B.7.9 Summary of Scheme Impacts on Cultural Heritage

Some 86 sites of archaeological, cultural and historical significance have been identified as directly affected by the construction and permanent development of the scheme, lying either in the swept path or buffer zone. A total of 316 listed buildings are predicted to have their setting affected, of which 78 are directly affected.

The 86 directly affected sites comprise:

- 16 sites of national importance;
- 20 sites of regional importance;
- 27 sites of local importance;
- 23 sites of little or no importance.

Of the 16 sites of national importance, the only Scheduled Ancient Monument is the Victoria Bridge in Leith Port. Of the remaining 15 sites of national importance (all in the buffer zone), all but Site 73 are railings, gatepiers and lamp standards associated with Category A Listed buildings. The significance of impact to all 16 of these sites is described as 'major adverse'.

The 20 sites of regional importance comprise:

- Site 3 – Roseburn Railway Bridge;
- Site 22 - proximity to where bronze age cists were found in 1846;
- Site 28 - Police box, Pier Place, Newhaven;
- Site 31 - Victoria Dock: sandstone dock and iron bollards;
- Site 34 - Alexandra Dry Dock hydraulic station;
- Sites 39 & 49 - proximity to 1560 fortifications (buried archaeology);
- Site 40 – Statue of Robert Burns;
- Sites 41-47 (inc), 51, 76& 84 – Iron railings, gatepiers and boundary; walls associated with Category B Listed Buildings;
- Site 50 – Statue of Queen Victoria;
- Site 81 – Police box, West Princes Street Gardens.

The 27 sites of local importance comprise:

- 20 non-listed structures (including the clock at London Road which will require relocation and the statues in Picardy Place);
- 1 site with proximity to potential buried archaeology (Site 48);
- 1 site with proximity to the Caroline Park designed landscape (Site 17);
- 5 Category C(S) Listed Buildings, or part thereof

The 23 sites of little or no importance comprise:

- 3 sites of historic street furniture associated with Category C(S) Listed Buildings;

- 13 sites of historic street furniture not associated with Listed Buildings;
- 3 boundary structures;
- 4 sites associated with Leith Docks.

Three sites are to be demolished, all of local importance. These are:

- The Caledonian Alehouse (Category C(S) Listed Building);
- Heart of Midlothian War Memorial (Category C(S) Listed Building -which may be relocated);
- Bridge, Groathill Road South (Not listed).

The Coltbridge Viaduct is to be modified to such an extent that the impact has been defined as partial demolition. Although not listed, this bridge lies within the Coltbridge and Wester Coates Conservation Area. A summary of the predicted impact categories is presented in *Table B.23*.

Table B.21 Summary of Cultural Heritage Impact Categories

	National importance	Regional importance	Local importance	Little or no importance
Major adverse impact	16	1	-	-
Moderate adverse impact	-	7	2	-
Minor adverse impact	-	12	24	23

The majority of sites (66 out of 86) have a suggested Level 1 mitigation response (detailed photographic record). A high proportion of such sites comprise historic street furniture in the buffer zone, most of which are unlikely to suffer physical impact during the works, but preventive measures should be considered to avoid damage, particularly where the features form part of Listed Buildings.

Thirteen sites are recommended for Level 2 mitigation (detailed standing building survey). This higher level of survey has been suggested due to the physical impact on such sites expected as a result of engineering works.

Level 3 mitigation (watching brief) is suggested for five sites. This includes the part of the route believed to pass through the Caroline Park designed landscape. However, it seems likely that some of this area has been rendered archaeologically sterile by modern development. The other four sites are areas of archaeological potential.

The two sites recommended for Level 4 mitigation (Detailed standing building survey and salvage) are both at Haymarket. This level of survey is deemed necessary unless it is found by detailed design that the demolition of the C(S) Listed Caledonian Ale House and the dismantling and relocation of the C(S) Listed Heart of Midlothian War Memorial can be avoided.

B.7.10 References

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Appendix C: Operations

C.1 General

This Appendix sets out the key elements and assumptions regarding system operations for Edinburgh Tram Line 1, as background to the appraisal. This section covers:

- Run time estimates;
- Provision of turnback facilities;
- Service patterns;
- Frequencies;
- Revenue system;
- Depot (operational issues); and
- Operating and maintenance costs.

The successful bidders for the operating concession will need to satisfy themselves that the proposed services and methods of operation are feasible and represent a sound basis for the operation of the system. While the basic parameters of the service will be specified by the promoters, some of the more detailed elements of the planning, design and operation of the system will be for the concessionaire to establish. The details of the methods of operation set out here should therefore not be regarded as a fixed specification but as series of working assumptions to demonstrate feasibility and provide the basis for appraisal.

C.2 Run Times

C.2.1 Background and Objectives

The single overarching objective from the operational viewpoint is to minimise journey times, so as to maximise the attractiveness of the service and minimise operating costs and rolling stock resources. This requires attention to:

- Vehicle performance;
- Running speed between stops;
- Stop dwell times; and
- Traffic signal delays.

Vehicle performance is not generally a major issue as the limiting factor on acceleration and braking is normally passenger comfort. Running speed between stops is important but provided the tram can operate free of obstruction by other traffic, the actual speed limit is not critical when there are frequent stops. In general tram speeds are governed by the speed limit on the adjacent highway, although a higher limit may be possible where the route is fully segregated. The key is to achieve free flow wherever possible so that the running speed is the maximum safe speed for any particular type of environment.

If a reasonable running speed can be achieved, the time spent standing at stops and traffic signals is the key determinant of overall journey times and average speed. A poorly performing system in terms of signal priority is likely to suffer in its overall performance.

The journey time needs to be not only as short as possible but also as predictable as possible, to maintain regularity of service. This means that signal priority in particular should be predictable and if possible adjustable in the case of a late running tram. Stop dwell times are less prone to variation but the vehicle and stop design should accommodate peaks in passenger numbers without increasing delays (thus avoiding the 'bunching' phenomenon to which pay-as-you-enter buses can be particularly susceptible).

