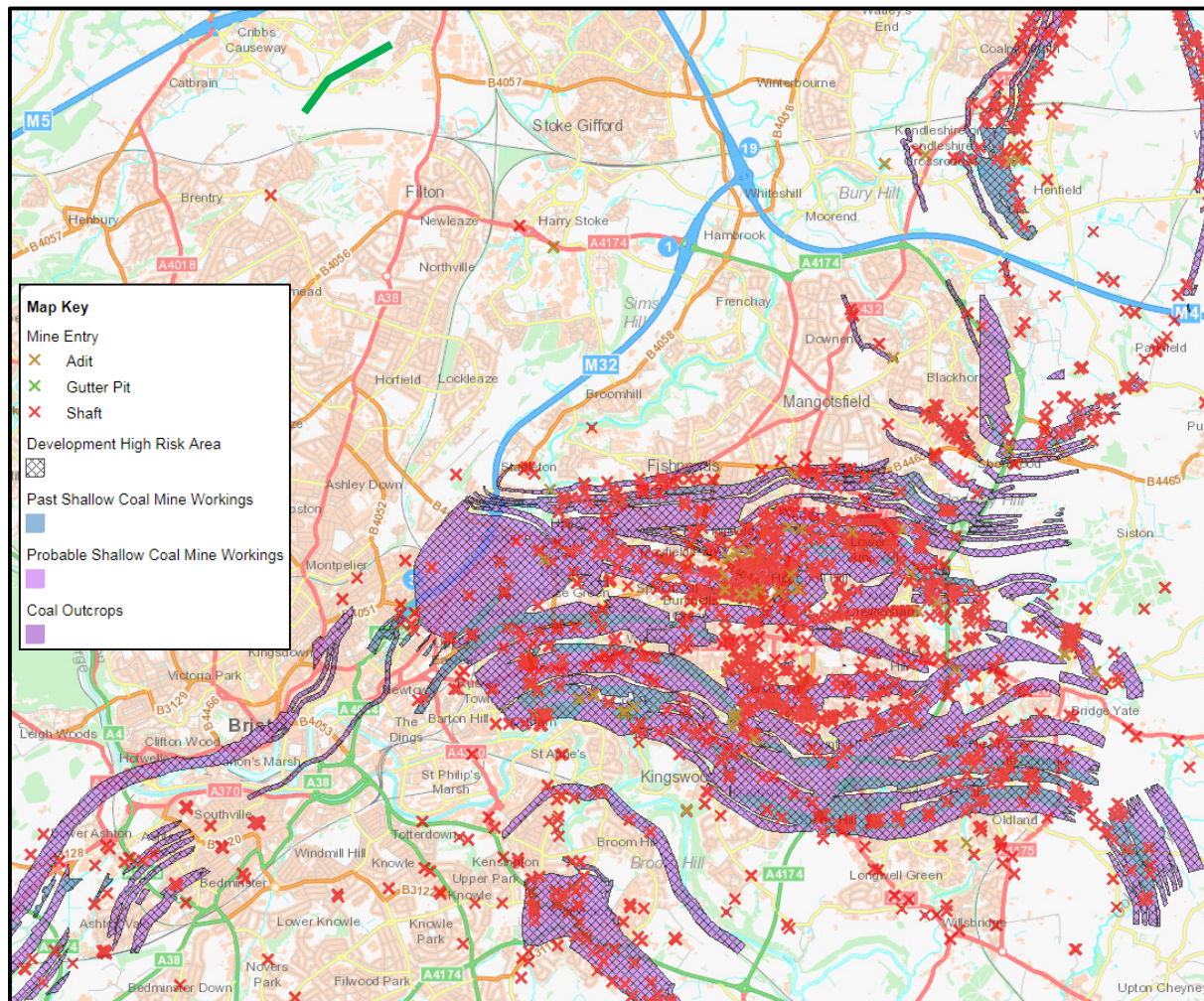


Figure 4.2: Coal Authority map

For the ground investigations viewed in the central and other areas, the coal measures appear to be deeper and below the depth of tunnelling. However, there is still considered to be a risk from the presence of mine shafts in these areas.

4.1.3 Tunnelling Boring Machine Options

As tunnelling is expected to be through mixed ground primarily encompassing weak / soft rock with a number of faults and water bearing gravels, the tunnelling face will need to be pressurised. A Slurry Tunnel Boring Machine (TBM) is recommended over an Earth Pressure Balancing Machine as it is more suited to soft rock. Sufficient space will need to be provided at the tunnelling drive site for the slurry treatment plant facilities.

4.1.4 Tunnelling Mitigation Measures

Due to the probability of shallow coal mining along the route of the metro, a thorough site and mining investigation and pre-tunnel construction ground stabilisation works, including grouting of mine workings, is recommended. This process was carried out for the 5km Shieldhall UIP tunnelling project in Glasgow, where the £1.6m ground and mining investigation included 180 boreholes to 50m depth,



geophysical surveys and materials' testing. This should also consider the potential risk from the pockets of methane gas, associated with these coal measures.

4.2 Tunnelling Logistics

4.2.1 Tunnelling Strategy

From the assessment of the Initial Tunnelling Review Technical Note and indicative alignment suggesting lines terminate in the centre of Bristol, it is assumed that at present each tunnel will be constructed using one TBM, rather than two. Therefore, in total two TBMs would be used to construct the tunnels for each line. This is a simpler solution than using two TBMs per tunnel (ie. four TBMs in total to construct each line) as it reduces the number of tunnel drive sites and supporting logistics requirements. The alternative of using two TBMs per tunnel can save time on the programme and reduce the tunnelling risks, and this can be examined in more detail during a subsequent feasibility study.

The feasibility study should also consider whether tunnel segments are to be produced remotely and brought to site, or produced on site. Producing the segments on site would require additional land for a segment factory and storage of segments, but would reduce vehicle movements associated with the importation of segments.

4.2.2 Tunnel Settlement

Experience from tunnelling in similar ground on the Glasgow Shieldhall project has suggested that if tunnels are driven with a reasonable clearance, and faults and geological risks are well managed, settlement can be expected to be relatively low. It is likely to be in the region of 10-20mm and below the 1% tunnel volume loss figure which is routinely used in settlement predictions. This indicates that to maintain settlement at an acceptable level on the WECA project, it will be important to maintain a clearance close to two tunnel diameters of cover where feasible, and particularly where tunnelling beneath sensitive buildings, structures including river walls, and utilities in poor condition. It will also be critical to understand the expected geology and geotechnical risks on route and to fill voids due to mine workings.

A typical example of this issue is Pen Park Caves. During feasibility design, it is recommended that research is undertaken to clarify the exact location and size of the Pen Park Caves, along with all other underground structures, and the alignment amended to avoid tunnelling through or unacceptably close to these structures. This de-risks the project and also takes into account issues such as the nationally important community of blind shrimps contained within this Site of Special Scientific Interest (SSSI).

These issues should be looked at during the feasibility stage where it is also recommended that the industry standard Phase 1 and 2 settlement assessments are undertaken, with particular attention paid to river walls, deep utilities, other tunnels and the many historic and listed buildings in Bristol. The map below (Figure 4.3) highlights the many listed buildings in Bristol City Centre as blue triangles, Scheduled Monuments in red and Listed Parks and Gardens in Green.



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

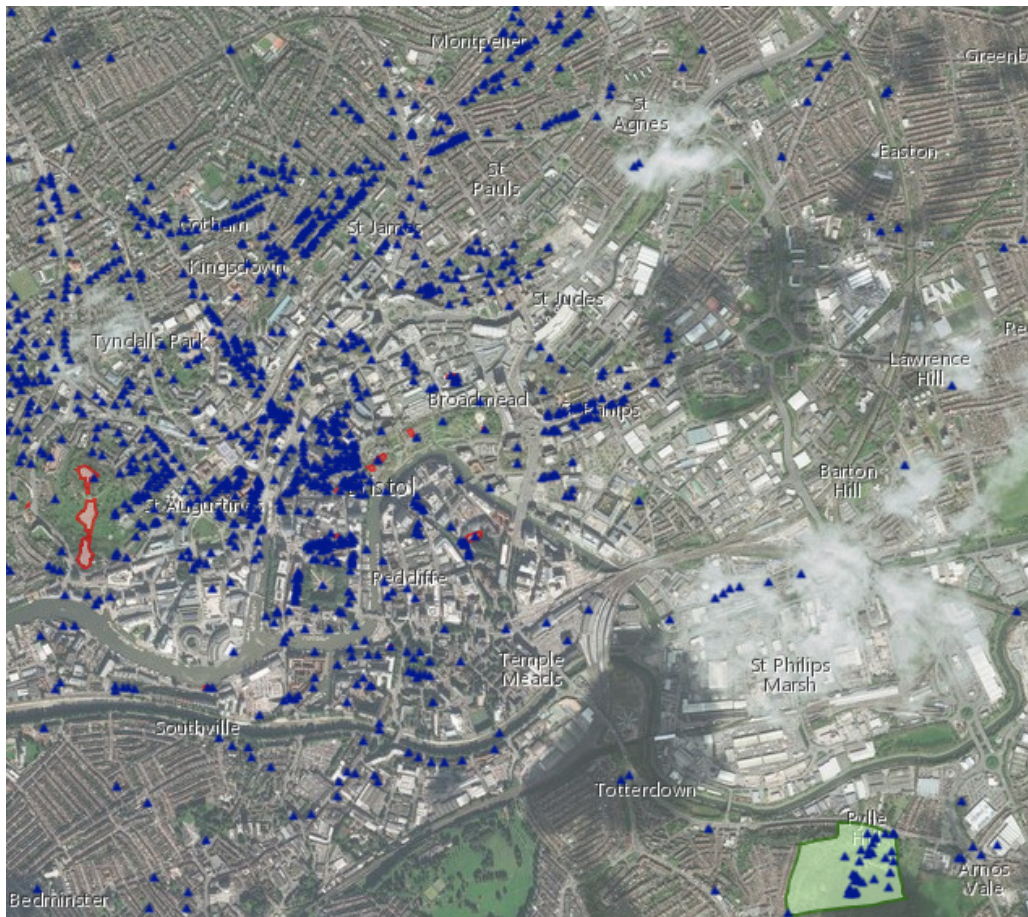


Figure 4.3 Map of Listed Buildings in Bristol City Centre

4.2.3 Construction

To enable tunnels to be constructed safely and efficiently, the following key logistical elements need to be in place:

- A site, typically an area of 30,000m² to 50,000m² to:
 - construct a box or tunnel portal
 - drive the TBM from
 - support the logistics including the storage of excavated material and tunnel segments
- The ability to remove excavated material from site by road, rail and/or river

This means the drive sites need to be large and have good road and preferably rail or river connections to support removal of excavated material and importation of concrete or tunnel segments. The operation of these sites will take into account environmental consideration such as hours of operation, impact of noise on the surrounding neighbourhood and traffic. If an average tunnel construction rate of 80m a week is assumed on average 4,500m³ of excavated material will need to be removed from the drive sites each week when both TBMs are running. This would require over 1,100 HGVs movements (ie. 550 empty HGVs coming into site then 550 leaving filled with excavated material) assuming each HGV carries 8m³ of material. This equates to 200 HGV movements per day assuming construction movements



only occur Monday to Friday and Saturday mornings. Alternatively, 16 No. 400m long train movements or 30 No. 200m long train movements would be required each week to remove this excavated material.

However, excavated material removal could easily increase up to around 7,000m³ during tunnelling peaks requiring over 1,500 HGVs per week, which is close to 300 per day.

There have been examples of tunnelling projects where the excavated material has been used effectively to construct local infrastructure or environmental schemes. An example of this is Crossrail where a total of 7 million tonnes of material was excavated during construction of which 98% will be re-used. Approximately 3 million tonnes of material was transported by rail to create a flagship wetland nature reserve twice the size the City of London at Wallasea Island in Essex. Similar projects could be considered for the WECA Metro study to make use of the material and potentially reduce constructions costs.

4.2.4 Tunnel Drive Sites

It is recommended that the feasibility study looks at drive site locations in detail and considers the option of driving tunnels further where impacts to sensitive structures or areas can be reduced or better connections to main roads, mainline rail or waterways made.

4.3 Programme

At this stage, the overall construction programme for each line is expected to be approximately 7 to 8 years, with the critical path mainly dictated by tunnelling progress. Note that this is after the planning, design and approvals process is completed, which could take a similar amount of time, allowing for a Transport and Works Act Order and other consents.

Following site set up the key activity will be to construct the tunnel portals to enable the tunnels to be driven. Tunnelling is expected to take approximately 30 months for each line, at an average rate of 80m per week. Although some projects have achieved over 100m per week, at this stage 80m is considered to be more realistic considering the difficult ground conditions and requirement to transition the TBM through a number of stations. Following tunnel construction, the key activities in the programme are expected to be the rail systems fit out and testing, which will be dependent on the type of technology employed, although one year for each is felt to be an appropriate allowance at this stage of the project.

It is assumed that most stations will be fairly simple in design and constructed at sites which require minimal demolition and set up works. These can be programmed around tunnelling, so are not on the critical path, as shown in the example within the typical outline critical path programme below.



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

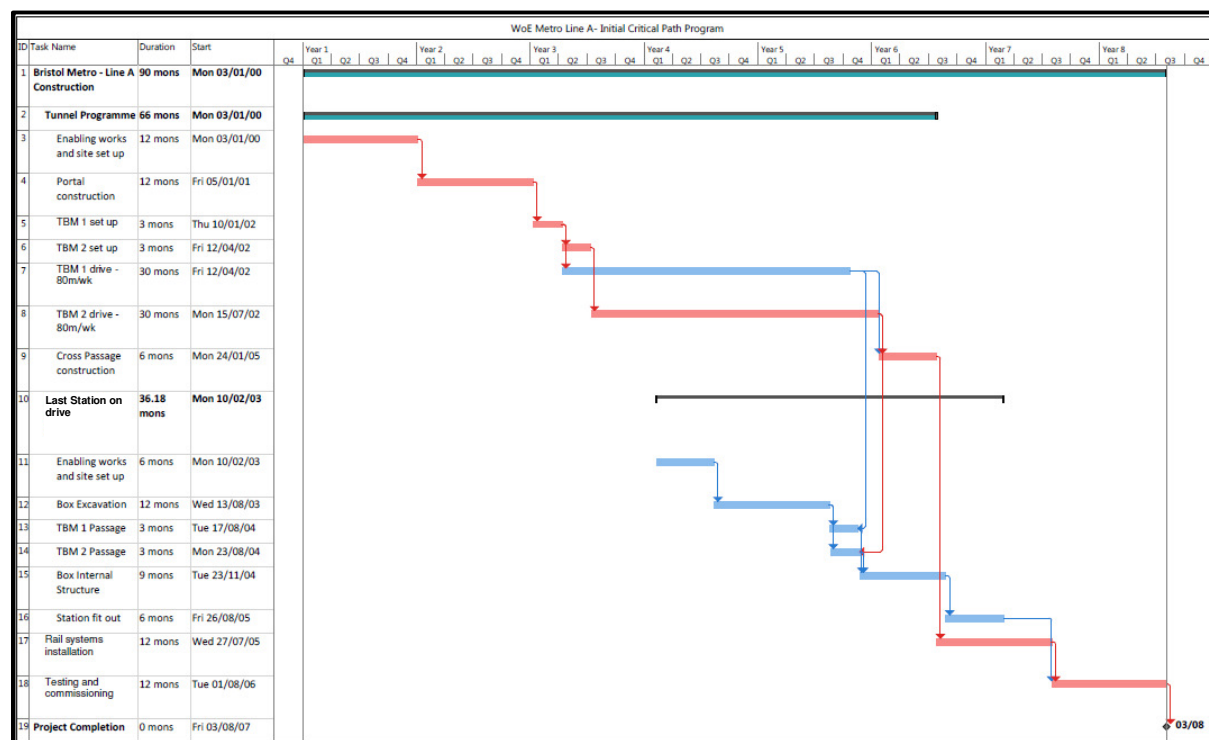


Figure 4.4. Outline Critical Path Programme

Using two TBMs for each tunnel has the potential to reduce the programme by approximately one year, however, this will require additional tunnel drive sites, potentially in the centre of Bristol and have extra costs for TBM's and supporting logistics. In this scenario, the station programme would also need to be looked at in greater detail as it may become part of the critical path

Depending on site conditions and presence of ecology at the tunnel drive sites there may be potential to reduce the enabling works duration by a few months, particularly if ecology surveys can be conducted prior to the project construction start date. Similarly, it is expected that there could be potential to reduce the rail system fit out and testing durations for the VAL system but this needs to be reviewed in greater detail.

4.4 Key Risks

The following key risks highlighted in the Initial Tunnelling Review Technical note and from previous tunnelling project experience are shown in the table below with mitigation measures and further work recommended:

Key Risk	Mitigation Measure	Further Work
Mixed / Poor Ground Conditions and high-water levels	Use of Slurry TBM Creation of detailed geological model for tunnel alignment Emergency Preparedness Plans	Desk Study and Ground Investigation Detailed review of geology and creation of detail model
Historic Mine Working	Pre-tunnel ground stabilisation works, including grouting of mine voids	Detailed ground and mining investigation including geophysical surveys.