The system requirements for an effective scheme can therefore be defined as follows:

- Segregation from traffic wherever possible – and certainly wherever congestion is likely;
- Maximum priority at junctions;
- Efficient boarding and alighting arrangements (for all people including those with mobility impairments); and
- A high standard horizontal alignment to minimise local speed restrictions and lateral acceleration – hence short radius curves should be used sparingly.

To these can be added further elements required to maximise the attractiveness of the system to passengers, including;

- High quality vehicles and traction control systems to minimise jerk rates;
- Frequent and regular 'turn up and go' service at all times; and
- Good quality pedestrian access to stops.

C.2.2 Run Time Model

Estimates of run times have been prepared using the Steer Davies Gleave run time model, which is based on the following key inputs:

- Vehicle performance – acceleration and deceleration rates;
- Link characteristics – distances, curvature, maximum speed; and
- Delay characteristics – stop dwell times, junction delays.

The model uses separate linear acceleration and deceleration rates. A value of $0.95 m/s^2$ has been used in both cases, which is well within the capabilities of modern tram designs and provides a satisfactory level of passenger comfort.

Run Time Model – Description

The alignment description in the model is broken down into sections of route characterised by:

- Length (m);
- Link type – which determines maximum speed; and
- Curve radius – which may reduce this speed (m).

The same format is used for lengths of track and delay points (stops and signal junctions). The latter differ in having zero length.

The section lengths have been measured from the alignment plans, based on the position of the front of the vehicle (head of platform or junction stopline), to the nearest 10m.

The link type is coded as LRT1/2/3a, in accordance with commonly used terminology. These terms do not distinguish between all the possible methods of operation, but are useful 'shorthand' and can be defined as follows:

LRT1:
- Carriageway shared between trams and other vehicles and/or pedestrians;
- Includes operation in mixed traffic, tram/bus only streets, pedestrian areas etc.;
- On-sight driving under normal traffic regulations.

LRT2:
- Semi-segregated right of way, with raised surface;
- Normally reserved for trams, but can be used by other vehicles in an emergency or to pass a stationary obstruction;
- On-sight driving under normal traffic regulations.

LRT3a:
- Fully segregated right of way, usually within the highway;
- May be accessible to pedestrians;
- On-sight driving under normal traffic regulations.

An additional category, LRT3b, applies to segregated sections with full railway signalling but this type of operation is not proposed on Edinburgh Tram Line 1.

These terms are broadly equivalent to the definitions in the HMRI Guidance, which uses the terms:

- Integrated on-street tramways;
- Segregated on-street tramways; and
- Off-street tramways.

in place of LRT1, LRT2 and LRT3a respectively.

In general, trams are not permitted to exceed highway speed limits. The HMRI guidance (paragraphs 214-215) states that:

> *"The maximum permitted speed of a tram on a carriageway shared with other road traffic may be the same as, or lower, but should not be higher than that for other traffic"; and*
>
> *"The maximum permitted speed of a tram on a segregated on-street section may be higher than that for other road traffic provided that the presence of the tramway is clearly indicated to other road users",*

also noting that:

> *"The higher speed should be agreed with the police and the Highway Authority."*

It is prudent at this stage to assume that the highway speed limit will be the absolute maximum throughout Line 1, even where the alignment is segregated. There may be opportunities to set higher limits in places, but these will need to be subjected to detailed risk assessments.

On the segregated section of line forming the western side of the loop, there is no adjacent highway to dictate speed limits, and the parallel footway will be separated from the tramway by a fence or, where width permits, a hedge or additional horizontal separation. Here a speed of 70 km/h (43.5 mph) has been assumed, corresponding to the maximum speed of most low-floor trams.

In the run time model the distinction between alignment types is only important in that it determines maximum speeds and the response to curving. For sections on or adjacent to the highway the maximum speed is determined by the highway speed limit, and the model therefore has variations within each alignment type. The types used in the Line 1 model, based on the alignment designs, are as follows:

LRT1_30	max speed 30 mph (48 km/h)
LRT2_30	max speed 30 mph (48 km/h)
LRT3a_30	max speed 30 mph (48 km/h)
LRT3a_50	50 mph general speed limit (but 70 km/h assumed as maximum tram speed)
LRT1_CC	speed limit 30 mph but in practice trams limited to approximately 20 mph (30 km/h)

The LRT1_CC alignment applies to City Centre and other streets where the 30 mph limit is unlikely to be reached because of interactions with other traffic.

The curve radius is used to adjust the maximum speed downwards if necessary, using a formula based on the maximum permissible lateral force. For on-street route sections (i.e. LRT1/2) this assumes no cant (superelevation), whereas for off-street sections (i.e. LRT3a), cant is assumed and hence curving speeds are higher.

Stops have been categorised in three types with dwell times as follows:

- 10 seconds for the suburban stops; and
- 20 seconds for busier suburban and City Centre stops.

Delays at junctions depend on the degree of priority that is practicable in the light of overall junction capacity and delays to other traffic, and vary by location. For this assessment, junction delays have been extracted from traffic modelling results, with some modifications where the models have not yet been optimised for tram priority.

The allocation of delays to particular junctions is one of the key determinants of overall run time – experience shows that the end-to-end time is more sensitive to junction delays (and stop times) than to running speeds or vehicle performance. In practice, the actual delay at a particular junction will vary between individual journeys – some will pass through without stopping, while others will – in extreme cases – wait a full signal cycle.

In situations where signals are likely to be linked, second and subsequent delays are set to a lower category or omitted, on the assumption that once a tram is given the signal to proceed, it has a clear run through the linked set of signals.

Depending on operating practices, it will probably be necessary on some journeys to change crews at an intermediate point, likely to be at the OCC. The run times do not take account of any time for this process in excess of the standard stop dwell time.

Run Time Model – Methodology

Starting from rest at a terminus, for each link the model uses the speed at the end of the previous section, the link speed itself (adjusted for curvature if required) and the speed at the start of the next link to calculate time spent and distance travelled in accelerating and decelerating.

In some situations, the link is too short for maximum speed to be reached. In this case the calculated acceleration and deceleration distances will exceed the link length, and the model adjusts the maximum speed downward until this is no longer the case. Similarly, if a link is too short to allow deceleration to the maximum speed of the following link, an adjustment is made to its speed to ‘force’ earlier deceleration, feeding back into the preceding link.

The resulting times, after any manual adjustments that may be required, are summed to give the total link time. Times spent at stops and signals are simply transferred directly as a time for each location.

C.2.3 Run Time Forecasts

The model forecasts a total time of 40.5 minutes around the loop, excluding any layover time allowance. The times between stops are shown in Table C.1.

Table C.1 Run Time Estimates

Departing	Cumulative Time (min)
Lower Granton Road	0.0
Granton Square	1.9
Granton Waterfront	3.4
Caroline Park	5.0
West Granton Access	6.9
Crewe Toll	8.0
Groathill Road North	9.2
Craigleith	10.2
Ravelston Dykes	11.4
Roseburn	12.7
Haymarket	14.3
Shandwick Place	16.5
Princes Street West	18.7
Princes Street East	19.8
St Andrews Square	22.0
Broughton Street	24.7
McDonald Road	27.2
Balfour Street	29.3
Duke Street	30.5
Constitution Street	32.2
Ocean Drive	33.8
Ocean Terminal	35.5
Newhaven Road	37.8
Lower Granton Road	40.5

C.3 Operating Patterns

C.3.1 General

In this section we discuss some of the basic assumptions required in developing an operating plan for Line 1:

- The range of basic service patterns;
- The requirement for layover points and the issues to consider in determining their layout and location; and
- The requirement for crossovers and the issues to consider in determining their location.

C.3.2 Basic Service Patterns

The configuration of Line 1 as a continuous loop poses special issues for service planning and operations because there are no ‘natural’ termini. Determining the service pattern is therefore more complex than with a simple end-to-end route. It has been assumed that the full service frequency is provided throughout the loop, i.e. there are no short workings.

A number of basic options have been considered:

- **(A) End to end running** with all trams turning back at a fixed point, preferably on the section with lowest patronage, and possibly at different locations by direction and time of day. Clearly this option would mean that all passengers travelling through the terminus would have to change trams. However, the advantage would be that seriously late-running trams could be turned short to resume their scheduled workings.
- **(B) Continuous loop running in both directions with a layover** at a single ‘terminus’ en route – this would be more convenient for passengers through the terminus, although they would still suffer a short delay equal to the layover time (less if the tram were late). Recovery of a delay less than the scheduled layover would be possible, but longer delays could only be recovered by complex turnbacks and switching of trams between opposite directions, or holding trams until regularity was recovered (with all trams running ‘late’ by the same amount, and hence at regular intervals).
- **(C) Continuous loop running in both directions with no layover** – the through passenger delay would be eliminated but there would be no recovery margin and the only way to recover from even minor delays would be complex turning back arrangements.
- **(D) Continuous loop running in both directions with ‘distributed’ layovers** – this would involve the same overall running time but with short scheduled layovers of a minute or two at several points around the loop. This would make reduce the perception of delays to passengers but would affect a larger proportion of passengers. Recovery from delays would be similar to (B).
- **(E) End to end running with an overlap on the busiest section** – this would combine the advantages of the other options by allowing trams to be turned short while providing most passengers with a through journey. Moreover, depending on the demand profile, it might be possible to tailor frequency to demand more closely and thus avoid significant additional mileage and operating cost. This option would also give a double frequency through the City Centre, where it is most likely to be needed, and could have minor operational advantages through segregating boarding and alighting passengers, but

would also have significant resource implications in terms of fleet size and operating costs.

Options (A) and (B) would involve a terminus en route, best placed along the waterfront section, close to the point of lowest demand. Options (C) and (D) would not require any specific terminal provision for normal service. In the case of (E), there would be a need for offline terminal platforms in two locations, but if these were at the branching off points for Lines 2 and 3, they could be incorporated in those lines later.

In the development of the service plan and the appraisal itself, Option (B) has been assumed.

C.3.3 Provision for Layovers

Some layover time is normally provided in any tram or other public transport service to allow for drivers changing ends (if reversing), resetting of controls and destination displays, entering trip data, recovery from minor delays etc. Depending on staffing arrangements, physical needs breaks may also be allowed for, though these may also be accommodated by crew changes at an intermediate point. In the absence of a recovery margin, layover times can be as short as 1-2 minutes, but it is usual to allow several minutes more than this.

For a loop service with a journey time of around 40 minutes, a layover of 4-5 minutes per circuit is an appropriate assumption. This figure is similar to those found on other LRT systems with a mixture of segregated and on-street operation. In practice the total cycle time (the sum of the loop run time and the layover) must be a multiple of the headway. The layover time is therefore also influenced by the actual values of the run time and headway, and is therefore generally adjusted to 'take up the slack' when planning the timetable. This may limit flexibility, especially at times when wider headways are being operated.

Furthermore, as both run times and service patterns will vary over the day, layover will also tend to vary, particularly at transitional times when depot run-out or run-in is occurring. Detailed timetable planning will establish the precise distribution of individual layovers at a later stage.

The actual layover required to maintain a defined level of reliability depends on the degree of variability in run times. At a later stage in the detailed planning of the scheme, a simulation will be required to confirm the operating plan and performance against specification.

C.3.4 Crossovers

Whatever service pattern and terminal location is adopted, facilities for turning back trams at intermediate points will also be required. The reasons for this are:

- To provide for scheduled short workings, perhaps operating at certain times on certain day – there are particularly likely to be required during transitions between early/ daytime/evening service periods;
- To allow services to be maintained over part of the route during disruption affecting a local area - either planned maintenance or caused by incidents such as vehicle or equipment failure, road accidents, property fires etc. (Such occurrences would entail the operation of an end-to-end service instead of a continuous loop); and
- To allow a failed vehicle to be returned to the depot by the shortest practical route.

Typically these facilities will consist of a simple (normally trailing[63]) crossover, operated from the control centre, which is sufficient for occasional use during disruption. A section of straight track with a minimum length of about 20m is required under normal circumstances; although crossovers on curves are possible, they may involve non-standard components, increasing the stock of spare parts that must be held.