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

Key Risk	Mitigation Measure	Further Work
Risk of TBM breakdown during long drives in difficult ground	Choice of high quality slurry TBM Use of 2 TBMs per tunnel Use stations and shafts to repair / maintain TBM	Thorough ground and mine working investigation Review of costs and benefits of using 2 TBMs
Tunnel alignment contains unacceptable sharp curves	Consider amending alignment especially on the northern section Review choice of sites and consider additional land, perhaps through partnership with Developers Design TBM and segments for tighter curves (although rail alignment still likely to be unacceptable)	Review of site selection Design alignment for optimum journey times and to minimise maintenance
Expected production rates for tunnelling cannot be achieved due to number of stations/ shafts on route	Revise programme or use two TBMs Reduce number of stations Ensure station sites are ready to receive TBMs or drive tunnel before constructing some stations	Produce detailed programme taking account of TBM transitions on site and station box construction
Damage to buildings and river walls from tunnel settlement	Maintain close to two tunnel diameters of cover between the tunnel and sensitive buildings / structures Mitigation or strengthening works to buildings / structures where necessary and targeted monitoring	Obtain building records Phase 1 and 2 settlement assessments, and Phase 3 where required Agree mitigation and monitoring measures
Damage to utilities from settlement	Maintain close to two tunnel diameters of cover to sensitive utilities where practical Divert or re-line utilities	Obtain utility records Phase 1 and 2 settlement assessments, and Phase 3 where required Agree mitigation and monitoring measures
Impact of line B portal construction	Review eastern portal Construct portal as a box	Further design work on portal and station



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

Key Risk	Mitigation Measure	Further Work
	Increase gradient to create shorter portal or construct west end in area of trees	Review of alternative options and depot location
Impact on sensitive land	Consider tunnelling terminal points, where rail connection can be made with depot. Increase gradient to create shorter portals Position portal and line away from sensitive areas	Further design work Review of alternative options and depot location
Choice and number of parks and green field sites unlikely to be acceptable with stakeholders and residents	Consider moving sites to industrial areas with main road and transport links where possible	Review of site selection and local land use

4.5 Recommended further work

The following further work is recommended as part of the development of the scheme feasibility study, to enable efficient tunnel construction and deliver a high-quality Metro scheme, should this mode prove to offer greater benefits than other modes.

4.5.1 Tunnelling and underground construction

A full desk study and historic mine review should be undertaken to inform the Feasibility Study. Potential obstructions on route need to be reviewed and a Phase 1 and 2 settlement assessment to understand the potential risk of damage to buildings, structures and utilities, is recommended. The potential tunnel rate and programme also needs to be reviewed, taking account of transitioning the TBM through station sites.

4.5.2 Tunnelling Strategy

A review of portal sites and benefits of tunnelling further should be reviewed. Based on this, a review and assessment of the costs, benefit and risks of driving two TBMs per tunnel should be carried out. The potential to remove excavated material by rail and river should also be considered. An assessment of whether tunnel segments are produced at site or a remote location is recommended.

4.5.3 Station Design

During feasibility, the outline station designs as presented in the cost report will need significant additional work to:

- Produce individual designs for the stations to take into account the size of construction sites, entrance location, potential passenger connections to the other line and existing transport links and development opportunities.
- Verify the station box is appropriately sized for passenger access, numbers and to meet evacuation and fire life safety requirements



4.5.4 Environmental Impacts

Although a full environmental statement would not be required at this stage, it is recommended that an environmental assessment is undertaken to consider all relevant environmental topics so the design can be amended and mitigations put into place, where required.

4.5.5 Potential Scheme Improvements

4.5.5.1 Alignment

Once the scheme's vehicle specification has been determined, a full alignment review will need to be carried out to confirm the acceptability of the alignment and highlight potential opportunities to improve the journey time and passenger experience, and reduce future maintenance costs.

4.5.5.2 Station and Depot locations

In combination with the alignment, station locations should be reviewed to meet engineering criteria but also to choose the optimum sites for connectivity and mitigate stakeholder objections. From experience of city metro projects including Crossrail and the London section of High Speed 2, it is recommended that stations are ideally located on brownfield sites by major roads with connectivity to existing train and bus transport links, where possible.

Similarly, the location and design of depots needs to be progressed as these facilities are likely to occupy a significant area and ideally be situated at sites used for constructing the scheme, such as the tunnelling drive site.

4.5.5.3 Shaft locations

The number and location of shafts needs to be reviewed to ensure the feasibility design meets the standard fire brigade criteria of having a shaft or station every 1 km, and to highlight where the project may intend to challenge these criteria.

4.6 Cost Narrative

4.6.1 Approach

Costs have generally been built up using the estimated costs for the London Underground Northern Line Extension (NLE) which were used for the Transport of Works Act to obtain powers for this scheme. This project was used as it is a city Metro, relatively recent with costs being compiled in 2013 and has other similarities:

- twin 5.2m Internal Diameter running tunnels
- new stations built using diaphragm walls, and Sprayed Concrete Lining (SCL) platform tunnel extensions
- intermediate ventilation shafts

The key differences are the length of the project as the tunnelling for NLE was only 3km long. This has been factored into tunnel costings and the size of trains, which are approximately twice the length of the trains planned for the WECA Metro. This effectively drives the length of stations and has an impact on the requirements for power and services.

Where feasible, the costs for items have been compared to other applicable projects, including High Speed 2 and Shieldhall Tunnel, and to industry guidance on tunnelling and rail costs. The cost per



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kilometre of the whole project has been compared to similar schemes, including Toulouse VAL Line A and Line B, Lille and Rennes. It is found to be estimated at a similar cost, although towards the higher end of the range of these schemes.

Costs are all quoted at 2017 prices (adjusting from reference scheme construction year prices where necessary). Where costs are quoted in other currencies, these have been converted into Sterling using an average exchange rate from the year of construction.

4.6.2 Summary of Costs

Costs have been divided into the following 13 areas and calculated for the three lines, except where noted in the following individual sections the design described in the July 2016 Initial Tunnelling Review Technical Note and the indicative alignment shown in the Bristol Metro – Outline Thinking presentation has been followed.¹⁰

Item	A38 North - Aztec West Estimate Cost (m)	A420 - Emersons Green Estimate Cost (m)	South Bristol - Airport Cost (m)	Average Cost %
Below Ground Stations	£284.0	£284.0	£182.0	23%
Above Ground Stations	£31.0	£24.0	£38.0	4%
Intermediate Shafts	£25.0	£25.0	£25.0	3%
Crossover Box	£20.0	£20.0	£20.0	2%
Running Tunnels	£266.0	£272.0	£268.0	28%
Tunnel Cross Passages	£18.0	£18.0	£18.0	2%
Portals	£13.0	£13.0	£13.0	3%
Earth Structures	£6.0	£6.0	£11.0	2%
Bridges	£6.0	£7.0	£14.0	2%
Trackwork	£51.0	£55.0	£59.0	7%
Linewide Systems	£80.0	£86.0	£90.0	10%
Depot	£50.0	£50.0	£50.0	6%
Rolling Stock	£80.0	£80.0	£60.0	7%
Total	£930m	£940m	£848m	

All prices include 'Oncosts' which cover the Contractor's head office and profit, insurance etc. This is generally taken as 10%, although 15% has been used for tunnelling related items due to additional contractor's costs associated with tunnelling. With an assumed additional 10% for land costs and 10% for client costs, including initial design work, the full scheme price is approximately £1.1bn per line. Costs are very similar for all lines, as the additional cost due to the length of South Bristol to Airport is

¹⁰ Initial Tunnelling Review, Jonathan Foster-Clark, 27th July 2016



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

balanced out by the additional underground stations for the other lines, which have a significantly higher cost per kilometre:

- A38 North - Aztec West Estimate = £1.13bn Cost per km = £90.0m
- A420 - Emersons Green Estimate = £1.14bn Cost per km = £84.3m
- South Bristol - Airport Estimate = £1.05bn Cost per km = £65.6m

As described in greater detail below, these costs per kilometre provide a reasonable comparison with the other European metro systems reviewed whose costs varied from £43m to £88m at 2017 prices, providing an average cost per km of £70m.

A contingency of approximately 30% should be added to the costs at this stage of the project. This implies the project may need to have a budget allocated of £4.3bn:

- A38 North - Aztec West Estimate = £1.46bn
- A420 - Emersons Green Estimate = £1.48bn
- South Bristol - Airport Estimate = £1.36bn

These costs could be reduced through value engineering including removing some stations or potentially reducing the length of tunnelling,

4.6.3 Below Ground Stations

4.6.3.1 Station Depth

The running tunnels are assumed to have a 5.2m internal diameter (ID) with 0.4m thick tunnel lining meaning their outside diameter (OD) is approximately 6m. Following good tunnelling practice, it has been assumed that for the majority of tunnelling the clearance above the tunnels will be close to twice the tunnel diameter so a clearance of 10m has taken. Including a 0.5m gap below the tunnel to drive or transfer the Tunnel Boring Machine through the station means that the top of the foundation slab at stations needs to be approximately 16.5m below ground level (BGL). With a foundation slab assumed to be up to 1.5m deep the depth of the station box is 18m BGL and the platform is approximately 13m BGL:

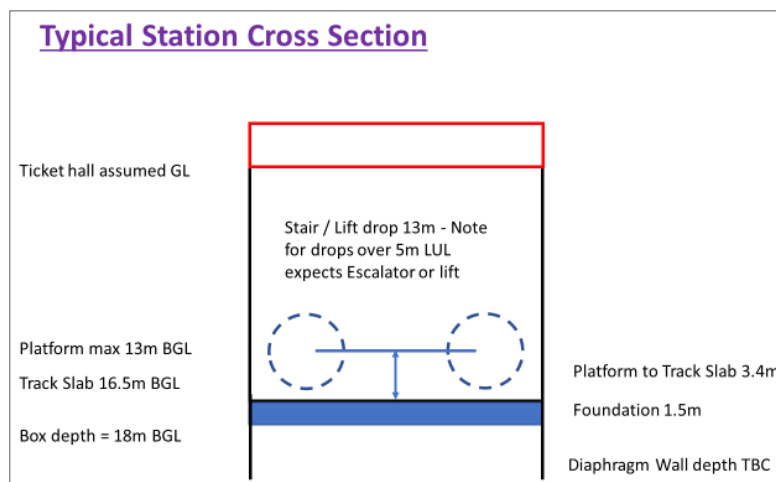


Figure 4.5 – Typical Station and Cross Section

The diaphragm walls (D-walls) are assumed to be 1m thick and constructed to a depth of approximately 25-30m deep depending on the ground conditions.



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4.6.3.2 Station Design

The stations have been space planned using London Underground standards and according to Station planning standard S1371. Access will be covered during detailed design, but, for example, if located sufficiently deep underground, the use of stairs may not be acceptable and passengers would transfer from ticket hall to platform using two 50-person lifts. Escalators would be desirable, but will require space within the station to accommodate the typical 30 degree incline they would need, and be close to 30m long for a 13m drop. It is also unlikely that the use of escalators would be justified by passenger numbers.¹¹

Platform lengths have been designed at 63m in line with the LUL station planning standard, which require platforms to be 3m longer than the longest train. Platform clearances generally meet the 3m minimum required by the LUL station planning standard, except beside the lifts where they are 2.5m wide. This meets the minimum width required for an above ground platform and is likely to be sufficient given the passenger numbers expected at these stations.

At this stage two types of station design have been assumed:

63m Diaphragm Wall Station

This type of station may be constructed at larger sites in key locations where a second entrance may be desirable, where there is an interchange and / or high passenger numbers are expected.

The station box needs to be 21m wide internally to accommodate lifts, platforms and a 5m track area to enable segmental tunnels to be driven by Tunnel Boring Machine (TBM) from the box, with sufficient clearance to the side walls for support. A distance of 1m between the internal edge of the segmental tunnel and the side D-wall has been assumed to allow for a supporting ring beam.

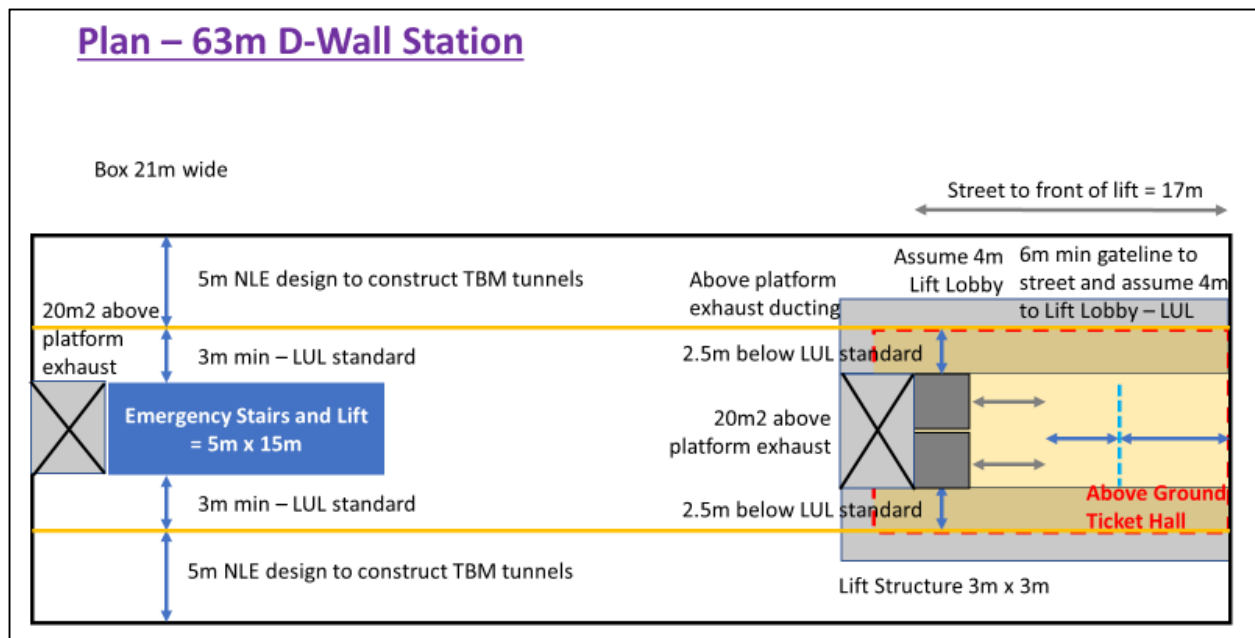


Figure 4.6: Typical 63m Long D-Wall Station Plan

¹¹ LUL Standard S1371 A6 - Station planning



40m D-Wall Station with Platform Extensions

This station is constructed as a 40m long D-wall box with four Sprayed Concrete Lined (SCL) 8m ID platform extension tunnels. To enable the SCL construction to be supported a 1.5m gap between the internal diameter of the SCL tunnels and D-Wall has been allowed for. This requires a station box width of 22m to accommodate lifts, platforms and a 5.5m track area to enable the platform tunnel construction.

This station will be constructed at smaller sites and where lower passenger numbers are expected, as there is a reduced circulation area at platform level. Due to the reduced amount of excavation, the station is expected to be slightly cheaper.

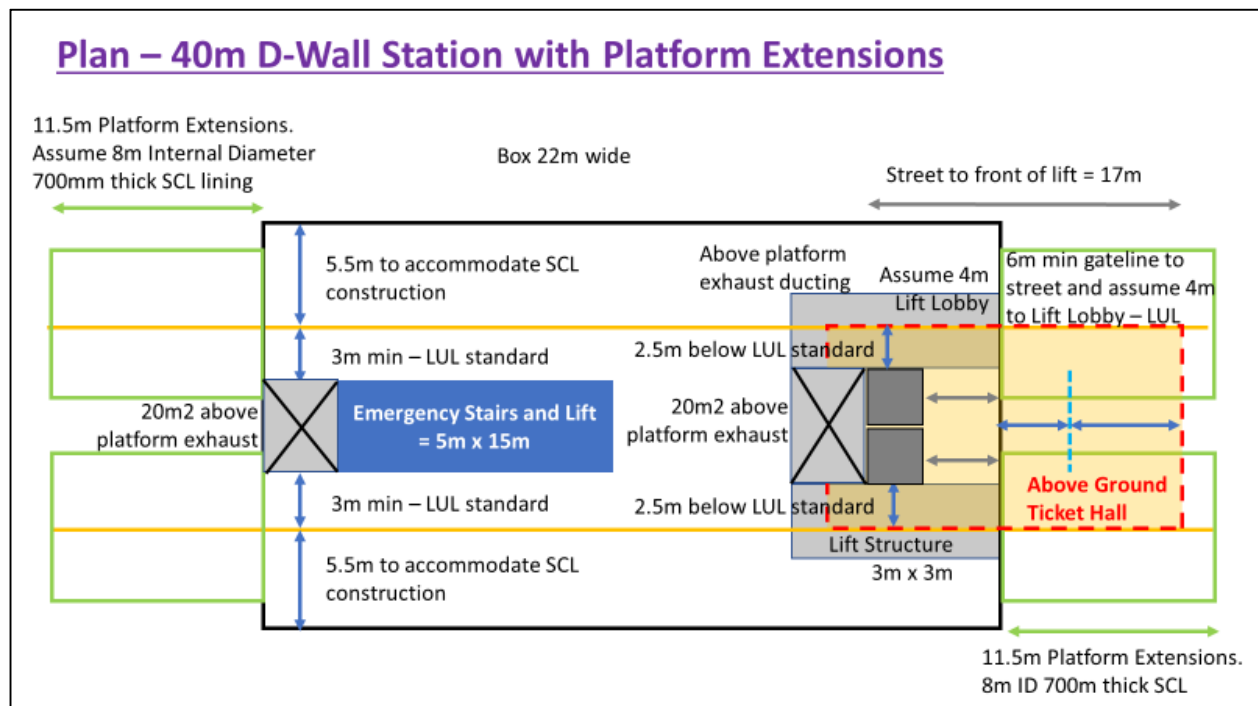


Figure 4.7: Typical 63m Long D-Wall Station Plan

Further work needs to be done on this type of station to verify passenger and emergency evacuation facilities meet requirements for the expected passenger numbers, and the stations can be built within the current sites selected for construction.

4.6.4 Below Ground Station Costs

The cost of constructing these stations has been based on the Northern Line Extension costs and adjusted according to the stations area or volume for the following individual elements:

Table 4.2a Breakdown of underground station cost elements

Element	Allowance based on
Enabling Works and Site Clearance	Minor site and mitigation works assumed.
Excavation	Comparison of box volume
D-Walls (inc capping beam)	Comparison of wall volume
Roof and Internals	Comparison of Area
Structures	Comparison of Area
Above Ground	Comparison of Area



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Arch Finishes	Comparison of Station Size / Volume
M&E Station Fit-Out	Comparison of Station Size / Volume
Overhead	Based on Cost of works
Platform tunnel extensions (where applicable)	Comparison of length
Oncost for head office and profit, insurance etc.	Standard 10% increase used

Based on this the following typical station cost at 2017 prices was calculated:

- 63m D-Wall Station = £26.9m
- 40m D-Wall Station with Platform extensions = £25.2m

At this stage, the following numbers of the different station types have been assumed per line:

Table 4.2b Breakdown of underground station types for each Line

Station types per line	A38 North - Aztec West	A420 - Emersons Green	South Bristol - Airport
63m D-Wall Station	4	4	3
40m D-Wall Station with Platform extensions	7	7	4

Note that stations which include platforms for multiple lines have been costed as two separate stations. This is because they will both require their own set of lifts, platforms and potentially entrances. The cost for additional connections between platforms is expected to be balanced by the savings from only having to use one site.