There are further limitations on the locations where crossovers can be provided, as a result of safety considerations. Such unsuitable locations include:

- Areas with a high density of pedestrians, who would be at risk from the movement of point blades; and
- Sections shared with traffic, where the regulations state that *"Such movements* [i.e. reversals or 'wrong direction' running] *on on-street tramways should only be made under the direction of a person holding an authority granted by the Chief Constable"*, effectively ruling out their use in normal timetabled operation.

Where trams are required to terminate in normal service, an offline reversing track, either at or beyond a stop, may be required to allow trams to lay over and reverse without obstructing other trams. However, if only occasional reversals have to be accommodated, particularly at less busy times, a crossover may be adequate. In any event any reversal must take place on a section of track segregated from other traffic as mentioned above.

The depot also provides reversing facilities by default and may be designed with a specific reversing facility for normal use. The depot location may therefore affect the selection of other turnback locations on the route nearby.

C.4 Service Frequency and Passenger Capacity

Because of the higher standards of comfort, tram systems are normally planned on the basis that a proportion of passengers will stand. In practice, standing passengers can often be observed on trams even when a significant number of seats is available – this rarely occurs with buses. The balance between seated and standing space, and the proportion of passengers to be provided with a seat, are influenced by:

- The economics of tram operation – the need to achieve an operating ratio greater than unity may mean that peak loadings cannot be met without a significant proportion of passengers standing;
- The relationship between peak and off-peak loadings – for example it may be considered more acceptable to require a large proportion of passengers to stand in the peak than in the off-peak, because of the different mix of trip purposes;
- Vehicle design, including length, the number of doors, the wheel configuration (becoming less important with recent modular 100% low-floor designs); and
- The ability of the system to operate coupled pairs of vehicles when demand warrants.

Some of these are defined in turn by system design parameters such as platform lengths and signal junction design (which may need extra provision if coupled pairs are to be accommodated).

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[63] A trailing crossover is one arranged so that vehicles have to reverse to cross to the other track – i.e. in normal operation they pass through the turnouts in the trailing direction.

Service Frequencies

The maximum passenger flows from the preliminary demand forecasts have been summarised in Table C.2, which sets out the maximum hourly flows on the western and eastern sectors (sides) of the loop for the Feasibility Study Route (Option 1).

Table C.2 also shows line capacity figures, based on a service of 8 trams per hour (i.e. a headway of 7½ minutes). The design of the vehicle has not been finalised at this stage but is likely to be about 32-40m in length, with a vehicle capacity of about 80 passengers seated and up to 230 passengers in total (based on standing at 4 passengers per square metre) [64]. The assumptions used in track alignment design allow for trams up to 40m in length to be used. These passenger capacities would give a line capacity of 1,840 total places per hour (pph) in each direction, of which 640 would be seated places.

Table C.2 Passenger Flows - Maximum by Sector

		All figures passengers per hour			
Forecast Year	**Time Period**	**Western Sector (City Centre to Lower Granton Road via Crewe Toll)**		**Eastern Sector (City Centre to Lower Granton Road via Leith Walk)**	
		Clockwise	**Anticlockwise**	**Clockwise**	**Anticlockwise**
2011	AM Peak	844	1,408	911	481
	Interpeak	367	488	497	295
	PM Peak	1,252	745	952	639
2026	AM Peak	1,125	**2,416**	1,623	756
	Interpeak	505	**662**	584	350
	PM Peak	1,636	1,102	**1,973**	872
Line capacity (total)		1,840 each direction (at 4 standing passengers per m^2)			
Line capacity (seated)		640 each direction			

In peak periods, figures shown in **bold** are in excess of <u>total</u> capacity (at 4 standing per m^2)
In the interpeak period, figures shown in **bold** are in excess of <u>seated</u> capacity

These figures show that in the **peak** hours, the flows in the year 2011 on both the eastern and western sides of the loop are well within the total capacity of 1,840 pph. In 2026, however, flows exceed this capacity in two cases. First, on the eastern sector the evening peak clockwise flow of 1,973 pph exceeds capacity by about 7%. This would mean that the standing density would be slightly more than 1 per 4 m^2, but by only a small amount. Secondly, the morning peak flow on the western sector, at 2,416 pph, would be in excess of the 1,840 figure by more than 30% and would be equivalent to a density approaching 6 per m^2. This would be undesirable on the grounds of both passenger comfort and stop dwell times and would therefore require mitigation. Ideally, the service would be increased to about 10 trams per hour, which would bring the standing density back close to 4 per square metre. This could be accomplished by ‘fine-tuning’ the timetable to provide a higher frequency over the affected section only, thus minimising the additional resources, though sufficient capacity to meet the clockwise demand on the eastern sector would need to be maintained. It is possible that this could be achieved without any additional vehicles in the fleet, by a mixture of short workings and a slight reduction in the service in the clockwise direction.

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[64] See main STAG2 Appraisal report, Chapter 6

In the **interpeak,** flows are within the seated capacity of a service of 8 trams per hour, with one minor exception. Thus, a seat would be available to any passengers who wanted one, bearing in mind that a proportion of passengers choose to stand even when seats are available. Whilst it would be operationally possible to reduce the service level in the inter-peak and thus increase load factors, this would result in some passengers being required to stand. Furthermore, sensitivity tests show that this would not reduce operating costs by a significant amount compared with the proposed flat frequency profile across the day. The 'flat' profile would be consistent with existing UK systems, which in most cases operate at the same frequency all day (the main exception being Manchester which operates at a slightly higher frequency in the AM peak only).

Outside the main weekday time periods (peak and inter-peak), lower frequencies will be required to meet the lower levels of expected demand. As an initial assumption for service planning and appraisal purposes, the profile shown in Table C.3 is proposed. To a large extent these frequencies will be flexible in response to actual demand during different time periods, so that (for example) on Fridays and Saturdays the evening service could be increased in frequency and last trams scheduled later. Although there would be some effect on the maintenance regime, the net effect on the appraisal case of variations in both service level and demand/revenue at off-peak times would be marginal.

Table C.3 Service Operating Periods and Frequency Profile

Day	Period	From	To	Frequency (trams per hour)
Monday-Friday	early morning	05:00	07:00	4
	AM peak	07:00	09:30	8
	Inter-peak	09:30	16:30	8
	PM peak	16:30	19:00	8
	evening	19:00	24:00	4
Saturday	early	05:00	09:00	4
	shopping hours	09:00	18:00	8
	evening	18:00	24:00	4
Sunday	early	08:00	10:00	4
	daytime	10:00	18:00	4
	evening	18:00	24:00	4

C.5 Revenue Collection System

Clearly with a system using large articulated vehicles with multiple doors, designed to provide a fast, regular and reliable service, the standard pay-as-you-enter ticketing system as used on most bus services in the UK is inappropriate. This is the case even with a high proportion of prepaid tickets, since ticket inspection is still required while the vehicle is stopped.

Systems using restricted access by means of barriers, such as used by main line and suburban railways, are also inappropriate for tram systems where the platforms at stops are part of the highway and accessible to non-passengers.

Most modern tram networks, including all those in the UK, therefore use a ticketing system based on unrestricted boarding and alighting through multiple doors, with fares payable either in advance, generally using ticket machines at stops (and subject to random checks on the vehicle), or to an onboard conductor. Manchester Metrolink uses off-vehicle ticketing with machines at stops, but heavy loadings mean that there are problems catering for demand and ticket checks at peak times are difficult. Croydon Tramlink uses ticket machines at stops but also benefits from integrated ticketing through being part of London Travelcard system. Both Sheffield Supertram and Midland Metro originally used ticket machines at stops but conductors have been introduced in response to vandalism and fare evasion. The Nottingham Express Transit system, now under construction, was originally intended to use ticket machines but will now use conductors. Merseytram is also planned to use conductors.

The key benefits of conductors are:

- A reduction in vandalism, both in-vehicle and of ticket machines (and associated cost);
- Reduced loss of revenue from fraudulent or free travel; and
- Higher security for all passengers, both real and perceived.

Steer Davies Gleave carried out some Stated Preference research specifically on this topic as part of the development of the Merseytram scheme. This research showed that operation with on-vehicle conductors improved the investment case and had added safety and security benefits, particularly for women and the elderly. The additional cost of employing conductors was outweighed by savings in capital and maintenance costs for ticket machines at stops, higher revenue (through increased patronage and reduced fare evasion) and perceived security benefits.

Notwithstanding the benefits of conductors, there can be difficulties in the recruitment and retention of suitable staff and to overcome this problem, some operators are currently training staff to be able to fulfil the role of both driver and conductor.

C.6 Fares and Ticketing

The City of Edinburgh Council Local Transport Strategy has an objective under Short Term Improvements (2001 – 2004) to achieve "the introduction of an integrated ticketing system with a single ticket valid for all travel in the city". In the programme for public transport the Council states that it will:

"Seek to achieve a full range of transferable and integrated tickets on local bus and rail services. The Council will pursue this in two main ways:

- *Encourage the two main bus operators in Edinburgh, who have introduced Transfair, a Sunday and evening integrated ticket, to extend this to all services at all times.*
- *Secondly, through the Southeast Scotland Transport Partnership, the Public Transport Fund (1999) awarded monies to develop a scheme, but it will also require resources to maintain a revenue-allocation system acceptable to all operators. The Council will seek significant operator contributions to such a system.*"

Unfortunately, First Edinburgh withdrew from the Transfair scheme in 2001 and have considerably reduced their network within the City. Lothian Buses are now the dominant operator, notably in the area to be served by Line 1.

Notwithstanding this setback, the objective remains of implementing an integrated ticketing scheme, of which the tram system will clearly be a key part. It will be essential to require prospective operators to commit to full participation in any scheme, including any smart card system[65].

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[65] Lothian Buses introduced a Smart card system in April 2001

The workings of the ticketing system itself will be under the control of the operator but, in addition to any integration requirements, a clear specification for the system will need to be defined in terms of:

- Ticket types to be issued/accepted;
- Fares scale for any operator-specific tickets offered;
- Sales outlets;
- Revenue protection measures;
- Ticket inspectors; and
- Penalty fares.

The revenue protection measures are made simpler by the use of conductors, but there will still be a need for random checks to maximise compliance. Much of this will be the responsibility of the operator.

C.7 Depot – Operational Issues

The key requirements for a depot in operational terms are that it must be:

- Secure;
- Accessible from the tram network (preferably adjacent to a passenger stop to enable crew changes to be made with minimal delay);
- Accessible by road for service vehicles (probably including tram delivery);
- Accessible to staff by all modes of transport;
- Positioned on the network so as to minimise empty running as far as possible; and
- Sufficient in size to accommodate the planned fleet with space for later expansion.

However, in most urban environments, the choice of depot location will be driven more by the size, planning status and environmental suitability of available sites than by the operational requirements discussed here.

The size of the depot will be determined by the fleet size but also by the stabling policy adopted. In the case of Line 1, a single site for all stabling and maintenance is clearly ideal, to maximise security. Any point on the loop will be equally accessible. However, with Lines 2 and 3 added, a decision will need to be taken on whether to concentrate all stabling at one depot or establish separate points for overnight stabling on Lines 2 and/or 3. The latter would minimise empty running and reduce the sensitivity of network-wide operations to any incident. Again the availability of suitable sites is likely to be as important as operational considerations.

C.8 Operating and Maintenance Costs

C.8.1 Staffing

It is assumed that the system is operated by a company set up for the purpose; in practice the actual form will depend on the structure of the successful concession company or consortium. For the purposes of estimating operating costs it has been assumed to be a stand-alone company structure containing all functions in-house, although out-sourcing of some activities is very likely.

The staffing structure of an operating company can be divided into:

- Management staff performing central functions such as financial control, accounts, personnel, marketing, etc.;
- Operations staff, consisting of drivers, conductors, controllers, supervisors, revenue system and control staff and instructors; and
- Maintenance staff, covering vehicles, track, Overhead Line Equipment (OLE), stops, ticketing and other equipment,, signalling and communications.

Staff numbers in some cases (notably drivers and conductors) can be estimated directly from operational statistics; in other cases they can be estimated from track mileage, fleet size etc. Some central management and support staff numbers can only be defined directly by comparison with experience elsewhere.