4.6.5 Summary

Following the process above, the total underground station costs have been calculated for each line:

- A38 North - Aztec West (11 underground stations) = £284.0m
- A420 - Emersons Green (11 underground stations) = £284.0m
- South Bristol - Airport (7 underground stations) = £182.0m

4.7 Above Ground Stations

Little detail is currently available for these stations beyond the expectation that they will be at grade and generally located in areas which do not require significant demolition or site preparation works. The estimate was made by adjusting and removing non-applicable elements from the underground station costs. This provided a reasonable comparison with research discussed in the Comparison of Capital Costs per Route-Kilometre in Urban Rail paper, which suggests that the cost of at grade stations is approximately 25% of underground stations.¹²

Based on this, the following typical above ground station cost at 2017 prices were calculated:

Above ground Station = £7.6m

¹² Comparison of Capital Costs per Route-Kilometre in Urban Rail, Bent Flyvbjerg, Nils Bruzelius and Bert van Wee, March 2007.



Giving overall costs of:

- A38 North - Aztec West (4 underground stations) = £31.0m
- A420 - Emersons Green (3 underground stations) = £24.0m
- South Bristol - Airport (5 underground stations) = £38.0m

4.8 Intermediate Evacuation Shafts

It is understood that passengers will be evacuated from trains via a walkway to the nearest station or, where stations are significantly further than 1km apart, they will be evacuated using intermediate evacuation shafts, in line with fire brigade guidance. From review of the current proposals, it has been assumed that two intermediate shafts will be required for each line, where stations are further than 1km apart. These shafts have been assumed to be 18m internal diameter circular shafts and costed using the cost build up from the Northern Line Extension. These costs have been compared against High Speed 2 general guidance, and specific costs for a circular 23m internal diameter shaft on the project, with prices factored for the size. These provided a reasonable comparison, and the WECA shafts were costed at:

Cost per Shaft = £12.6 m

- A38 North - Aztec West (4 underground stations) = £25.0m
- A420 - Emersons Green (3 underground stations) = £25.0m
- South Bristol - Airport (5 underground stations) = £25.0m

4.9 Crossover Box

Although not mentioned within the tunnelling technical note, it is assumed that one underground track crossover box would be required for each line, with an additional surface crossover to enable services to interchange between lines and allow for tunnel closures for maintenance or in emergencies. Therefore, an allowance has been included within costs for an underground crossover box based on Northern Line Extension costs, but reduced in length to account for the shorter trains:

Crossover Box cost per line = £20.0m

4.10 Running Tunnels

4.10.1 Running Tunnel Costs

Costs for the running tunnels have been built up using NLE costs, with amendments made for the length of tunnel and programme duration assuming an average tunnelling rate of 80m per week. Specific risk items have been removed from the NLE costs and £10m has been included to cover the risk of mine workings, in addition to the inclusion of general risk of £10m for each line. Additionally, an efficiency factor was included within calculations of the direct tunnelling costs. This was to account for the WECA tunnels greater length of Tunnel Boring Machine tunnelling, 9km-10km compared to the NLE's 2.5km length. This factor was derived from the graph below taken from the HM Treasury and Infrastructure UK's Infrastructure Cost Review report: ¹³

¹³ Infrastructure Cost Review: Technical Report, HM Treasury and Infrastructure UK's Infrastructure, December 2010

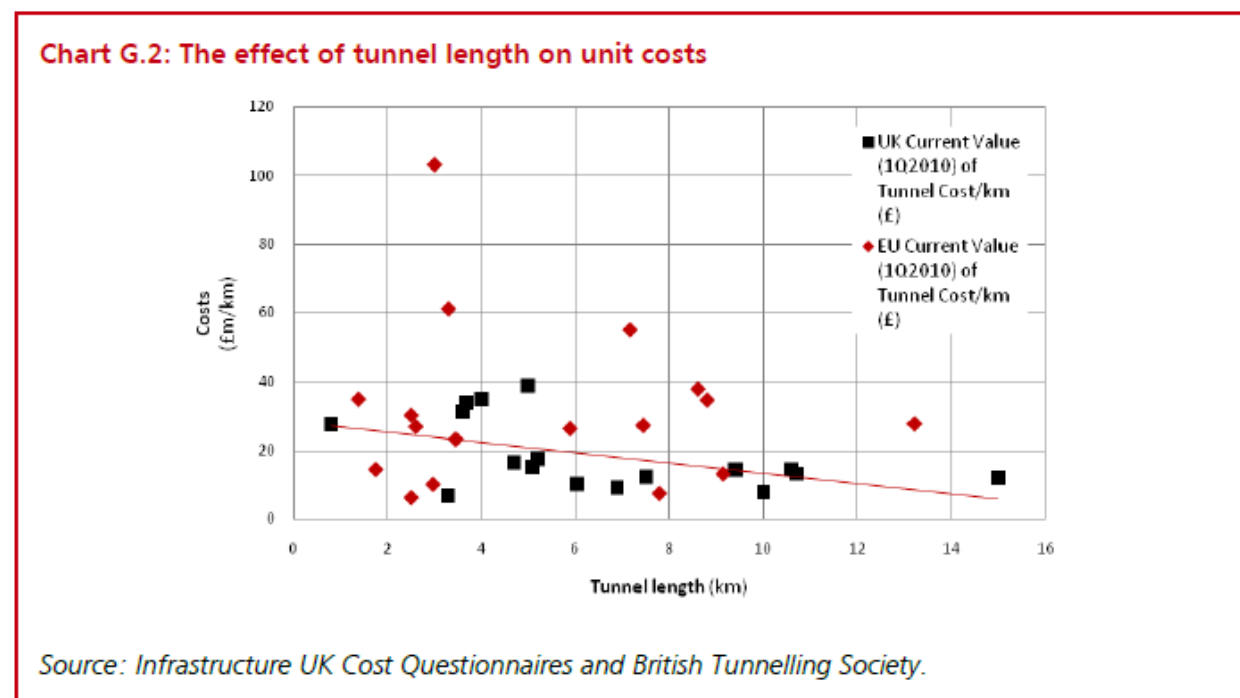


Figure 4.8 Graph indicating the effect of tunnel length on unit cost for tunnelling

From this graph it was concluded that, in comparison to the NLE costs, it would be reasonable to reduce the direct tunnelling costs by approximately 40%. Using this approach, tunnelling costs for the scheme were estimated as:

- A38 North - Aztec West = £266.0m
- A420 - Emersons Green = £272.0m
- South Bristol - Airport = £268.0m

This gave costs per kilometre for tunnelling on the WECA project of between £13m and £14m

4.10.2 Tunnel Construction Benchmarking

As the graph above also includes the costs of portals and shafts, when these were added to the tunnelling costs the full costs were reasonably close to those predicted from the graph, at 2017 prices. Costs were also found to be in line with those that could be built up using the High Speed 2 cost report.¹⁴ To verify tunnelling costs were applicable for ground conditions and geological risks present in Bristol, a comparison was carried out with the cost estimate for the Shieldhall Tunnel project, constructed in similar ground in Glasgow. Once factored for size and length, this project was estimated as approximately 20% lower than the WoE estimate, suggesting this WoE cost estimate is suitably conservative for this stage of project.

¹⁴ High Speed Rail London to the West Midlands and Beyond - HS2 Cost and Risk Model, High Speed Two (HS2) Limited, December 2009



4.11 Cross-Passages

For this cost estimating exercise, it was assumed that a cross-passage would be required every 500m and typically midway between stations or intermediate shafts. Reviewing the route suggests there would be approximately 10 cross-passages per line, however further alignment work is required during the feasibility stage, with optioneering to determine the location and numbers of cross-passages required. Costs built up from NLE costs suggest that:

- Typical cost per Cross-passage = £1.8m
- Cost for 10 Cross-passages for each line = £18.0m

4.12 Portals

The cost for the portals has been estimated based on construction costs of the NLE station boxes and factored for the size of the portal, assuming a portal depth to track of 10m and 5% track gradient. Costs built up from NLE costs suggest that:

- Typical cost of one portal for each line = £13.0m

Costs for High Speed 2 portals were then reviewed and found to be comparable.

4.13 Embankments and Cuttings

As the design has not been progressed far enough to obtain detailed costs for embankments, an allowance is included within the costs based on a conservative assumption that 20% of the above ground alignment is on Embankment and 20% is within cutting. Costs were then allocated based on the Lowest value in the cost range for the construction of embankments and cuttings on High Speed 1 at 2008 prices:¹⁵

- Embankment cost per km = £4.1m
- Cutting cost per km = £2.9m

Based on this the costs for Embankments and Cuttings on the WoE Metro at 2017 prices would be:

- A38 North - Aztec West = £6.0m
- A420 - Emersons Green = £6.0m
- South Bristol - Airport = £11.0m

4.14 Bridges

The typical cost of a two-span bridge assuming a height of approximately 5m to provide acceptable highway clearances was estimated using guidance from the High Speed 2 cost report:

- Typical bridge = £1.0m

¹⁵ Comparison of High Speed Lines' CAPEX, BSL Management Consultants GmbH & Co. KG, 2009



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From a review of the route the following allowances should be included in the estimate:

- A38 North - Aztec West (9 Bridges) = £6.0m
- A420 - Emersons Green (10 Bridges)= £7.0m
- South Bristol – Airport (20 Bridges) = £14.0m

4.15 Trackwork

The cost of trackwork will be highly dependent upon the light rail system technology which is chosen for the scheme. At present, it has been estimated based on the NLE cost build up, with a reduction factor used to account for the assumption that the system will be simpler than London Underground's, to build up costs as follows:

Table 4.3. Breakdown of trackwork costs

Track Element	A38 North - Aztec West Cost Estimate(m)	A420 - Emersons Green Cost Estimate(m)	South Bristol - Airport Cost Estimate(m)	NLE Cost adjustment
Mass concrete trackslab – underground sections	£13.2	£14.2	£13.5	Same cost/m used
Ballast trackbase – overground sections	£1.1	£1.2	£2.2	Allowance for 25% cost of trackslab
Track	£12.7	£13.7	£16.2	Assumed 50% cost
Crossovers	£1.0	£1.0	£1.0	Assume 2 crossovers but 2/3 cost each
Trackbed drainage	£9.0	£9.7	£10.5	Same cost/m used for underground. 50% of cost/m for above ground
Maintenance walkway – underground	£7.6	£8.2	£7.8	Same cost/m used
Maintenance walkway -above ground	£1.9	£2.1	£1.9	Allowance for 25% of underground walkway cost
Oncosts	£4.6	£5.0	£5.3	10% used
Total	£51.0	£55.0	£59.0	

These costs will require further review and adjustment once the technology option has been developed.



4.16 Lineside Services

In addition to the trackwork, once the technology has been detailed for the train systems the cost for the lineside services can be reviewed in much greater detail. At present a cost representing 50% of NLE costs have been assumed and factored for the length, and compared to a cost per metre for HS2. This gives an estimated cost allowance of:

- A38 North - Aztec West = £80.0m
- A420 - Emersons Green = £86.0m
- South Bristol - Airport = £90.0m

4.17 Depot

For this stage of the project it is assumed that one depot will be required for each line and based on expected costs for the expansion of the DLR Beckton depot, the following allowance should be allocated:

- Each Line = £50m

4.18 Rolling Stock

From the number of stations and length of the lines and requirement for a 2 minute headway, allowing for train maintenance and breakdowns, it has been assumed that 40 trains are needed for each line. Based on a review of Tram, Metro and Light Rail costs from around the world, at this stage a cost of £2million per train is assumed, which suggests the following allowances need to be made in the budget:

- Each Line = £80m

The costs for trains and systems provide a reasonable comparison to the 9km Rennes VAL trains and system, which is understood to have cost €165m for a 16 train peak service in 2002, although it is not known how this cost was broken down between trains and systems/services.¹⁶

4.19 Comparison with other Light Metro Schemes

Using information within the Comparison of Capital Costs per Route-Kilometre in Urban Rail paper, the cost per kilometre of the WoE Metro estimate was compared to a number of European light metro schemes.

Table 4.4a. Cost comparison for European Metro construction

Line	Length/km	% in Tunnel	Construction year	Construction Cost/km	Cost/km – 2017 prices
A38 North - Aztec West	12.5	75%	-	-	£90.0m
A420 - Emersons Green	13.5	75%	-	-	£84.3m

¹⁶ VAL Mini-Metro Line - France, railway-technology.com, <http://www.railway-technology.com/projects/val/>



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Table 4.4a. Cost comparison for European Metro construction

Line	Length/km	% in Tunnel	Construction year	Construction Cost/km	Cost/km – 2017 prices
South Bristol - Airport	16	60%	-	-	£65.6m
Lille VAL RT	29	75%	1988	£30,690,000	£77.6m
Rennes Val	9.4	NA	2002	£35,051,197	£53.6m
Toulouse VAL Line B	15	NA	2007	£43,000,000	£56.3m
Toulouse VAL Line A	9.7	90%	1993	£44,823,529	£86.1m
Toulouse VAL Line A ext	2.2	NA	2004	£60,425,532	£87.6m
Turin Metro Phase 1	9.6	100%	2005	£40,000,000	£56.4m
Average					£70m

Presenting this graphically shows that the WoE lines estimate is reasonably in line with these construction costs per kilometre, but at the higher end of the range:

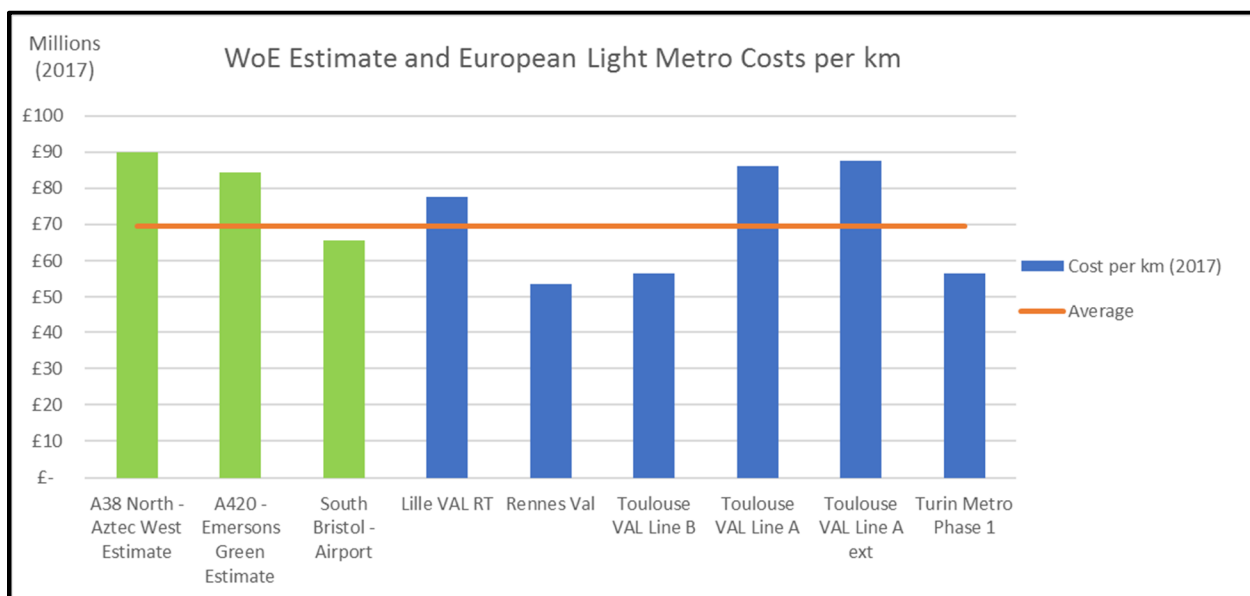


Figure 4.9 - Estimate of WoE metro costs per kilometre compared to European Metros

Costs from Metro projects in North America were also compared, but found to be significantly higher than European systems and so not felt applicable. Projects from Asia and South America were reviewed



SECTION 4 – CAPEX INCLUDING GROUND CONDITIONS AND ROUTE ALIGNMENT

and provided similar costs per kilometre, although there was significant variation in terms of scale and cost, and assumed cost of living in the country.

Table 4.4b. Cost comparison for Asian and South American Metro construction

Line	Length/km	% in Tunnel	Construction year	Cost(\$)/km – 2002 prices	Cost(£)/km – 2017 prices
A38 North - Aztec West	12.5	75%	-	-	£90.0m
A420 - Emersons Green	13.5	75%	-	-	£84.3m
South Bristol - Airport	16	60%	-	-	£65.6m
Singapore	67	30%		\$54,500,000	£55.6m
Seoul	116.5	80%		\$65,800,000	£67.1m
Calcutta	16.5	95%		\$59,900,000	£61.1m
Mexico City Line B	23.7	25%	2000	\$43,800,000	£44.7m
Caracas Line 3	4.4	100%	1994	\$98,400,000	£100.4m
Santiago Line 5 Extension	2.8	100%	2000	\$71,800,000	£73.2m
Average					£67m

4.20 Summary and further work

4.20.1 Cost summary

Costs have been divided into the following 13 areas and calculated for the three lines.