It is likely that, to facilitate staff recruitment and retention and to enable the operator to respond to short-term operational requirements, there will be some flexibility between staff grades, with (for example) some conductors being trained as drivers and vice versa.

C.4 shows the staff numbers assumed and estimated in the model.

Table C.4 Staff Numbers

MANAGEMENT, FINANCE AND ADMINISTRATION STAFF	
Managing Director	1
Finance & Administration Director	1
Finance Assistant	1
Accountant	1
Training Manager	1
Personnel Manager	1
Marketing Manager	1
Admin Assistant	2
Secretarial/Clerical	5
Sub Total	**14**
OPERATIONS STAFF	
Operations Director	1
Operations Manager	1
Assistant Operations Manager	1
Clerical	2
Controllers	16
Supervision	14
Instruction	2
Drivers	40
Senior Conductors	8
Conductors	32
Revenue Control Inspectors	4
Sub Total	**121**
MAINTENANCE STAFF	
Maintenance (Engineering) Director	1
Senior Engineers	5
Vehicles Supervisors	2
Vehicles Technicians	4
Signals & Telecoms Inspectors	2
Signals & Telecoms Technicians	2
Cleaning staff	13
Track staff	7
E&M Inspectors	2
E&M Technicians	2
Civils Inspectors	2
Civils Tradesmen	2
Revenue System	5
Sub Total	**49**
TOTAL	**184**

C.8.2 Operating Cost Model

Operating and maintenance costs have been estimated using the Light Rapid Transit Operating Cost Model developed by Steer Davies Gleave, which builds up the total annual cost of operating the system from a number of variables or characteristics. These can be separated into a number of main categories:

- System characteristics - operating days per annum, hours of operation, etc.;
- Route characteristics - route lengths, journey time, peak and off-peak frequencies, number of stops, etc;
- Vehicle characteristics - method of propulsion, weight;
- The management/staffing structure of an operating company (as set out above);
- Shift lengths, holiday entitlements, expected sick days, number of staff required on duty etc. to determine the number of operational staff required.

Also in the model are a series of cost rates and assumptions relating these system descriptors to annual costs, including:

- Salary levels by grade;
- Energy costs per vehicle kilometre and centrally;
- Vehicle maintenance costs fixed and per vehicle kilometre;
- Fixed equipment maintenance costs per route/track kilometre;
- Revenue collection costs;
- Insurance;
- Overheads; and
- Policing.

The model reflects the relationships between the assumptions and input variables and resulting cost estimates in different ways. Some, particularly operations costs, vary directly with the size of the system (defined by service pattern, route length, number of stops etc.), whereas others, such as certain management and administration costs, will be fixed within a range of alternatives under consideration. Other costs, such as maintenance costs, are semi-variable, where costs include a fixed element and increase with system size but less than proportionally. Insurance and policing are based on experience elsewhere, on a route kilometre basis. Overheads are added as a proportion of total costs.

C.8.3 Operating Cost Estimates

Table C.5 shows a summary of the operating cost estimates input to the appraisal together with some operating statistics output from the model.

Table C.5 Operating Cost Estimates and Statistics

Component	Sub-component	Operating Costs (£m pa)
Staff		**3.96**
of which	*Drivers*	*0.81*
	Conductors	*0.63*
	Other operations staff	*0.97*
	Management and administration staff	*0.48*
	Maintenance and engineering staff	*1.07*
Power		**0.28**
Maintenance materials		**0.66**
Insurance		**0.27**
Policing		**0.20**
Overheads		**0.27**
Rates		**0.19**
Total Operating Cost		**5.82**
Operating statistics:		
Annual vehicle kilometres (million)	**1.30**	
Operating cost per vehicle km	**£4.47**	
Annual vehicle hours	**61,100**	
Operating cost per vehicle hour	**£95**	

C.9 Vehicle Technologies

There are three main categories of LRVs/trams currently available which are based upon the height of the tram floor relative to the running surface: *High Floor, Partial Low Floor and Low Floor*. These descriptions also reflect the evolution of tram design, although none of these categories are obsolete and each has its own relative merits which are set out below. All three of these types can be further classified as single or articulated. The articulated vehicles can be single-, double-, triple- or multiple-articulated. Both single and articulated trams can be operated as single units or assembled into pairs or trains according to the required capacity.

C.9.1 High floor trams

High floor trams are mainly suited for use in segregated corridors, in sub-urban areas, on disused heavy rail lines or on lines used commonly by trains and trams, where high speed is required. They require high boarding platforms, typically 850-1000mm and therefore on lines not already equipped with high platforms the civils works required to accommodate these trams are usually more expensive than trams with lower floors.

The advantages of these vehicles come from their simple construction, high riding quality, speed (90-120km/h is attainable), easy equipment inspections, easy passenger accessibility and low purchasing costs.

If it is necessary to provide step wells for boarding the tram from low level tram stops this results in poor accessibility for mobility impaired travellers. These factors mean that high floor trams are not generally suited to the urban environment where high platforms cause physical obstacle and strong visual impact.

C.9.2 Partial low floor trams

These trams offer high and low floor sections with the principal aim of improving accessibility, especially for mobility impaired travellers. They are mainly suited for use in urban and sub-urban areas where high speed is also required. They provide a good riding quality and can attain speeds of up to 80-100 km/h. The low floor sections usually make up approximately 50-70% of the floor area and are generally at the doors. Internal access to high floor sections of the tram must be negotiated by steps.

C.9.3 Continuous low floor trams

These are the most modern of available trams and provide the most accessible passenger vehicles, facilitating kerb boarding for users of all levels of mobility and age. These trams are mainly suited for use in urban environments where low visual impact is required. These vehicles offer fewer limitations on operations and can be easily customised internally to accommodate special requirements, for example, cycles and wheel chairs. Some are capable of negotiating very tight curves (radii 18m). On straight segregated track they can operate at speeds of 70-80km/h.

The disadvantage of low floor trams is that the on-board auxiliary equipment must be accommodated on the body roof. At present they are more expensive than the partly low floor types.

C.9.4 General LRV Specification

Currently no particular light rail vehicle (LRV) or tram has been chosen for use on the Edinburgh system. However, it is understood that TIE is seeking to implement a high quality low floor system. This issue paper therefore sets out to provide a guide on the range of vehicle characteristics currently available on the market and to define an outline vehicle specification to be adopted for design.