Item	A38 North - Aztec West Estimate Cost (m)	A420 - Emersons Green Estimate Cost (m)	South Bristol - Airport Cost (m)	Average Cost %
Below Ground Stations	£284.0	£284.0	£182.0	23%
Above Ground Stations	£31.0	£24.0	£38.0	4%
Intermediate Shafts	£25.0	£25.0	£25.0	3%
Crossover Box	£20.0	£20.0	£20.0	2%
Running Tunnels	£266.0	£272.0	£268.0	28%
Tunnel Cross Passages	£18.0	£18.0	£18.0	2%
Portals	£13.0	£13.0	£13.0	3%



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Item	A38 North - Aztec West Estimate Cost (m)	A420 - Emersons Green Estimate Cost (m)	South Bristol - Airport Cost (m)	Average Cost %
Earth Structures	£6.0	£6.0	£11.0	2%
Bridges	£6.0	£7.0	£14.0	2%
Trackwork	£51.0	£55.0	£59.0	7%
Linewide Systems	£80.0	£86.0	£90.0	10%
Depot	£50.0	£50.0	£50.0	6%
Rolling Stock	£80.0	£80.0	£60.0	7%
Total	£930m	£940m	£848m	

All prices include 'Oncosts' which cover the Contractor's head office and profit, insurance etc. With an assumed additional 10% for land costs and 10% for client costs, including initial design work, the full scheme price is approximately £1.1bn per line:

- A38 North - Aztec West Estimate = £1.13bn Cost per km = £90.0m
- A420 - Emersons Green Estimate = £1.14bn Cost per km = £84.3m
- South Bristol - Airport Estimate = £1.05bn Cost per km = £65.6m

Contingency of approximately 30% should be added to the costs at this stage of the project. This implies the project may need to have a budget allocated of £4.3bn:

- A38 North - Aztec West Estimate = £1.46bn
- A420 - Emersons Green Estimate = £1.48bn
- South Bristol - Airport Estimate = £1.36bn

These costs could be reduced through value engineering including removing some stations or potentially reducing the length of tunnelling,

4.20.2 Further Work

Although it is considered that this study presents a reasonable estimate for costs at this stage of the project, it is recognised that further work needs to be undertaken in several areas to obtain a more accurate cost estimate, particularly in terms of costs for rail systems and rolling stock. Specifically, the following costs have not been considered in any detail as part of this exercise:

- Above ground station design
- Removal and disposal of excavated material
- Works to infill mine voids
- Lengths and designs of bridges and earth structures
- VAL trackwork requirements and systems
- Noise mitigation/barriers or ground borne noise and vibration mitigations



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- Land costs and redevelopment value
- Depot location and design
- Value engineering initiatives

During a subsequent feasibility study it is recommended that costs are built up by taking dimensions and using detailed agreed rates. In addition, stations should be designed individually, but maintain commonalities in design for efficiency and to create a unified image for the metro.



SECTION 5

Demand, Benefits and Outline Value for Money Assessment

5.1 Approach

This chapter sets out our outline demand and benefits assessment, and an initial view on the potential Value for Money case for the scheme.

The assumptions used in the development of the various demand and funding options have restricted the costs and opportunities to discrete opportunities and modelling that is available. In assessing the likely benefits from the scheme, there are likely to be further synergies and opportunities that need to be understood, yet cannot currently be fully quantified. These areas include:

- Suppressed demand in the models. An assessment shows that in the pre-Joint Strategic Plan (JSP) version of GBATS4 there is between 4% and 10% of all mode trips suppressed within the traffic models. Therefore, it is reasonable to assume that the impact of the additional development proposed in the JSP will intensify this effect. As such a significant percentage of the trips from the JSP proposed developments are likely to be suppressed. This supports the need for a significant level of multi-modal intervention across the network. This is unlikely to be met by current modes.
- Impact on modelled user behaviour due to changing choices of younger people and the changing mix of house and workplace choices. There is some empirical evidence that there is a change in travel use by the millennial generational population. This is likely to mean that in the next few years travel by private car will become less attractive to these users, with the balance being addressed by integrated mobility packages and other technology derived travel options. This includes travel by Uber, Slide etc and familiarity with these modes will continue to affect levels of car ownership. Similarly, this generation's relative location, mobility and focus on affordable areas all support use by the proposed Metro.

5.2 Scheme Demand

5.2.1 Demand Segments

This section presents the approach and early results for the demand estimates as part of the WECA Underground Metro study.

Forecasts have been developed for the following market segments based on linear offsets rather than point offsets, as the exact location of stations is not currently defined. This provides an equivalent to a 1km point demand:

- Transfer from Public Transport within a 500m capture band
- Transfer from Car within a 500m capture band
- Additional transfer from Public Transport and Car between 500m and 750m
- Park & Ride facilities at the end of the proposed metro lines
- Airport demand



SECTION 5 – DEMAND, BENEFITS AND OUTLINE VALUE FOR MONEY ASSESSMENT

The in-scope demand for the car and public transport segments (both within 500m and up to 750m) is based on GBATS model demand matrices¹⁷ for 2036. The GBATS outputs are provided for three time periods – AM peak hour, inter-peak hour and PM peak hour. These are then annualised, based on standard factors, to provide annual demand estimates.

For P&R and Airport Demand, bespoke demand estimates have been prepared.

5.2.2 Transfer Rates from Public Transport and Car (GBATS)

To estimate the future Metro demand, a high-level approach has been adopted which links the abstraction rates from existing modes – Public Transport and Car – to estimated changes in Generalised Journey Times between these modes and assumed Metro Generalised Journey Times.

Generalised Journey Times (GJT) for Public Transport and Car are inputs from the GBATS model as presented in the previous section. The Generalised Journey Time for Metro is a function of a number of variables, including in-vehicle time, wait time (at stations), access/egress time (walking to and from origin/destination), and interchange time.

The relative improvement in generalised journey times ‘with Metro’ (the Do Something) compared to public transport time without Metro (Do Minimum) has been used to inform the percentage transfer or abstraction rate from public transport and car respectively.

The detailed abstraction assumptions are set out below, but the overall abstraction rates are:

- The overall capture rate from Public Transport is 81% within 500m, and 50% for trips between 500m and 750m. This reflects the significant journey time advantage that Metro would provide over the public transport (in most cases bus) alternative.
- For Car, the overall capture rate is 18%. Within 500m and 15% between 500m and 750m.

On the basis of these assumptions, the overall demand estimate for WECA Underground Metro would be 22m for this market segment.

5.2.3 Park and Ride Demand

Park & Ride facilities may be proposed to be constructed at the end of the Metro lines, to facilitate users’ access to Metro towards central Bristol when starting their trips from outside the Metro scope area.

Five sites have been assumed as part of this demand assessment (across the three lines). It is assumed that each site would be 75% occupied, and have converted car movements to Metro trips using a vehicle occupancy factor of 1.4.

The annual demand estimate for P&R is 3.5m trips per annum.

5.2.4 Airport Demand

A bespoke estimate of potential Airport demand has been made as this segment is less well represented within the GBATS model.

At the time of this study’s publication, demand at Bristol Airport was around 7.5 million passengers per annum. This is expected to grow significantly, with passenger trip volumes of 20 million by 2036.

¹⁷ Including growth in demand that’s forecast in the JSP.



It is assumed that the Metro share for the Airport trips will be 20% of the total trips, which results in 4 million Airport passenger trips and therefore an additional 8 million Metro trips per annum (each passenger trip is associated with two surface access trips).

5.2.5 Annual Demand Summary

The table below summarises the annual demand generated by the Metro, split by demand segment:

Demand Segment	Annual Demand (million trips per annum)
Transfer from Public Transport	11.6
Transfer from Car	12.4
Park & Ride	3.5
Bristol Airport	8.0
Annual Total Demand	35.5

5.2.6 Demand Sensitivities and Range Estimates

A number of sensitivity tests have been undertaken to reflect potential interventions that may take place alongside the construction of the Metro system. These tests represent upsides to the 'central' forecast and show:

- **Bus franchising:** this test considers the conversion of the bus system into a franchise to reduce competition between operators and to allow for a more coordinated timetable between bus and Metro. It has been modelled as an uplift to demand transferred from public transport to Metro by a 15% within the 750m catchment band.
- **Car constraint:** this test represents additional constraints to car access to Central Bristol, for instance through a congestion charge. It has been modelled as a 50% increase in demand abstracted from cars.
- **Additional development:** above JSP levels through a combination of an increase in housing development densities and additional development around Metro stations. This has been modelled as a 15% increase in the abstraction rates from public transport and cars (excluding P&R).
- **Generated Demand:** In the current analysis, there is no allowance for brand new trips induced by the effect of a step change intervention that would affect the mobility patterns in the region, increasing the propensity to travel. This has been modelled as a 15% increase in demand relative to that generated within the 750m catchment area, excluding the P&R demand.

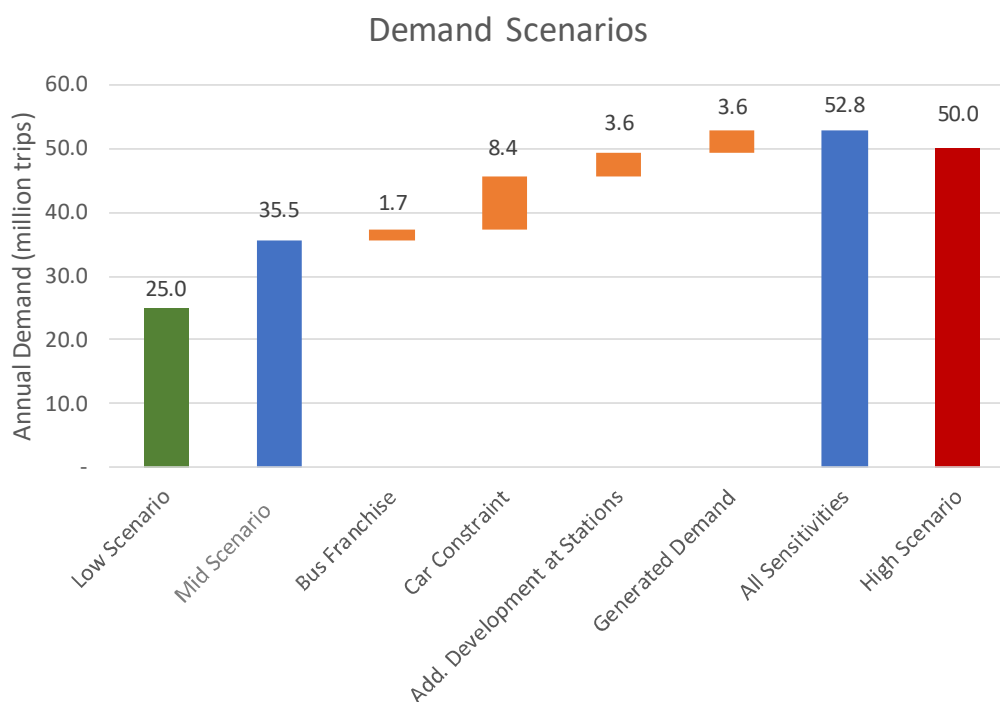
A downside test has also been considered, which examines the effect of a lower assumed transfer rate from car. This reflects the greater confidence in the forecast of abstraction from public transport, where the base in-scope market is understood. Movements within the study area reflect a wider range of trip purposes (including many where there would be a strong aversion to using public transport, for instance school run, those with mobility constraints, shopping, etc.) and where, for many trips, the car would offer a door-to-door alternative. There is therefore greater uncertainty about the level of potential abstraction from car. A test has been undertaken which reduced the transfer from car by 50%.

The sensitivity test results are presented in the table below:



SECTION 5 – DEMAND, BENEFITS AND OUTLINE VALUE FOR MONEY ASSESSMENT

Scenario	Increment	Annual Demand	% Change
Mid Scenario	-	35.5m	-
Bus franchising	1.7m	37.3m	4.9%
Car constraint	8.4m	43.9m	23.6%
Additional development	3.6m	39.1m	10.1%
Induced demand	3.6m	39.1m	10.1%
All sensitivity tests	17.3m	52.9m	48.7%
Lower car abstraction	-6.2m	29.4m	-17.4%



The sensitivities show that the range estimates of demand for WECA Underground Metro are in the range of 29m to 53m trips per annum.

The demand forecasts are clearly high level at this stage. It is suggested that a sensible range estimate to use at this stage would be:

- A 'mid' estimate of 35m trips per annum
- A 'low' case of 25m trips per annum
- A 'high' case of 50m trips per annum

The demand benchmarking and revenue and benefits forecasts have been prepared for this range estimate.



5.2.7 Demand Benchmarking

A demand benchmarking exercise has been undertaken, comparing key metrics for WECA Underground Metro with other similar systems in the UK.

Two key metrics have been considered: number of journeys per route kilometre and number of journeys per proposed station/stop. Note that there is some dissymmetry in the data presented below due to other systems' figures corresponding to 2016 data, but WECA Underground Metro data corresponding to 2036, as per the demand forecasts estimates.

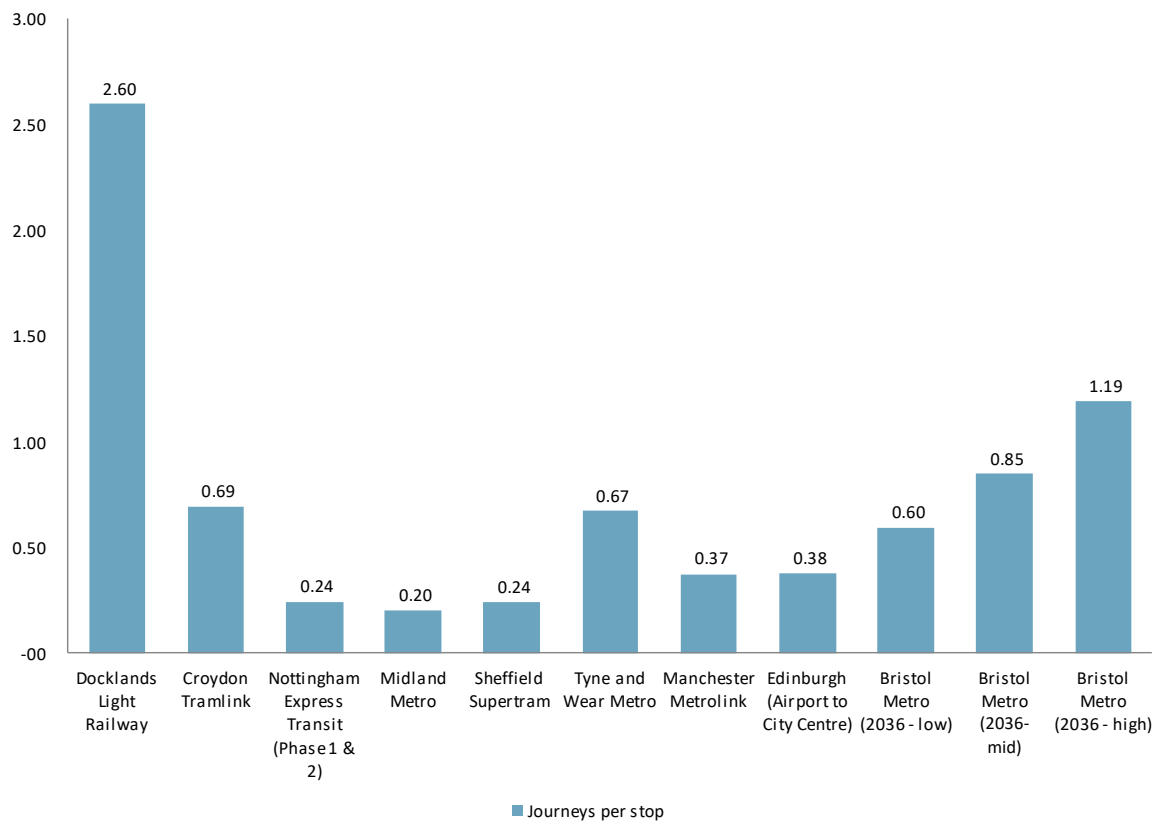
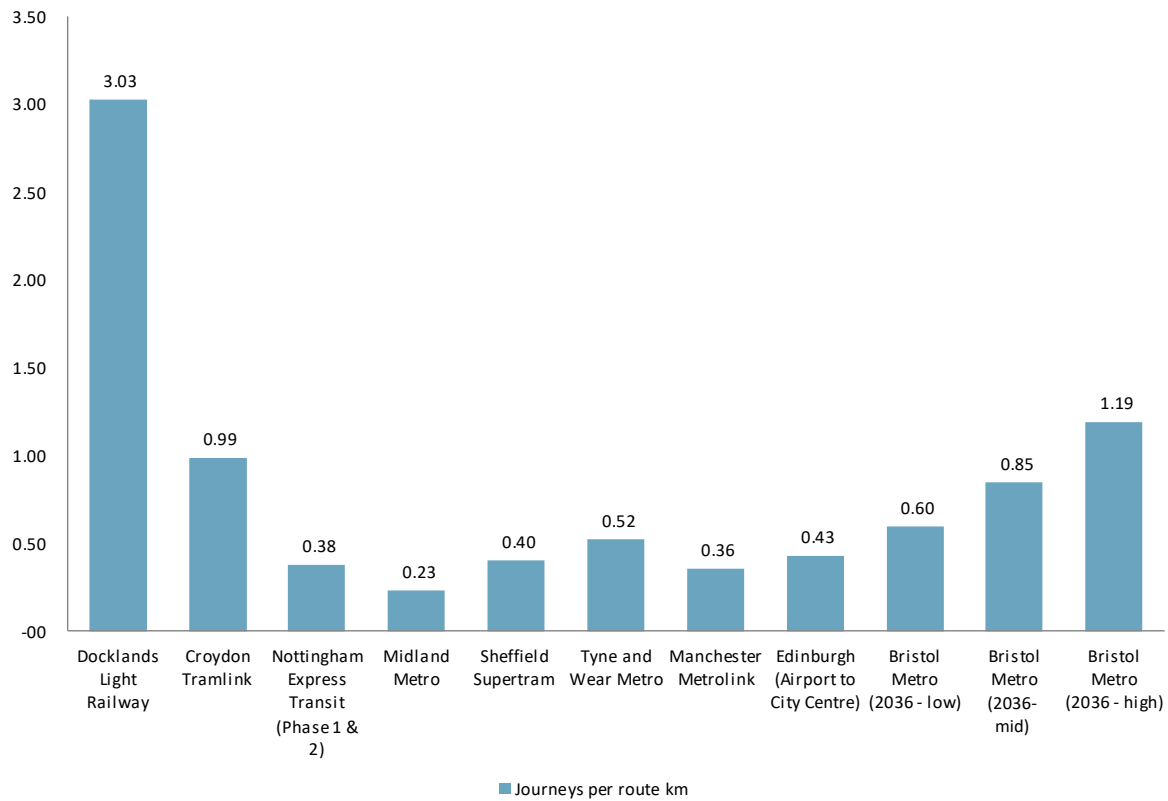
Two WECA Underground Metro scenarios have been considered to compare against the other systems: a 'Mid' scenario, which includes the 750m catchment band and the P&R sites; and 'Low' and 'High' scenarios, which provide a range within which demand estimates could oscillate – 25 to 50 million annual passengers. The table below shows the comparison of the different systems

	Docklands Light Railway	Croydon Tramlink	Nottingham Express Transit (Ph 1 & 2)	Midland Metro	Sheffield Supertram	Tyne & Wear Metro	Manchestr Metrolink	Edinburgh (Airport to City Centre)	WECA Undrgrnd Metro 2036 - low	WECA Undrgrnd Metro 2036 - mid	WECA Undrgrnd Metro 2036 - high
Route miles	24	17	20	13	18	48	60				
Route km	39	27	32	21	29	77	97	14	42	42	42
Number of stops	45	39	50	24	48	60	92	16	42	42	42
Passenger journeys (m)	116.9	27	12.2	4.8	11.6	40.3	34.3	6	25.0	35.5	50.0
Journeys per route km	3.03	0.99	0.38	0.23	0.40	0.52	0.36	0.43	0.60	0.85	1.19
% diff vs. Bristol	-61%	21%	214%	419%	197%	128%	235%	178%	100%	41%	0%
Journeys per stop	2.60	0.69	0.24	0.20	0.24	0.67	0.37	0.38	0.60	0.85	1.19
% diff vs. Bristol	-54%	72%	388%	495%	393%	77%	219%	217%	100%	41%	0%

The figures overleaf show the comparison of these key metrics for all the systems analysed:



SECTION 5 – DEMAND, BENEFITS AND OUTLINE VALUE FOR MONEY ASSESSMENT





The analysis shows that Bristol demand benchmarks lower than London schemes (DLR and Croydon Tramlink) but higher than other (non-London) UK systems. The Bristol numbers are for 2036 whereas the demand for other systems is based on data for the most recent year (2016). If it is assumed that demand for other systems grows by 3% per annum over a 20-year period, this would imply an 80% growth over the period. This would bring the better performing of other UK systems more in line with the WECA Underground Metro forecasts for a 2036 comparison year.

The trip rates (demand per stop and per route km) are typically higher for many European mass transit schemes, such as the VAL system that operates in Toulouse and Lille (where journeys per stop are 1.9m and 1.7m respectively – about 50% higher than the ‘high’ Bristol estimate. The higher trip rates for VAL are likely to reflect the greater concentration of economic activity in the city centre and the higher density of residential development (typically large apartment blocks) along transit corridors. However, these figures also point towards the potential demand that Bristol could look to achieve if a pro-active policy of transit oriented development were pursued.

5.3 Scheme Revenue and Benefits

The metro system would generate revenue from its passenger farebox. It has been assumed that the initial metro fare would be £2.00, as a flat rate for all trips across the network and across the day. This fare is expressed in 2017 prices. In addition, a premium fare at £6.00 per trip has been considered for all additional trips generated from/to Bristol airport, to reflect similar fares elsewhere in the country.

The table below shows the revenue generated in the central, low and high scenarios:

Scenario	Annual Demand	Annual Revenue (2017 prices)
Mid	35.5m	£103.1m
High	50.0m	£145.0m
Low	25.0m	£72.5m

Benefits calculated for the Metro system mainly include three sources:

- User benefits for demand transferred from public transport
- User benefits for demand transferred from car
- Non-user benefits or highway externality benefits. These include congestion, accident reduction and air quality benefits. In the current assessments, these are calculated using standard relationships and assumptions, and as such would be assessed in more detail as scheme design progresses.

The benefits for the central case and for the high and low scenarios are presented in the table below (expressed in 2010 values):

Scenario	Annual Demand	Annual Benefits (2010 values)
User benefits (public transport)	-	£76.1m
User benefits (car)	-	£62.7m
Non-user benefits (externalities)	-	£21.3m
Mid	35.5m	£160.1m
High	50.0m	£225.2m
Low	25.0m	£112.6m



5.4 High Level Value for Money Assessment

A high-level economic appraisal has been undertaken to assess the Value for Money provided by the construction of WECA Underground Metro. Data produced in the previous sections along with assumptions on the remaining aspects has been gathered to inform this analysis.

5.4.1 Appraisal Period

The following assumptions around the appraisal period have been considered to undertake the analysis:

- Opening year: 2030
- Demand cap year: 2048
- End of appraisal: 2089

5.4.2 Scheme Costs

The Present Value of Costs (PVC) is comprised of three components: capital costs, operating costs and net revenue.

Annual net revenue is estimated as the difference between the revenue generated by the Metro, as presented above, and the revenue lost by other public transport providers. An average fare of £1.50 has been assumed for the latter, which would be lost by all the trips transferring from other public transport to Metro. Annual net revenue for the scheme is £89m (in 2017 prices), with £103m generated by the Metro and £17m lost by other public transport.

Capital cost for construction of the Metro system has been estimated at £4.3bn in 2017 prices, including contingency risks. In calculating present values of cost for value for money assessment, it has been assumed that the capital cost is incurred at uniform rate across the construction period prior to the Metro opening year. Optimism bias has been included in the calculation of present values of cost.

Annual operating cost for the Metro system would depend on several factors, including the mode, frequency of operation and assumptions around staffing levels. Initial outline operating costs figures have been derived from an assessment of the total vehicle km that the system would run on an hourly then daily and ultimately annual basis, and multiplying this by a unit cost per vehicle km. The cost per vehicle km assumed has been derived from existing schemes, where this can be identified or assumed.

At the lower end, a driverless system operating at a service level of every 5 minutes would have an annual operating cost of around £20m in 2017 prices, whereas a DLR type mode at a higher frequency would be over £40m+ per annum. For the purposes of the appraisal an assumed annual operating cost of £30m per annum has been considered.¹⁸ This implies a level of service that could comfortably accommodate the ‘mid’ demand forecast scenario. It is assumed that there is no growth above RPI to operating costs over time, although in reality there might be some real growth, for instance linked to staff wages growth.

¹⁸ Based on figures from DLR of \$6 per car km (‘Rail and Underground International Benchmarking Report’ Rail and Underground Panel, 2015), reduced to 60% of the total to represent a lower frequency system.



All costs have been profiled and discounted over a 60-year appraisal period and their values have been expressed in 2010 prices and discounted to 2010 to derive the Present Value of Costs. The table below summarises the main components of the PVC:

Cost Category	Value (£m, 2010 values)
Capital Costs	£4,522m
Operating Costs	£333m
Revenue	-£1,079m
Public Value of Costs (PVC)	£3,776m

5.4.3 Operating Ratio

The ratio of revenue to operating costs is used to demonstrate the ability of a public transport scheme to deliver an operating surplus and thus avoid the need for continuing operating cost subsidy. At this early stage of a scheme development, a number of significant assumptions have had to be made to inform cost and revenue estimates.

On the revenue side:

- Relatively simplistic demand forecasting
- Assumed yield of £2 per trip which is 33% higher than the average fare calculated in GBATS of £1.50 per trip (allowing for concessions). Airport service trips are £6 per trip (similar to the current bus service from Temple Meads)
- Pulling yields back to the GBATS average would give a significant reduction

On the Operating cost side:

- figures that cover the short run operating costs of a system have been used as these are readily reported in accounts – whereas medium and longer-term maintenance aspects are an additional factor to be considered
- system frequency is assumed at 5 mins – this should accommodate demand – though user friendliness and system capacity will allow for double this level.

In summary, the mid revenue estimate is £103.1m gross. Reducing the fares by 25% to equvalate to the GBATS assumption would yield £77m gross and a net (excluding lost PT revenue) of £60m.

The mid operating costs are £30m for LRT, £40m for light underground type operation. Should frequency increase to 2.5mins headway – this would very broadly (it's not a direct relationship) double operating costs – so £60m and £80m. In both cases, the medium and long run operating costs would need to be covered in some way by the revenue as well as the defined short-term costs.

It can therefore be concluded that the system has the potential to cover its operating costs, but that more work, including detailed financial modelling, will be required to confirm these working assumptions.

5.4.4 Scheme Benefits

The Department for Transport (DfT) issued a consultation on the draft new WebTAG Wider Impacts Guidance regarding the quantification of economic impacts in September 2016. The consultation closed at the end of 2016 and DfT is currently analysing the consultation responses. This guidance provides an



SECTION 5 – DEMAND, BENEFITS AND OUTLINE VALUE FOR MONEY ASSESSMENT

approach to classifying the assessment of economic impacts according to levels which are differentiated according to the maturity of the analytical techniques employed. Within each level and for any given scenario, consistent assumptions about land-use change must be applied to the analysis of all impacts:

- **Transport User Benefits** – these are based on time-savings, and implicitly assume a fixed land use
- **Wider Impacts** = these are productivity benefits that are additional to time savings
- Induced Investment Effects including **Dependent Development** – these can occur where a transport scheme is transformational, and results in a change in the scale and pattern of development.

An estimate has been made of the conventional transport benefits and the high-level assessment of wider impacts and dependent development.

5.4.5 Transport User Benefits

The Present Value of Benefits (PVB) has been derived from the Annual Benefits estimates for 2036 as in the previous section of this report. Annual Benefits have been profiled using demand growth, Value of Time growth and discounted to 2010 values for consistency with general appraisal guidance.

Below is a range estimate for the level of user benefits, based on the demand ranges reported earlier in this chapter.

Scenario	Annual Demand (million trips)	Annual Benefits (£m, 2010 values)	60-year Benefits (PVB) (£m, 2010 values)
User benefits (public transport)	-	£76m	£1,621m
User benefits (car)	-	£63m	£1,336m
Non-user benefits (externalities)	-	£21m	£454m
Mid	35.5m	£160m	£3,410m
High	50.0m	£225m	£4,797m
Low	25.0m	£113m	£2,399m

5.5 Wider Economic Impacts

Wider benefits occur where changes in transport costs deliver additional productivity benefits over and above those captured within the ‘conventional’ transport user benefits included within Level 1. Level 2 benefits include:

- Static clustering (agglomeration)
- Labour supply impacts
- Output change in imperfectly competitive markets

Static Clustering (Agglomeration)

Agglomeration benefits quantify productivity changes that result from increased clustering of business activity, and better matching between business needs and skills availability. Agglomeration-based productivity benefits are likely to be experienced in a transport scheme brings economic centres closer together. The WECA Underground Metro Phase 1 is likely to improve the connectivity between, and



across key corridors and Bristol City Centre, significantly increasing the overall level ‘effective density’ – the measure of agglomeration.

Labour supply impacts

Based upon the scheme options developed, and the potential for improved public transport along the scheme corridor, there is the opportunity for the scheme to reduce the journey costs associated with travelling to work, improve the financial return to individuals from employment, and hence increase the overall supply of labour within the local economies along the corridor.

Imperfectly Competitive Markets

Imperfect competition benefits quantify the increase/decrease in output by firms resulting from changes in transport costs. They represent the welfare gain achieved as consumers’ willingness to pay for the increased output will exceed that of producing it. Imperfect competition benefits are estimated as a fraction of the total business users time savings and therefore are likely to be significant where a scheme demonstrates significant time savings to users.

Based on our previous experience in similar schemes, it is considered that the total of the three Wider Economic Impacts presented above would deliver an additional 40% of the ‘conventional’ benefits.

For the Mid case, the Present Value of Benefits was £3.4bn in 2010 values. The Present Value of Benefits including the Wider Economic Benefits would amount to nearly £4.8bn.

The table below summarises the impact of the Wider Economic Benefits on each of the three scenarios considered:

Scenario	Annual Demand (million trips)	PVB (£m, 2010 values)	PVB with Wider Economic Benefits (£m, 2010 values)
Mid	35.5m	£3,410m	£4,774m
High	50.0m	£4,797m	£6,716m
Low	25.0m	£2,399m	£3,358m

5.6 Dependent Development and Land Value Uplift

Land Value Uplift (LVU) can be claimed where a transport intervention is a facilitator of new development. This can be in the form of an enabler of a development that otherwise would have not come forward or impact of the delivery rate and accelerate the delivery. DCLG’s appraisal guide, published December 2016, recommends a ‘Land Value Uplift’ approach to valuing the benefits of development. Central to LVU is the test of ‘dependence’ to ascertain whether transport is the key constraint stopping the developments from being ‘viable’.

The ‘value’ of the development is site specific and generally the value is greater where:

- The level of development density supported as a result of the transport intervention is higher than if the transport scheme had not been delivered
- The land use changes to a more productive use such as from greenfield or brownfield to housing or commercial use



Potential Impact of WECA Underground Metro

The delivery of WECA Underground Metro will likely result in enhanced public transport connectivity for areas currently poorly served by public transport. In a city where congestion levels are already high, the need for a reliable public transport network is vital. The delivery of the WECA Underground Metro is likely to have an impact on land values along the route and lead to increased delivery of housing stock and/or acceleration of the delivery rate.

Similarly, employment sites along the route could be densified, as a result of better public transport accessibility for employees and lesser need to provide parking spaces.

LVU can be 'scored' where a transport scheme allows a market failure to be overcome. There are four ways in which LVU can happen:

- If, as a result of overcoming coordination failure, the transport scheme opens up sites to development
- If the transport scheme incentivises land developers to develop the land at a faster rate than otherwise would have been the case
- If the transport scheme allows for densification of developments
- If the transport scheme leads to a higher quality/value developments

Three scenarios under which WECA Underground Metro could generate LVU benefits have been considered are:

1. Change in land use from industrial to residential or commercial – where change in use is premised on / enabled by the implementation of the scheme. E.g. Barking Riverside Extension opening up former brownfield site.
2. Increase in intensity of use of for an existing land use - E.g. WECA Underground Metro allows existing areas of designated housing to be developed to a higher density (denser development, fewer parking spaces).
3. Bringing forward / accelerating development - i.e. WECA Underground Metro increases viability of development and brings forward housing delivery faster than would otherwise be the case.

Any estimate of LVU would need to be subject to detailed work. However, the scale of uplift could be significant (for Barking Riverside and uplift was around £250m for an additional 6,800 dwellings – an uplift equivalent to around £37,000 per additional unit). If WECA Underground Metro were to enable, for example, 10,000 additional dwellings, this could deliver a land value uplift of around £300m. There is also a potential land value uplift associated with the higher density and more intensive development of commercial land used in the corridors and the city centre.

The role of transport as an enabler of housing is increasingly recognised by Government. Earlier this year DCLG announced a Housing Infrastructure Fund totalling £2.3bn, which made up to £250m available to scheme promoters for strategic housing initiatives. Summary of Potential Value for Money

A Value for Money assessment has been undertaken on the mid, high and low scenarios based on the benefits and costs calculated. This assessment is summarised in the table below (excluding and including the Wider Economic Benefits).



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Economic Appraisal	Mid Scenario	Low Scenario	High Scenario
Public Value of Benefits (PVB)	£3,410m	£2,399m	£4,797m
PVB including WEI	£4,774m	£3,358m	£6,716m
Public Value of Costs (PVC)	£3,776m	£4,096m	£3,337m
Net Present Value (NPV)	-£365m	-£1,697m	£1,460m
NPV including WEI	£999m	-£738m	£3,379m
Benefit Cost Ratio (BCR)	0.90	0.59	1.44
BCR including WEI	1.26	0.82	2.01

The VfM performance, with Wider Economic Benefits, would deliver a benefit-cost ratio of between 1.3:1 and 2.0:1. This suggests a value for money case for the scheme can be made, that would sit in the DfT's categorisation of medium/high value for money. The inclusion of Land Value Uplift has the potential to enhance the VfM performance further, though DfT guidance is clear that LVU cannot be added to the BCR.

It should be noted that these results are preliminary and based on a number of assumptions and slight variations to these assumptions could affect the Value for Money categorisation. Further, more detailed work would be required to develop the economic case to a greater level of detail to provide a more robust VfM assessment.

The value for money case will also need to be developed within the context of the broader strategic objectives for the scheme. In particular, for mass transit to deliver the capacity, connectivity and accessibility that will support a higher level of growth (housing and employment) and economic activity (GVA and GVA per worker) than could be achieved under either a 'business as usual' scenario or with on-street transit options that would not overcome the constraints on growth and movement that could be provided by a tunnelled solution.

5.7 Summary

5.7.1 Demand

The table below summarises the annual demand generated by the Metro, split by demand segment:

Demand Segment	Annual Demand (million trips per annum)
Transfer from Public Transport	11.6
Transfer from Car	12.4
Park & Ride	3.5
Bristol Airport	8.0
Annual Total Demand	35.5



SECTION 5 – DEMAND, BENEFITS AND OUTLINE VALUE FOR MONEY ASSESSMENT

Sensitivity tests reflect potential interventions that may take place alongside the construction of the Metro system. A downside test has also been considered, which examines the effect of a lower assumed transfer rate from car. The sensitivity test results are presented in the table below:

Scenario	Increment	Annual Demand	% Change
Mid Scenario	-	35.5m	-
Bus franchising	1.7m	37.3m	4.9%
Car constraint	8.4m	43.9m	23.6%
Additional development	3.6m	39.1m	10.1%
Induced demand	3.6m	39.1m	10.1%
All sensitivity tests	17.3m	52.9m	48.7%
Lower car abstraction	-6.2m	29.4m	-17.4%

The sensitivities show that the range estimates of demand for WECA Underground Metro are in the range of 29m to 53m trips per annum. The demand forecasts are clearly high level at this stage, so a sensible range estimate to use at this stage would be a 'mid' estimate of 35m trips per annum, 'low' case of 25m trips per annum and 'high' case of 50m trips per annum.