The following provides indicative performance parameters for a typical modern tram.

Table C.6 Performance parameters for a typical modern tram

Characteristic	Typical Street Running LRV	Comments
Overall length	22m - 35m (up to 48m modular)	Envelope of vehicle lengths available
Vehicle width	2.30m - 2.65m	Envelope of vehicle widths available
Vehicle height	3.20m -3.40m	Envelope of vehicle heights available
Floor height (above top of rail)	300mm – 350mm (low floor) up to 915 mm	Envelope of vehicle floor heights available
Track gauge	1435mm	Standard track gauge
Doorway width	1,200mm - 1,300mm	Envelope of vehicle Doorway widths available
Seating capacity (including tip ups)	60 - 80	Envelope of seating capacities available
Passenger capacity (4/m²) normal	100 - 230	Envelope of passenger capacities

Characteristic	Typical Street Running LRV	Comments
load		available (normal load)
Passenger capacity (6/m²) max service load	200 - 320	Envelope of passenger capacities available (max service load)
Line voltage	750V d.c.	Standard Line voltage
Maximum speed	70km/h – 100km/h	Envelope of maximum speeds available
Absolute minimum horizontal radius	18m	Absolute minimum horizontal radius available.
Usual minimum horizontal radius	25m	Usual minimum horizontal radius available.
Minimum vertical radius	400m - 500m	Envelope of minimum vertical radii available
Expandable vehicle (modular)	Yes	Most tram vehicles considered are expandable
Multiple unit operation	Yes	All tram vehicles considered are capable of multiple unit operation
Single-ended* or double-ended	Either type	For Edinburgh double-ended more practical, although single-ended possible.
Maximum gradient	6% - 10%	Envelope of maximum gradients available
Maximum acceleration rate (crush load on straight & level track)	1.00m/s² - 1.30m/s²	Envelope of maximum acceleration rates available
Maximum service braking rate	1.00m/s² - 1.30m/s²	Envelope of maximum service braking rates available
Maximum emergency braking rate	2.50m/s² - 3.00m/s² (note: HMRI requirement is 3.00m/s²)	Envelope of maximum emergency braking rates available
Design life (body structure)	30 years	Design life of all vehicles considered
Braking systems	Mechanical, electrical, electro-magnetic (track)	Braking systems employed by the vehicles considered.

*Normal operation unidirectional, in emergency can be operated in reverse

C.9.5 Proposed LRV Design Specification

A number of tram vehicles have been considered in compiling the following assumptions, including the Ansaldo Transporti, Firema T68, the Alstom Citadis tram and the Adtranz Incentro tram vehicle. A further review of other possible tram vehicle types has been undertaken in summary to confirm the validity of the following assumptions.

It has been assumed that geometric design will comply fully with the requirements of Railway Safety Principles and Guidance 1996 published by HMSO.

It is assumed for the purposes of STAG 2 alignment development that the trams will be semi-low floor and not total low floor vehicles. This implies a floor height of between 300 and 400mm. This type of vehicle has been adopted in order to ensure that the alignment characteristics will cater for *most* currently available rolling stock. It should be noted however, that as trams are frequently variations on a basic vehicle derivative, no guarantee can be given in relation to the ability to accommodate any particular vehicle in the future.

Table C.7 Characteristics of Typical Street Running LRV

Characteristic	Typical Street Running LRV
Overall length	32m inclusive
Vehicle width	2.65m
Vehicle height, excluding pantograph	3.365m (from top of rail to roof)
Floor height (above top of rail)	350mm
Track gauge	1435mm
Doorway width	1200 - 1300 mm
Seating capacity (including tip ups)	65 - 80
Passenger capacity (4/m²) normal load	100 - 230
Passenger capacity (6/m²) max service load	200 - 320
Line voltage	750V d.c.
Maximum operating speed	80km/h
Maximum design speed	85km/h
Absolute minimum horizontal radius	25m
Desirable minimum horizontal radius	30m
Minimum vertical radius (sag or hog)	500m
Desirable vertical radius (sag or hog)	1000m
Expandable vehicle (modular)	Yes
Multiple unit operation	Only in case of breakdown and emergency (see note)
Bi-directional	Yes
Maximum gradient	6.5%
Maximum acceleration rate (crush load on straight & level track)	1.00m/s² - 1.30m/s²
Maximum service braking rate	1.10m/s² - 1.30m/s²
Minimum emergency braking rate	3.0m/s²
Operational acceleration and braking rate	0.9m/s² (for use in run time and operational assessments)
Design life (body structure)	30 years

Note

It is presently assumed that vehicles will not require to be coupled together during normal operation. This assumes that single units will be capable of providing the required capacity to meet patronage demands during the design life of the system. Early confirmation of the likely patronage demand and hence this assumption is required.

C.10 Traction technology

C.10.1 Summary

There are more than 350 light rail systems currently in operation worldwide, almost all of which are powered by some form of electrical traction. Of these systems, the overwhelming majority use a traditional system of overhead line equipment (OLE) with traction power supplied from a suspended contact wire via a pantograph to the tram (or light rail vehicle – LRV). The exact form and extent of OLE and associated infrastructure vary between systems depending upon factors such as; size of the network, number of trams, tram technology and route topography.

New technologies are being developed for a variety of transport applications which might offer either alternative traction methods or alternative means of power collection. This paper summarises the relative merits of these technologies, providing an opinion on their possible application for the Edinburgh Tram and the risks associated with implementing such technology.

The paper concludes that the principal disadvantage of almost all of these new technologies or systems is that they are either conceptual or still at the trial stage of development, and do not exist as "off the shelf" products.

Formally assessing such a diverse range of potential systems would be highly complex, but it is clear that there would be considerable uncertainty and very high technical and commercial risks affecting a new tramway system that was also using radically novel technologies.

Of the alternative power collection technologies discussed, the APS power collection system being developed for Bordeaux holds the most promise being the closest to a "off the shelf" system. It is recommended that the implementation of the APS system in Bordeaux is monitored and reviewed in the lead up to Edinburgh Tram's procurement.