Benchmarking analysis shows that demand is lower than London schemes (DLR and Croydon Tramlink) but higher than other (non-London) UK systems. The trip rates (demand per stop and per route km) are typically higher for many European mass transit schemes, such as the VAL system that operates in Toulouse and Lille. The higher trip rates for VAL are likely to reflect the greater concentration of economic activity in the city centre and the higher density of residential development along transit corridors, and point towards the potential demand that Bristol could achieve if a pro-active policy of transit oriented development were pursued.

5.7.2 Revenue and operating ratio

Assuming an initial metro fare of £2.00 (flat rate for all trips across the network and across the day in 2017 prices), and a premium fare at £6.00 per trip for trips from/to Bristol airport, generates the revenue shown below for central, low and high scenarios:

Scenario	Annual Demand	Annual Revenue (2017 prices)
Mid	35.5m	£103.1m
High	50.0m	£145.0m
Low	25.0m	£72.5m

The central operating costs are £30m for LRT, £40m for light underground type operation. Should frequency increase to 2.5mins headway, this would broadly double operating costs. In both cases, the medium and long run operating costs would need to be covered in some way by the revenue as well as the defined short-term costs. It is considered that the system has the potential to cover its operating costs; more work, including detailed financial modelling, is required to confirm this assumption.



5.7.3 Value for money assessment

A Value for Money assessment has been undertaken on the mid, high and low scenarios based on the benefits and costs calculated. Benefits include transport user benefits, non-user benefits (externalities) and wider economic impacts (agglomeration, labour supply and imperfect markets). In addition, dependent development and land value uplift has also been considered. The assessment is summarised in the table below.

Economic Appraisal	Mid Scenario	Low Scenario	High Scenario
Public Value of Benefits (PVB)	£3,410m	£2,399m	£4,797m
PVB including WEI	£4,774m	£3,358m	£6,716m
Public Value of Costs (PVC)	£3,776m	£4,096m	£3,337m
Net Present Value (NPV)	£-365m	£-1,697m	£1,460m
NPV including WEI	£999m	£-738m	£3,379m
Benefit Cost Ratio (BCR)	0.90	0.59	1.44
BCR including WEI	1.26	0.82	2.01

The preliminary VfM performance, with Wider Economic Benefits, would deliver a benefit-cost ratio of between 1.3:1 and 2.0:1. This suggests there may well be a value for money case for the scheme.

Note that, although Land Value Uplift has the potential to enhance the VfM performance further, DfT guidance is clear that LVU cannot be added to the BCR. Notwithstanding this, if WECA Underground Metro were to enable, for example, 10,000 additional dwellings, this could deliver a land value uplift of around £300m. There is also a potential land value uplift associated with the higher density and more intensive development of commercial land used in the corridors and the city centre.



SECTION 6

Funding Assessment

6.1 Introduction

An important question in developing and implementing a large-scale transport infrastructure scheme is identifying how it can be funded. This is particularly important given the wider economic and political environment of a tighter public purse, leading to the end of an era where UK central government grant funding would be made available provided the proposed scheme had a strong case and was technically feasible.

A robust funding strategy for large scale transport infrastructure schemes should consider finding ways of capturing the uplift in land value and the economic benefits enabled by the scheme, as this can reduce reliance on the public purse. For instance, WECA Underground Metro will help increase land values which, through the use of an appropriate funding mechanism, could be retained by the public sector to pay for a proportion of the initial infrastructure costs (e.g. by providing a revenue stream that supports borrowing).

Capturing these benefits to generate funding for transport infrastructure can be achieved by an appropriate funding package that utilises the powers available to local authorities and combined authorities. For instance, land value or benefit uplifts could be captured through introducing tax supplements on businesses or residents and ring-fencing direct development taxes such as development levies.

This section focuses on funding; it is important to distinguish the difference between funding and financing. Funding refers to what capital ultimately pays for the costs of the scheme i.e. it does not need to be directly repaid¹⁹ while financing refers to how the capital requirements of the scheme are met through sources that do need to be repaid.

An assessment of the funding potential to support WECA Underground Metro has been undertaken and is presented below. This assessment focuses on funding that can be generated locally from third parties (i.e. not local grant funding) and presents Mid and Optimistic funding scenarios. It is important to note that the assessment presents a range of different potential funding sources and does not consider at this stage the economic, environmental and most importantly, political challenges in developing and agreeing a robust funding package.

6.1.1 Policy Context

Public investment in the UK is more dependent than ever on finding sufficient funding and increasingly the ability to generate revenues locally is determining whether a scheme is taken forward. As central government funding has become increasingly constrained, the days when a public investment would be delivered largely on the economic, social or environmental benefits it generates have gone. In addition, devolution has focused decision making on seeking to find local beneficiaries for any particular investment.

¹⁹ Funding contributions may be 'repaid' indirectly to the contributor by gaining financial benefits that result from the scheme (for instance, businesses who may gain financially through improved productivity after the scheme).



SECTION 6 – FUNDING ASSESSMENT

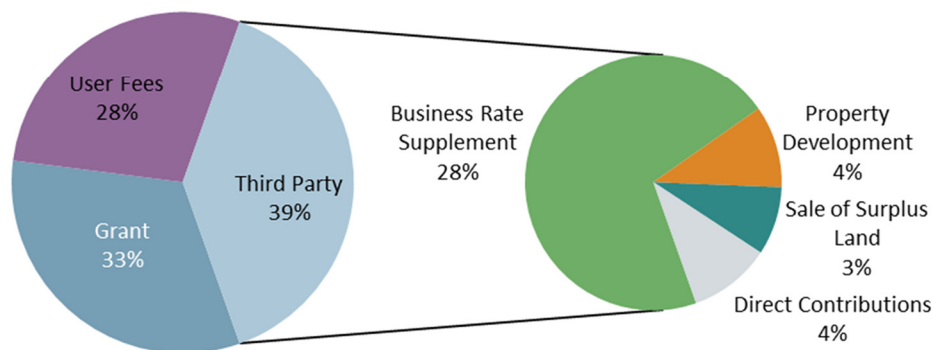
Crossrail can be seen as setting the benchmark for establishing the case for public investment in transport infrastructure and in particular identifying and securing an appropriate funding package. These include the following broad principles:

- At least 50% of funding required to deliver a transport infrastructure project is from local sources
- That the project should be able to cover its longer run operating, maintenance and ideally renewal costs
- That a mix of local funding can be secured including support from local businesses, development and users
- That the wider economic benefits of the project are significant and that increased taxes can help recover any central government outlay (particularly increased productivity, generating additional and higher paying jobs)

Crossrail

Crossrail is Europe's largest transport project, delivering a new 21km underground urban railway and connections to the existing UK national rail network, increasing capacity of London's transport network by 10% along with transforming the city-region's connectivity.

One of the biggest challenges was developing a robust funding strategy for the £15bn project and securing its approval. Crossrail is being funded by a range of income streams, many of which have never been used before, including a business rate supplement and development levies across London. Analysis was undertaken to make the case for investment in Crossrail and the value generated, for example by assessing how local businesses will see increased activity resulting from Crossrail's opening. This was critical in securing support from stakeholders to introduce the new income streams representing over 2/3 of total funding.

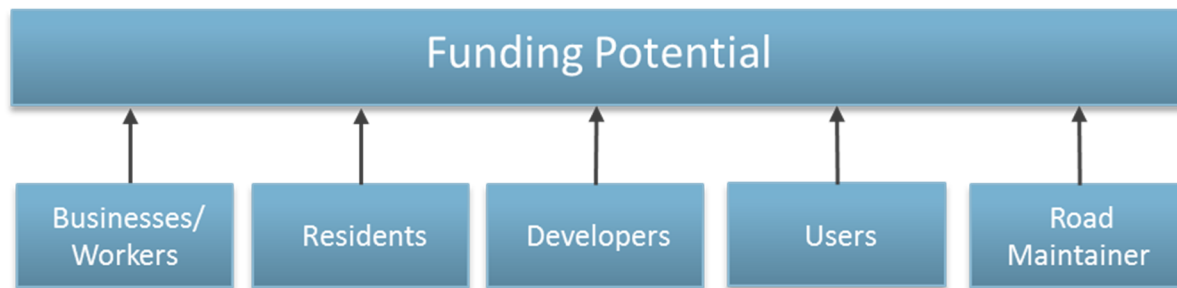


6.2 Beneficiary Pays

A key concept in our assessment of new funding and financing options is that of 'benefactor pays'. This concept is based on the principle that those who benefit from the improvement in transport should contribute to its cost where beneficiaries include direct users of the development, such as passengers, and economic beneficiaries i.e. those who obtain increased economic benefit either in capital or revenue terms from the improved transport provision.



An improvement in transport can result in a range of beneficiaries. An overview of the potential beneficiaries of the WECA Underground Metro has been provided below including how they may benefit from the project.



Businesses/Workers benefit from the Metro through agglomeration as greater productivity and lower costs arise from the concentration of economic activity. The increased concentration has a productivity 'bonus' that is shared between businesses and workers that can lead to increased revenues and/or reduced costs. In addition, businesses can benefit from being able to draw from a wider pool of prospective employees who can more easily access their business.

Residents benefit from the Metro through improved connectivity and increased mobility and (if they own their property) through the uplift in land values.

Developers benefit from the Metro through an increase in land value as more businesses and/or residents look to relocate to the area. This benefit translates into a financial benefit as higher land values can result in higher density developments and/or an increase to rental values and/or sale incomes.

Users of transport services benefit from the Metro through reduced journey times, improved reliability and/or improved frequency. These benefits allow users to access a wider pool of jobs and can lead to productivity gains where both may result in financial benefits to the user.

The Road Maintainer benefits from the Metro through reduced road usage as people increasingly travel by public transport, walking or cycling as opposed to private car. In this instance, it may reduce the need to expand the road network around Bristol to meet growing demand.



6.3 Approach Overview

This section includes the general approach undertaken to identify a short list of funding option and some general assumptions in our approach.

6.3.1 Long List/Short List of Funding Options

A long list of 20 funding options has been identified for the WECA Underground Metro and assessed against this long list based on potential contribution, legal deliverability, political deliverability and alignment with beneficiaries. From this assessment, a short list of seven possible funding options is identified, which is quantified and combined into Mid and Optimistic funding scenarios. The short-listed funding options are shown below.

Table 6.1: Short Listed Funding Options

Funding Mechanism	Beneficiary
Business Rate Supplement	Businesses
Workplace Parking Levy	Businesses/Workers
Road Pricing Scheme	Road Users
Highway England Contribution (Shadow Toll)	Road Maintainer
Council Tax Precept	Residents
Community Infrastructure Levy	Developers
Local Tax Retention	Businesses/Residents

6.3.2 General Assumptions

6.3.2.1 Scheme Costs

A comparison of funding estimates with the capital costs of WECA Underground Metro has been made, which are assumed to be £3,320m in real 2017/18 terms. Financing costs are likely to be required to meet the upfront capital costs of the project, for example interest payments. However, note, the capital costs estimate does not include financing costs.

It is assumed that the operating costs from the Metro will be at least equal to the revenue generated from the scheme and therefore there is no farebox surplus or deficit. It is worth noting that Crossrail is using future surplus revenues to help fund nearly a third of the capital costs.

6.3.2.2 Commercial and Residential Developments

A key driver of the funding potential is the forecast development within the West of England region. In our Mid scenario, forecasts of commercial developments over the next 25 to 30 years from the WoE 2015 Economic Development Needs Assessment have been used, for the forecast of residential developments the WoE *Joint Spatial Plan, Infrastructure Position Statement* from 2015 has been used.

The improved connectivity due to the introduction of WECA Underground Metro can support greater density developments in the West of England, through for instance, adjacent station developments. The impact of this on the short-listed funding sources has been considered by assuming an uplift in the increase of residential development by 20% outside of Bristol and 25% in Bristol, in an optimistic development growth scenario (i.e. not our mid scenario).



6.3.2.3 Funding Sources

The funding mechanisms identified are those that the local authorities or Combined Authority has the power to implement²⁰ (i.e. they do not require primary legislation). However, included is a council tax precept as although a precept on council tax did not feature in the Devolution Deal, it is understood that this can be included in a future deal and additionally the growth in council tax could be ring-fenced under current legislation, as seen in funding the 2012 London Olympics. There is some potential for a revenue surplus to be used to service a capital loan, though this will require significantly more detailed consideration of costs and revenues over time than done so far at this stage.

There is also potential for direct contributions to support the Metro from larger developers or landowners and Bristol Airport given the Metro is likely to serve the airport. However, it is not expected that this would generate significant funding and has therefore not been considered in this analysis.

Funding estimates are all provided in real 2017/18 terms and over a 25 to 30-year period. The annual growth of rates used in the funding calculations have been assumed to grow in line with inflation.

Manchester Metrolink

The Metrolink 'Big Bang' expansion includes a £1.5bn Metrolink investment programme which will triple the size of the network. The extent of the project will help reduce congestion levels, with an estimated five million fewer cars on the road network, increasing public transport trips per day from 55,000 to more than 90,000.

The projects successful delivery is primarily attributable to Greater Manchester Combined Authority (GMCA) and their ability to resource innovative funding sources following the rejection of a new road pricing scheme by public referendum.

The ten councils worked together to generate funding through a series of authority wide mechanisms and agreed a prioritisation of schemes to fund based on the GVA and employment growth potential and overall cost across the authority.

The Metrolink extension is part of the transformational growth project which is seeing major investment, including bus priority measures, six new and better cycle routes into the city centre and major rail improvements, all of these align with the GMCA vision of becoming a self-reliant city region.



²⁰ Note, this may be subject to approval with other parties e.g. a Business Rate Supplement and the Local Enterprise Partnership.



6.4 Short Listed Funding Options

In this section, the assumptions and funding estimate by source is presented.

6.4.1 Business Rate Supplement (BRS)

6.4.1.1 Context

Business Rates is a tax charged to businesses based on the value of their premises. In England and Wales, it is based on the rateable value of a business's property which is aligned with the market value of the property. It is understood that the 2016 West of England (WoE) Devolution Deal will provide WECA authorities the power to levy a BRS in addition to Business Rates to fund infrastructure during the development phase of this project. The BRS is capped at 2p in the pound of rateable value and requires agreement from the local business community through the local enterprise partnership. Note, this may need to be considered should there be other competing demands for this funding.

It should be noted that the options identified below are a shortlist of funding options based on an initial desktop study and will require more detailed analysis to confirm the funding package required.

6.4.1.2 Assumptions

The table below outlines our key assumptions to estimate the funding potential of a BRS.

Table 6.2: Business Rate Supplement Key Assumptions

Item	Assumption	Rationale/Notes
Supplement Rate:	2% on rateable value	Based on WECA Devolution Deal which caps a business rate supplement at 2%.
Geography applied to:	Bristol, South Gloucestershire and Bath and North East Somerset	Aligns with the local authorities in WECA
Proportion of BRS allocated Metro:	100%	Assumed levy would be introduced to support the Metro and therefore would be fully allocated to the project
Proportion of Business Rate Income Exempt due to Small Business	10% (of total business rate income)	Based on the proportion of BRS exemption in Greater London. To achieve this proportion, it is likely the exemption will need to be below the £50,000 in London due to the difference in property values in West of England.

The business rate supplement has been estimated from two components:

- The current commercial property in WoE in 2017/18
- The forecast increase in commercial property over the next 25 to 30 years

The current commercial property estimate is based on the official government Business Rate receipts from 2017/18 by local authority. While the BRS income from new commercial developments over the next 25 to 30 years is based on the forecast on commercial developments in the WoE 2015 Economic Development Needs Assessment and an estimated average business rate income per m² based on the current overall commercial property and business rate income generated, split by local authority.

An exemption of small businesses is included in our calculation based on the proportion of businesses exempt in Greater London. When introduced in Greater London to support Crossrail, the BRS was only charged to businesses with a rateable value above £55,000 (which has now increased to £70,000 from 2017/18). To achieve the same proportion of exempt businesses, the level at which the exemption is set



in WECA will need to be lower than the level in Greater London due to the differences in property values between the West of England and London.

The implementation costs for a council tax precept have been assumed to be negligible as it is an extension of current practises.

6.4.1.3 Results

The table below outlines the funding income that could be generated over a 25 year or 30-year period.

Table 6.3: BRS Funding Potential

Scenario	Funding Potential; £m; Real 2017/18		
	Existing commercial developments	New commercial developments	TOTAL
25-year Period	£413m	£57m	£470m
30-year Period	£495m	£83m	£578m

As noted above, the introduction of a BRS in WECA would require agreement from the local business community through the local enterprise partnership. While this is subject to interpretation and could require a vote of affected parties (all businesses in the Combined Authority), it could also be a consultation with affected parties and formal agreement with the LEP (i.e. not subject to a vote of affected parties).

6.4.2 Council Tax Precept

6.4.2.1 Context

The council tax precept consists of a levy in addition to the current council tax rate which would be retained locally and used to fund Bristol's metro system. It is understood that WECA do not currently have the power to raise a council tax levy under the current Devolution Deal, however, this power may be provided in a future deal, which would likely fall within the timescales of the Metro. Alternatively, a proportion of the growth in council tax could be allocated to the Metro to create this funding stream.

6.4.2.2 Assumptions

The table below sets out the main assumptions made for a council tax precept collection.

Table 6.4: Council Tax Precept Key Assumptions

Item	Assumption	Rationale / Notes
Average council tax rate	Band D	Average Band of council tax rate
Precept rate:	2%	This is comparable with the Olympic council tax levy and the cap on annual council tax growth
Collection rate:	98%	Average current collection rate across local authorities in 2017/2018
Proportion of council tax precept allocated to the metro:	100%	Assumed levy would be introduced to support the Metro and therefore would be fully allocated to project
Geography applied to:	Bath & North East Somerset, Bristol, South Gloucestershire and North Somerset	Aligns with authorities within the West of England



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A council tax precept of 2% is assumed, which equates to a £26-£31 annual increase in council tax charge to a Band D house. This compares to a £20 levy introduced in 2006 in Greater London to support the 2012 Olympic Games.

The council tax precept has been estimated from two alternatives:

- A precept on the 2017/18 residential properties in each local authority
- A precept on the forecast increase in residential properties over the next 25 to 30 years

The precept on the 2017/18 residential properties is based on official government statistics on council tax receipts by authority available from the *Department for Communities and Local Government*²¹. While the council tax precept collected through new residential properties was calculated from the forecast increase in residential properties over the next 25 to 30 years in the *Joint Spatial Plan, Infrastructure Position Statement* from 2015. An uplift on residential developments has been modelled due to the potential higher densities a Metro could support.

The implementation costs for a council tax precept have been assumed to be negligible as it is an extension of current practises.

6.4.2.3 Results

The table below outlines the funding income that could be generated over a 25 year or 30-year period under the mid development growth and under an uplift in development growth due to the Metro.

Table 6.5: Council Tax Precept Funding Potential

Scenario	Funding Potential; £m; Real 2017/18	
	Mid Development Growth	Uplift Development Growth
25-year Period	Exiting residential: £249m	Exiting residential: £249m
	New residential: £39m	New residential: £47m
	Total: £288m	Total: £297m
30-year Period	Exiting residential: £299m	Exiting residential: £299m
	New residential: £56m	New residential: 69m
	Total: £355m	Total: £367m

6.4.3 Community Infrastructure Levy (CIL)

6.4.3.1 Context

The CIL is a development levy that local authorities can introduce on residential and commercial developments to help fund the delivery of infrastructure projects. Currently CIL is charged on residential developments in all the four authorities: Bath & North East Somerset, Bristol, South Gloucestershire, and North Somerset. CIL is currently only charged on commercial developments (excl. retail) at 'prime locations' in South Gloucestershire and is not charged in the other authorities²².

²¹ <https://www.gov.uk/government/statistics/council-tax-levels-set-by-local-authorities-in-england-1.2017-to-2018>

²² http://www.bathnes.gov.uk/sites/default/files/sitedocuments/Planning-and-Building-Control/Planning-Policy/CIL/cil_draft_charging_schedule_revised.pdf
<https://www.bristol.gov.uk/documents/20182/33588/CIL+Charging+Schedule.pdf>
<https://www.southglos.gov.uk/documents/CIL-charging-schedule.pdf>
<https://www.n-somerset.gov.uk/wp-content/uploads/2015/11/CIL-charging-schedule-1.pdf>



CIL funding could be used to support WECA Underground Metro either by increasing the current CIL rates (and allocating this increase to support the Metro) or by allocating a proportion of the CIL income under the current charging rates to the authority. It is understood that CIL income under the current charging rates is likely to be allocated to other infrastructure projects and therefore have considered increasing the current CIL rates to support the Metro.

6.4.3.2 Assumptions

The table below outlines key assumptions used to model the potential funding from CIL.

Table 6.6: Community Infrastructure Levy Key Assumptions

Item	Assumption	Rationale / Notes
Additional CIL charge:	Additional charge of £25 / m ² for both residential and commercial developments	Based on the Bristol CIL Viability Study
Geographies applied to:	Bath & North East Somerset, Bristol, South Gloucestershire and North Somerset	Aligns with authorities within the West of England
Payment type:	One off payment	Aligned with legislation and charging schedules
Proportion of council tax precept allocated to the metro:	100%	Assumed levy would be introduced to support the Metro and therefore would be fully allocated to project

Increasing the residential CIL charge by £25 / m² would increase the average CIL charge to between £75 - £100 / m² in the four local authorities. This is comparable with the Maximum viable CIL rate in the Bristol CIL Viability Study which identified that a levy of between £90-£130 / m² would not impact on development and is less than half CIL charges seen in London (e.g. Southwark charge £200 / m² for residential developments in their mid-value zones).

As noted above, the commercial CIL rate is primarily £nil across the four local authorities. The additional charge on commercial properties of £25 / m² has been included but only in the Optimistic funding scenario.

As with the Business Rate Supplement, forecasts of commercial developments over the next 25 to 30 years was based on the *Economic Development Needs Assessment* from 2015 while as with the Council Tax Precept, forecast of residential developments was based on the *Joint Spatial Plan, Infrastructure Position Statement* from 2015. As previously, an uplift on residential developments due to the potential higher densities that could be supported by the Metro has been modelled.

Note, it is assumed that the increase to the CIL charge is not significant enough to impact the viability of developments in the West of England and therefore the forecast level of development is not impacted by the change in CIL rate.

6.4.3.3 Results

The table below outlines the funding income that could be generated over a 25 year or 30-year period under the central development growth and under an uplift in development growth due to the Metro.



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Table 6.7: Community Infrastructure Levy Funding Potential

Scenario	Funding Potential; £m; Real 2017/18	
	Mid Development Growth	Uplift Development Growth
25-year Period	Resi: £211m; Com: £97m; Total: £308m	Resi: £257m; Com: £97m Total: £354m
30-year Period	Resi: £354m; Com: £117m; Total: £370m	Resi: £308m; Com: £117m; Total: £425m

6.4.4 Road Pricing

6.4.4.1 Context

Road Pricing consists of a charge to all road users within a defined zone. Alongside creating a funding stream for the Metro, it would support travel demand management by encouraging modal shift from private car and support the introduction of clean air zones in the city. The implementation of road pricing has historically met opposition from the public, notably in Manchester in 2008. Furthermore, the costs to implement and operate a road pricing scheme are significant.

6.4.4.2 Assumptions

The following table shows the main assumptions made for Road Pricing in the West of England.

Table 6.8: Congestion Charge Key Assumptions

Item	Assumption	Rationale / Notes
Charge	£3/day; £750/year	Indicated in the Joint Transport Study – Options for Fiscal Measures Draft Report
Implementation costs	55% of gross revenue	Indicated in the Joint Transport Study – Options for Fiscal Measures Draft Report
Proportion allocated to the metro:	100%	Assumed levy would be introduced to support the Metro and therefore would be fully allocated to project
Geographies considered:	Central Bristol and Central Bath	Assumed the road pricing would only be implemented within the central regions of cities

The Road Pricing funding estimate is primarily based on the *WoE Joint Transport Study* entitled *Options for Fiscal Measures*. Funding from a Road Pricing scheme in the city areas of Bristol and Bath has been estimated.

6.4.4.3 Results

The following table shows the funding potential for Road Pricing over a 25 year or 30-year period.

Table 6.9: Road Pricing Funding Potential

Scenario	Funding Potential; £m; Real 2017/18
25-year Period	£578m
30-year Period	£693m



6.4.5 Highway England Contribution (Shadow Toll)

6.4.5.1 Context

The introduction of WECA Underground Metro will lead to significant modal shift from road to rail, reducing road demand into Bristol and the surrounding area. This may prevent the need to further upgrade A-roads and motorways to cater for future growth in road demand (e.g. adding an additional lane or converting a motorway into a smart motorway). Due to this future cost saving, there may be the potential for Highways England to reallocate funding for the road upgrades in the surrounding area to support WECA Underground Metro. This approach has been discussed recently as a way to deliver a more integrated transport strategy and has been considered by Highways England where costs to deliver increased capacity beyond the current national 'smart motorway' programme would be exorbitant.

The application of this funding source would need to be negotiated and agreed with Highways England. Evidence illustrating the potential modal shift from road would support this process alongside a mechanism that shared risk on the level of modal shift between Highways England and the authorities. For instance, contributions could be based on the level of road traffic against a baseline without the Metro.

6.4.5.2 Assumptions

The following table shows the main assumptions made for Road Pricing in the West of England.

Table 6.10: Highway England Contribution Key Assumptions

Item	Assumption	Rationale / Notes
Cost of upgrading to smart motorways	£23m per lane mile	Based on estimate of upgrading the M4 to a smart motorway
Cost of an additional lane to a A-road	£7m per lane mile	Based on the estimate of an additional lane to the A303.
Length of motorway prevented from requiring upgrade	13 lane miles	Length of motorway adjacent to Metro alignment
Length of A-roads prevented from requiring upgrade	34 lane miles	Length of A-roads adjacent to Metro alignment
Proportion allocated to the metro:	50%	Assumed half of HE savings could be allocated to Metro

In addition to the savings on road upgrades, there would also be a marginal saving on road maintenance as there would be fewer lanes to maintain. This estimate has been included in our analysis, however the impact is minimal.

6.4.5.3 Results

The following table shows the funding potential for the Highway England Contribution, which is independent of the period considered.

Table 6.11: Highway England (Shadow Toll) Funding Potential

Scenario	Funding Potential; £m; Real 2017/18
25 to 30-year Period	£273m



6.4.6 Workplace Parking Levy (WPL)

6.4.6.1 Context

A workplace parking levy consists of a charge on businesses within a defined administrative boundary, based on the number of workplace parking places they provide. Local authorities have the power to introduce a WPL in their district where any scheme must be confirmed by the Secretary of State. A WPL is currently in operation in Nottingham where, in 2016/17, £9.4m was generated based on an annual charge of £379. The charge increases annually in line with RPI.

Alongside creating a revenue stream to support the Metro, a WPL incentivises modal shift, effectively increasing the demand for public transport and therefore ridership and farebox of the Metro. A WPL can also shift land uses away from off-street parking and into additional development, which is likely to have further beneficial economic and financial benefits to local authorities, offsetting any loss of car parking revenue.

It should be noted that WECA do not currently have the powers to raise Business Rate Levy but will be seeking these powers in the near future.

6.4.6.2 Assumptions

The following table shows the main assumptions made for a WPL in the West of England.

Table 6.12: Highway England Contribution Key Assumptions

Item	Assumption	Rationale / Notes
Cost of parking license in City Centres (per space per annum)	Lower Scenario: £750 Higher Scenario: £1,250	A £750/£1,250 annual charge equates to £3/£5 per day. The higher rate of £5 per day is still well below commercial parking rates in the Bristol area.
Cost of parking license in Outer City areas (per space per annum)	Lower Scenario: £375 Higher Scenario: £750	A £375/£750 annual charge equates to £1.50/£3 per day.
Number of parking spaces	Bristol: 38,500 Bath: 4,500 North East Fringes: 35,500	Average number of parking spaces in the Joint Transport Study – Options for Fiscal Measures Draft Report
Proportion of spaces exempt from charge	20%	Based on the Joint Transport Study – Options for Fiscal Measures Draft Report
Implementation costs	£10m initial set up; operating costs 10% of revenue	Based on the Joint Transport Study – Options for Fiscal Measures Draft Report
Proportion allocated to the metro:	100%	Assumed levy would be introduced to support the Metro and therefore would be fully allocated to project

The introduction of a WPL may lead to a reduction in workplace parking spaces where businesses look to reduce the charge they are obligated to pay. Conversely, the growth in commercial properties in WoE may increase workplace parking as new developments include parking provision. As a simplifying assumption, it is assumed that these factors have a net nil impact and that the level of workplace parking spaces remains constant over time.

6.4.6.3 Results

The following table shows the funding potential for a WPL over a 25 and 30-year period and under the 'lower sceanrio' and 'higher scenario' charging structure outlined in Table 6.12.


Table 6.13: Workplace Parking Levy Funding Potential

Scenario	Funding Potential; £m; Real 2017/18	
	Lower Charge	Higher Charge
25-year Period	£628m	£1,194m
30-year Period	£756m	£1,435m

6.4.7 Local Tax Retention

6.4.7.1 Context

In October 2015, the Chancellor of the Exchequer announced that by the end of 2020, 100 per cent of business rates income would be devolved to local government and core grant funding via revenue support grant would end. In addition, local authorities will be permitted to reduce the non-domestic rating multiplier in their areas.

WECA is one of the pilot areas for the scheme and from 1 April 2017 will retain 100% of business rates but forego the Revenue Support Grant. This will have a neutral impact initially; however, it will allow the local authorities to retain any growth in business rates.

The impact of capturing the uplift in local business rates and council tax from future development has been considered in funding the WECA Underground Metro. It is noted that a proportion of the increase in tax receipts from council tax and business rates will be needed to support the services provided by the authorities for the growing population. However, a proportion of the retained tax receipts from council tax and business rates could be allocated to the Metro. For instance, the 2017 London Finance Commission report suggests that a share of future increases in local taxes should be set aside to fund transport and other public infrastructure.

6.4.7.2 Assumptions

The following table shows the main assumptions for local tax retention in the West of England.

Table 6.14: Local Tax Retention Key Assumptions

Item	Assumption	Rationale / Notes
Geography applied to:	Bristol, South Gloucestershire and Bath and North East Somerset	Aligns with the local authorities in WECA where BRR occurs
Proportion of BRS allocated to Metro:	20%	Assumed the majority of tax increase will be required to support the services provided by the authorities

The local tax retention estimate is driven by forecast development where residential estimates and commercial estimates were taken from the 'Economic Development Needs Assessment' and the 'Joint Spatial Plan, Infrastructure Position Statement' from 2015.

6.4.7.3 Results

The following table shows the funding potential if 20% of the increase in council tax and business rate receipts are retained over a 25 and 30-year period under the central development growth and under an uplift in development growth due to the Metro.



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Table 6.15: Local Tax Retention Funding Potential

Scenario	Funding Potential; £m; Real 2017/18	
	Mid Development Growth	Uplift Development Growth
25-year Period	£761m	£845m
30-year Period	£1,096m	£1,217m

6.5 Funding Scenarios

As discussed above, an effective funding strategy for the Metro should look to target the beneficiaries of the scheme where the funding contribution by beneficiary should aim to be proportional to the benefits received.

With this objective, the short-listed funding options is arranged into a series of funding scenarios that aim to target each of the beneficiaries of the scheme without overcharging an individual beneficiary.

The funding scenarios are summarised below:

Table 6.16: Summary of Funding Scenarios

Scenario	Period of Funding	Include Development Uplift	WPL Charging Scenario	CIL Charge	Funding Source Included?						
					BRS	HEC	WPL	CTP	CIL	RP	LTR
Mid	25 years	No	Central	Resi only	✗	✓	✓	✓	✓	✗	✗
Mid (alternative)	25 years	No	n/a	Resi only	✓	✓	✗	✓	✓	✗	✗
Optimistic	30 years	Yes	High	Resi and comm	✗	✓	✓	✓	✓	✗	✗
Optimistic (alternative)	30 years	Yes	Central	Resi and comm	✗	✓	✓	✓	✓	✓	✗
Local Tax Retention	30 years	Yes	High	n/a	✗	✓	✓	✓	✗	✗	✓

Mid Scenario. This scenario assumes: a 25-year period; no uplift in development due to the Metro; the mid charging structure for WPL; an increase in CIL on residential only; and funding contributions from Highway England, a Workplace Parking Levy, a council tax precept and a community infrastructure levy.

Mid Scenario (alternative). This scenario is an alternative mid scenario where a Business Rate Supplement is implemented as opposed to a Workplace Parking Levy. Both of these funding options target businesses and as such are unlikely to be implemented together to prevent a single beneficiary being charged twice.

Optimistic Scenario. This scenario assumes the same funding sources are implemented as the Mid scenario but increases the period of funding to 30 years, increases the WPL charging rate to the 'high' charging structure and includes an increase in CIL on residential and commercial developments.



Optimistic Scenario (alternative). This scenario is an alternative to the Optimistic scenario where a Road Pricing is introduced as opposed to increasing the WPL charging structure.

Local Tax Retention. This scenario is based on retaining and allocating a proportion of council tax and business rates from new developments towards the Metro. It is combined with contributions included in the Mid Scenario including from, Highway England, a Workplace Parking Levy and a council tax precept.

6.6 Results

Figure 6.1 below outlines the funding contribution under each of the funding scenarios in real 2017/18 prices compared to the capital costs of £3,320m. While Figure 6.2 shows the total funding generated as a proportion of the schemes capital costs.

These illustrate that the funding in the Mid Scenario achieves over 40% of the capital costs while the Mid (alternative) scenario achieves just over 35%. This is due to the BRS generating £158m less funding than the WPL.

The funding contribution increases to more than 75% of the capital costs of the scheme in the two Optimistic scenarios. This illustrates that the increase in funding generated from the 'high' WPL charging structure is estimated to generate a very similar level of funding to the introduction of Road Pricing in the centre of Bristol and Bath.

The Local Tax Retention option is shown to have the potential to generate significant funding where £1,217m funding is estimated to be generated under the assumption that 20% of the retained uplift in council tax and business rates is allocated to the Metro. Combining this with a contribution from Highways England, a Workplace Parking Levy and a council tax precept has the potential to generate 100% of the capital costs (excl financing costs and optimism bias) of the Metro.

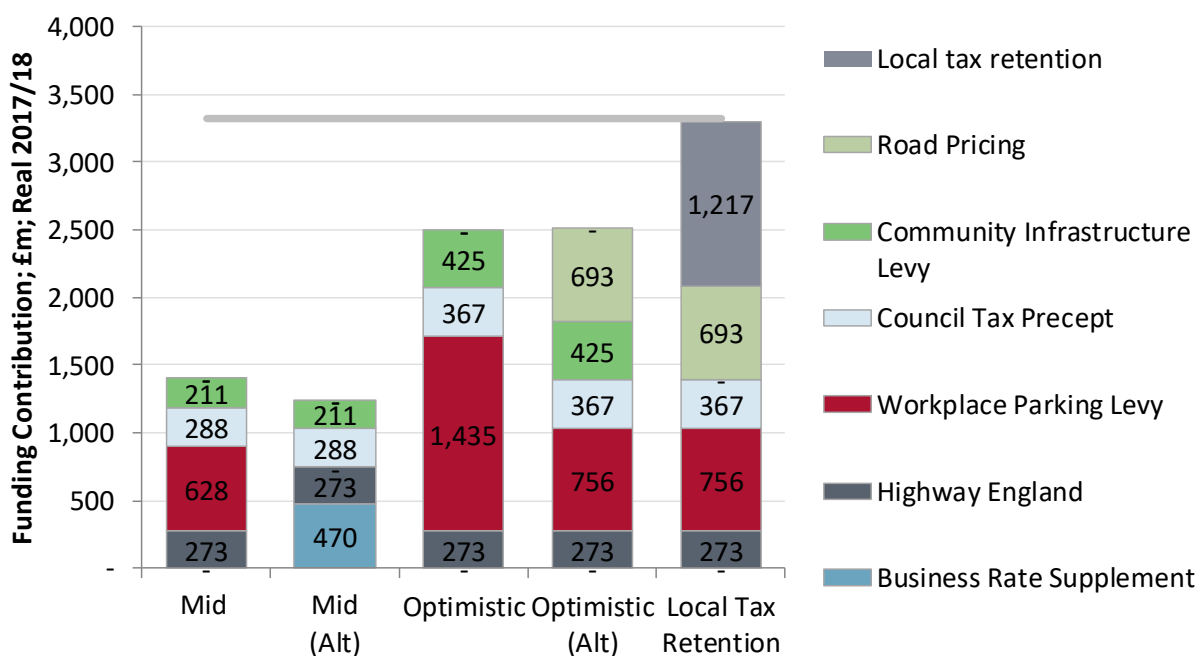


Figure 6.1: Funding Contribution by Funding Scenario



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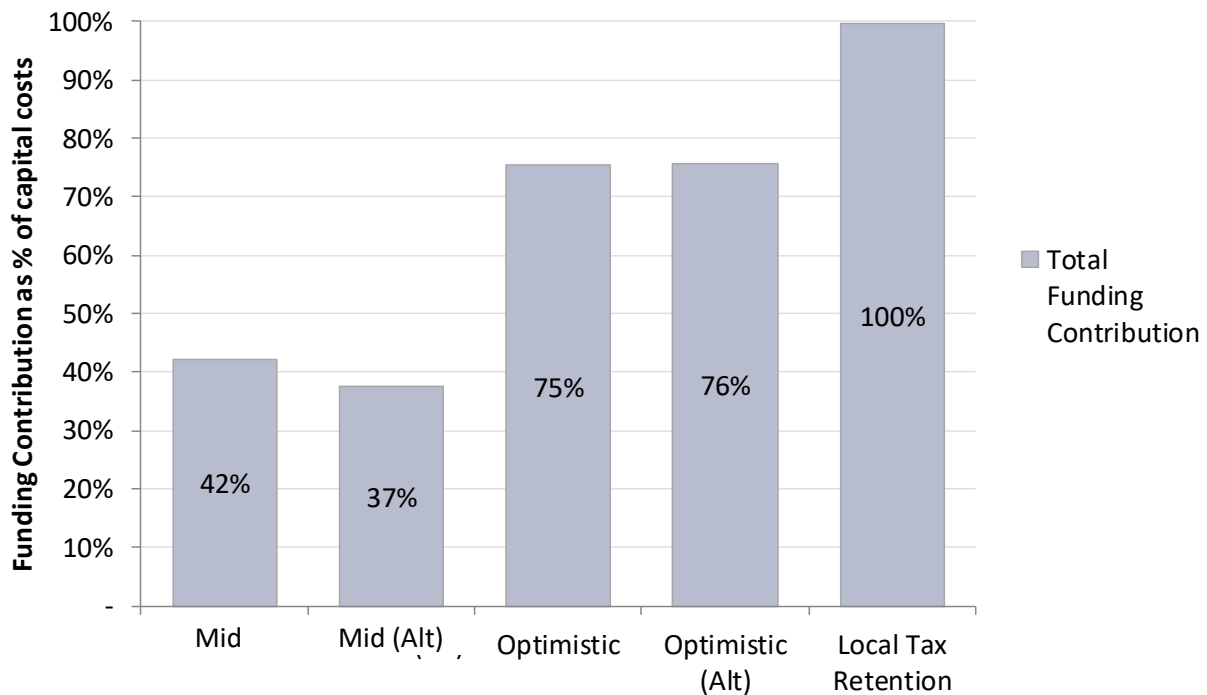


Figure 6.2: Funding Contribution as proportion of capital costs

6.7 Conclusions and Next Steps

6.7.1 Conclusion

As central government funding has become increasingly constrained, the ability to generate revenues locally is having a greater influence on whether a scheme is taken forward. In addition, devolution has focused decision making on seeking local beneficiaries of a scheme for investment. It is therefore important to utilise the powers available to local authorities and combined authorities to create funding strategies that capture benefits of the scheme, generating local funding to support transport infrastructure.

Regarding WECA Underground Metro, the following local funding options have been short-listed from a long list of options as being the most attractive in securing support. These have taken into consideration the likely beneficiaries of the Metro and the powers available to WECA:

- Business Rate Supplement;
- Council Tax Precept;
- Community Infrastructure Levy;
- Road Pricing;
- Workplace Parking Levy; and
- Local Tax Retention (business rates and council tax)



These local funding options were arranged into a series of funding scenarios with the objective of targeting beneficiaries of the scheme without overcharging individuals. It was estimated that between 35% and up to 100% of the capital requirement of the Metro (excl. financing costs or Optimism Bias for capital costs) could be generated from various combinations of these local funding options.

6.7.2 Next Steps

The next steps are to narrow the short-listed funding options to form a preferred funding strategy for the Metro. This process should include:

- Consultation with the various local public and private bodies to gauge views on funding options
- Gathering material/evidence to aid with consultation, such as an assessment of the wider economic benefits of the project to illustrate the widespread benefits of the Metro
- Understanding the level of local grant and central grant that could support the Metro and the requirements to receive this funding

In relation to consultation, many of these funding options are subject to support/agreement from public or private bodies. For instance:

- For WECA to introduce a council tax levy, power needs to be granted through a government deal with support from the local authorities within WECA and government
- For WECA to introduce a BRS, agreement from the local business community is required through the local enterprise partnership as well as government support
- The allocation of council tax and/or business rates from new development to the Metro will need to be agreed with local authorities
- An increase to the CIL charging rate will need to be agreed with the respective charging authority

Consulting with these various public and private bodies will help to filter the funding options/scenarios presented above to identify the most feasible funding strategy.

Furthermore, preparing and presenting evidence that illustrates the benefits from the Metro during this consultation will increase the chance of support for the scheme. For instance, when introducing a BRS in London, a wider economic benefits assessment of Crossrail was undertaken to demonstrate that the benefits received by businesses in each borough was greater than the support being they would provide.

Finally, understanding the availability of local and central grant funding would clarify the level of local third-party funding that would be required. Again, using evidence to illustrate how the grant funding could leverage third party funding for the Metro and unlock economic benefits would be a powerful message.



SECTION 7

Conclusions and recommendations

7.1 Introduction

CH2M and Steer Davies Gleave have been commissioned to undertake a pre-feasibility study to explore the viability of light underground Metro options, such as light rail systems, in the Bristol region. The study has captured the expected costs, benefits and funding opportunities for the WECA region.

The report is intended to inform Bristol City Council, as the Lead Authority, along with other Local Authorities and WECA of whether this form of transport is a viable option to be considered further as part of a wider and more detailed assessment of rapid transit route options for the various corridors

7.2 Technology

Current indicative demand estimates for the proposed WECA Underground Metro suggest that the planning capacity for the system should be about 3,000 passengers per hour per direction. This fits within the capacity of bus-based systems but will require higher frequency or high capacity systems, but that many of the other modes considered have potentially much higher capacities. These modes can also operate at lower capacity. Personal Rapid Transit is a mode which could ultimately operate across the general road network as a form of autonomous vehicle. But in its present form its capacity is too low to be appropriate for Bristol. However, it is assumed that bus based systems (unless using an emission-free power source) are not appropriate for underground operation.

Cambridge AVRT is a proposed mode which is very different from the others. The proposed system of individual shuttles, with multiple enforced transfers, limited numbers of stations and longer 'first/last mile' links could make the system less attractive to passengers. In particular, the AVRT concept is not compatible with the indicative routes and station locations identified for the WECA Metro.

The other technologies considered have some common features – all feature wheeled vehicles with mechanical guidance and capable of operation as single vehicles or in trains of coupled vehicles. Whilst these different modes have developed separately and have their own characteristics, most of these are not inherent to the mode.

For a given line capacity requirement there is a trade-off between the capacity of individual trains and the frequency of service. With driver-operated trains this has typically tended to favour the use of relatively high capacity trains running at relatively low frequency to reduce the driver costs – one of the largest components of a system's operating costs. For underground systems, this effect is tempered by the need to provide more costly, larger underground stations to accommodate the longer trains. It should be noted that the rolling stock requirement is independent of this balance – it is simply a matter of whether there are many small trains or fewer large trains. The implications for the capital and non-staff operating costs of the trains are therefore small.

Automatic operation is already a feature of many mass transit systems which are fully segregated. With the use of automatic operation, some staff costs are avoided. This favours the use of more frequent smaller trains on a new-build system.

The sizing of stations, particularly underground stations, is determined by capacity needed for normal operation and emergency situations. For normal operation, the length of platforms required is determined by the longest trains using the system. The rest of the infrastructure is sized based on



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passenger throughput, subject to minimum requirements. For a typical underground station, the minimum requirement will comprise one set of up escalators, one set of down escalators and at least one lift from ground level to each platform. The capacity of this minimum provision will be sufficient to meet the demand at many (if not all) stations, and hence will determine the size of the station access infrastructure.

Use of more frequent, smaller trains also results in a more even flow of arriving passengers, compared with larger, less frequent trains where the arriving passenger flow will come in waves. This makes better use of the station access infrastructure, and reduces congestion in the station, providing better conditions for passengers.

Most mass transit modes have a passenger capacity of 6-7 passengers per metre length of vehicle. Thus, for a planning capacity of 3,000 passengers per hour, the system will need to deliver a service with an aggregate vehicle length of around 450m per hour. This could be supplied by different combinations of vehicle lengths and headways (e.g. 20m vehicles at 2.5 minute headway or 60m vehicles at 8 minute headway).

7.3 Route and capital Costs

7.3.1 Cost summary

Costs have been divided into the following 13 areas and calculated for the three lines.

Item	A38 North - Aztec West Estimate Cost (m)	A420 - Emersons Green Estimate Cost (m)	South Bristol - Airport Cost (m)	Average Cost %
Below Ground Stations	£284.0	£284.0	£182.0	23%
Above Ground Stations	£31.0	£24.0	£38.0	4%
Intermediate Shafts	£25.0	£25.0	£25.0	3%
Crossover Box	£20.0	£20.0	£20.0	2%
Running Tunnels	£266.0	£272.0	£268.0	28%
Tunnel Cross Passages	£18.0	£18.0	£18.0	2%
Portals	£13.0	£13.0	£13.0	3%
Earth Structures	£6.0	£6.0	£11.0	2%
Bridges	£6.0	£7.0	£14.0	2%
Trackwork	£51.0	£55.0	£59.0	7%
Linewide Systems	£80.0	£86.0	£90.0	10%
Depot	£50.0	£50.0	£50.0	6%
Rolling Stock	£80.0	£80.0	£60.0	7%
Total	£930m	£940m	£848m	



All prices include 'Oncosts' which cover the Contractor's head office and profit, insurance etc. With an assumed additional 10% for land costs and 10% for client costs, including initial design work, the full scheme price is approximately £1.1bn per line:

- A38 North - Aztec West Estimate = £1.13bn Cost per km = £90.0m
- A420 - Emersons Green Estimate = £1.14bn Cost per km = £84.3m
- South Bristol - Airport Estimate = £1.05bn Cost per km = £65.6m

Contingency of approximately 30% should be added to the costs at this stage of the project. This implies the project may need to have a budget allocated of £4.3bn:

- A38 North - Aztec West Estimate = £1.46bn
- A420 - Emersons Green Estimate = £1.48bn
- South Bristol - Airport Estimate = £1.36bn

These costs could be reduced through value engineering including removing some stations or potentially reducing the length of tunnelling,

7.3.2 Further Work

Although it is considered that this study presents a reasonable estimate for costs at this stage of the project, it is recognised that further work needs to be undertaken in several areas to obtain a more accurate cost estimate, particularly in terms of costs for rail systems and rolling stock. Specifically, the following costs have not been considered in any detail as part of this exercise:

- The routes were based on an initial desktop study to identify indicative alignments and typical station spacing. Detailed work t
- Above ground station design
- Removal and disposal of excavated material
- Works to infill mine voids
- Lengths and designs of bridges and earth structures
- VAL trackwork requirements and systems
- Noise mitigation/barriers or ground borne noise and vibration mitigations
- Land costs and redevelopment value
- Depot location and design
- Value engineering initiatives

During a subsequent feasibility study it is recommended that costs are built up by taking dimensions and using detailed agreed rates. In addition, stations should be designed individually, but maintain commonalities in design for efficiency and to create a unified image for the metro.



7.4 Demand and Value for Money

7.4.1 Demand and revenue

Annual demand generated by the Metro is estimated at 35.5m trips, with 11.6m transferring from other public transport, 12.4m transfer from cars, 3.5m are park & ride users and 8m trips relate to Bristol Airport. Sensitivity tests reflect potential interventions that may take place alongside the construction of the Metro system. A downside test has also been considered, which examines the effect of a lower assumed transfer rate from car. The sensitivities show that the range estimates of demand for WECA Underground Metro are in the range of 29m to 53m trips per annum. The demand forecasts are clearly high level at this stage, so a sensible range estimate to use at this stage would be a 'mid' estimate of 35m trips per annum, 'low' case of 25m trips per annum and 'high' case of 50m trips per annum.

Benchmarking analysis shows that demand is lower than London schemes (DLR and Croydon Tramlink) but higher than other (non-London) UK systems. The trip rates (demand per stop and per route km) are typically higher for many European mass transit schemes, such as the VAL system that operates in Toulouse and Lille. The higher trip rates for VAL are likely to reflect the greater concentration of economic activity in the city centre and the higher density of residential development along transit corridors, and point towards the potential demand that Bristol could achieve if a pro-active policy of transit oriented development were pursued.

Assuming an initial metro fare of £2.00 (with premium fares for trips from/to Bristol airport), generates the revenue of £103.1m for the mid scenario, £72.5m for the low scenario and £145.0m for the high scenario. Mid operating costs are £30m for LRT, £40m for light underground type operation, it is considered that the system has the potential to cover its operating costs; more work, including detailed financial modelling, is required to confirm this assumption.

7.4.2 Value for money assessment

A Value for Money assessment has been undertaken on the mid, high and low scenarios based on the benefits and costs calculated. Benefits include transport user benefits, non-user benefits (externalities) and wider economic impacts (agglomeration, labour supply and imperfect markets). In addition, dependent development and land value uplift has also been considered. The assessment is summarised in the table below.

Economic Appraisal	Mid Scenario	Low Scenario	High Scenario
Public Value of Benefits (PVB)	£3,410m	£2,399m	£4,797m
PVB including WEI	£4,774m	£3,358m	£6,716m
Public Value of Costs (PVC)	£3,776m	£4,096m	£3,337m
Net Present Value (NPV)	-£365m	-£1,697m	£1,460m
NPV including WEI	£999m	-£738m	£3,379m
Benefit Cost Ratio (BCR)	0.90	0.59	1.44
BCR including WEI	1.26	0.82	2.01



The preliminary VfM performance, with Wider Economic Benefits, would deliver a benefit-cost ratio of between 1.3:1 and 2.0:1. This suggests there may well be a value for money case for the scheme.

Note that, although Land Value Uplift has the potential to enhance the VfM performance further, DfT guidance is clear that LVU cannot be added to the BCR. Notwithstanding this, if WECA Underground Metro were to enable, for example, 10,000 additional dwellings, this could deliver a land value uplift of around £300m. There is also a potential land value uplift associated with the higher density and more intensive development of commercial land used in the corridors and the city centre.

7.5 Funding

The following local funding options have been short-listed for WECA Underground Metro from a long list of options as being the most attractive in securing support. These have taken into consideration the likely beneficiaries of the Metro and the powers available to WECA:

- Business Rate Supplement;
- Council Tax Precept;
- Community Infrastructure Levy;
- Road Pricing;
- Workplace Parking Levy; and
- Local Tax Retention (business rates and council tax)

These local funding options were arranged into a series of funding scenarios with the objective of targeting beneficiaries of the scheme without overcharging individuals. It was estimated that between 35% and up to 100% of the capital requirement of the Metro (excl. financing costs or Optimism Bias for capital costs) could be generated from various combinations of these local funding options.

The next steps are to narrow the short-listed funding options to form a preferred funding strategy for the Metro. This process should include consultation with the various local public and private bodies to gauge views on funding options, gathering material/evidence to aid with consultation, and understanding the level of local grant and central grant that could support the Metro and the requirements to receive this funding. Note that, in relation to consultation, many of these funding options are subject to support/agreement from public or private bodies. Consulting with various public and private bodies will help to filter the funding options/scenarios presented above to identify the most appropriate funding strategy.

Preparing and presenting evidence that illustrates the benefits from the Metro during this consultation will increase the chance of support for the scheme. Understanding the availability of local and central grant funding would clarify the level of local third-party funding that would be required.

7.6 Next steps

The conclusion of this study is the WECA Underground Metro should be included as part of the wider WECA Metro Study which will fully assess all options when considering the wider Metro network identified in the JSP.

It should be noted that routes were based on an initial desktop study to identify indicative alignments and typical station spacing. Detailed work will be required to identify route lengths, station numbers and percentage of underground/overground running.



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Should this proposed mode prove to offer greater benefits than other modes, to fully understand the engineering challenges, explore the funding options and clarify the legal and legislative requirements to implement a system, a full feasibility study is recommended. This should include a Geotechnical survey to provide a better understanding of the ground conditions along the proposed corridors. It should be understood that a significant proportion of proposed corridor will be under existing properties and therefore full invasive investigation will not be possible but selective samples will provide a better understanding of ground conditions.

It is likely that engagement will be required with manufacturers and operators of existing systems to gain a better understanding of construction and operating issues.

Availability of land to construct portals, station access and ventilation facilities will need to be identified and potentially secured through the planning process.