In short, alternative technologies cannot at present guarantee a practical traction system with the consistency and quality of operation and service that is aspired to for the Edinburgh Tram.

It is recommended that the scheme is developed on the basis of a traditional OLE format. This strategy does not preclude the possibility of adopting alternative systems at a later date, if and when the practicality and overall viability of such alternatives can be demonstrated in the context of the operational requirements of Edinburgh Tram.

C.10.2 Traction Technology Options

The following outlines the main points relevant to existing systems and new systems under development.

Dual Power Supply Systems

Typically high voltage OLE supply in addition to 750v dc voltage tram supply to allow running on conventional electrified railway.

Examples of these systems are increasingly popular in Germany and France to allow the local rail network to be integrated with the city centre tramway.

e.g. Karlsruhe, Germany: 750V dc and 15kV ac overhead power supply

Saarbruken, Germany: 750V dc and 15kV ac overhead power supply

Aulnay, France: 750V dc and 25kV ac overhead power supply

Alphen an der Rijn, Holland: 750V dc and 1500V dc overhead power supply

Dual Fuel and Stored Energy Systems

The most common use of dual technology to date has been with buses and other forms of lightweight motor vehicle. In these instances a diesel engine is often combined with battery/fuel cell technology.

Electric-Diesel: A diesel-electric unit and a conventional 750v dc voltage tram supply

e.g. Nordhausen, Germany: 750V dc overhead and 180kW diesel electric unit. The electric-diesel tram incurs a 13 passenger loading penalty compared with the all electric version of the same tram.

Stored Energy: A flywheel system for energy storage.

An example of the application of flywheel technology is the Parry People Mover, which uses a LPG fuelled diesel engine to drive the flywheel system. This technology has not progressed beyond the small demonstrator and prototype stage. There are safety issues associated with the integrity of high energy flywheels and their housings which could make formal acceptance of such systems problematical.

Flywheel energy storage has been used in sub-stations as part of the fixed electrical power supply system, but from an operator or passenger perspective the result would be a conventional tramway.

Battery power: All or part of the systems energy from batteries

There are no known tramway systems currently using battery technology. Attempts have been made to use battery power over intervals during the last 100 years. The fundamental issues are the weight and volume required for traction batteries if reasonable performance and range are to be achieved.

The tonnage of existing battery types and the space required would have a considerable impact on passenger capacity and it is unlikely that a practical system will be available for at least 10 years or more. Some battery bus systems are in service, for example Santa Barbara, California, but the vehicles have a fraction of the capacity of a tramway vehicle, and the scope of the service provided is limited. Operational requirements for rapid re-charging on bus systems reduces battery life, increasing costs.

The tractive effort of a tram is much higher than a bus (due to combination of its weight and acceleration) and it is the difference in scale which prevents battery technology advancing at present. General discussions with some manufacturers has indicated that some early research and trials are underway but, if successful, this will only allow trams to travel short distances (i.e. hundreds of metres) without OLE.

Fuel Cell power: All or part of the systems energy from fuel cells

Fuel cell technology is currently under intense development for automotive applications, either as a single power source or in combination with a conventional engine. There are no known tramway systems using or proposed to use this technology at present. The first fuel cell powered buses and coaches have recently entered service in a few cities, but it is unlikely that a practical system will be available for at least 10 years or more. High pressure storage of hydrogen would be required on-board to fuel the vehicles.

C.10.3 Power Collection Options

Conventional Overhead Line Equipment (OLE)

This is the almost universal method employed on current tram/light rail networks, although the exact format does vary between systems. In essences it incorporates a suspended conductor wire supplying a voltage of typically 750dc to the tram or light rail vehicle via a pantograph attached to the vehicle roof. The key points to this system are:

Positive:

- Proven track record.
- Quiet operation; compared to conventional combustion engines.
- Energy efficient
    - Good power to weight ratio.
    - Highest acceleration.
    - No power used when vehicle is coasting or stationary.
    - Regeneration possible when coasting or braking.
- Compatible with the vast majority of current light rail vehicles.
- Cost effective procurement due to wide spread availability of technology and expertise.

Negative:

- Requires significant investment in OLE infrastructure.
- Visual impact, although this can be alleviated by appropriate design.
- Obstruction to maintenance adjacent to tramway; procedures and agreements required with 3rd parties and emergency services.
- Perceived electrocution safety risk, although readily mitigated through appropriate design to relevant standards and guidance.

Carefully designed OLE need not be unduly obtrusive if the aesthetics are considered from the outset. If a classic twin track down the centre of the road is adopted then a possibility could be a central post and cantilever system, possibly incorporating street lighting, which would eliminate much of the need for headspans across the full street width. This would be tantamount to hiding the OLE by making it a feature of the streetscape.

Ground based electrical power systems

Historically, there have been various surface collection systems employed in the UK and elsewhere. The one that survived the longest was the plough system used in London. Such systems were neither widespread or particularly successful and were eventually replaced by OLE based traction supplies. Implementation of such a scheme in Edinburgh should therefore be undertaken cautiously.

The London system was the most extensive and used a circular section conduit between the rails within which were placed power rails. The plough was connected to the tramcar by a link passing through a continuous slot in the roadway.

A modern equivalent is a concept scheme called *APS (Alimentation par Sol),* which is being developed in France and is intended for implementation in Bordeaux. This may offer a viable "state of the art" electrical based system when fully tested and proven in operation.

The system consists of a surface supply rail placed centrally between the running rails level with the road surface and divided into insulated segments, each 8m long. The contact surface is 8cm wide, surrounded by insulating strips 3cm wide.

Current collectors mounted underneath the tram activate the power rail which is only energized under stationary or moving vehicles. At all other points the power strip is not energized, and therefore poses no hazards to pedestrians or other surface traffic crossing the alignment. The exposed sections in advance and to the rear of the tram are always isolated.

The arrangement is comparable to the Ansaldo 'STREAM' concept which provides both supply and return surfaces within the street for guided buses. This technology has been under trial in Trieste, Italy using 12 and 18 metre buses. Experience to date from STREAM seems to be far from encouraging.

An obvious concern for *APS* concept in the context of the UK is that of the 8cm surface contact strip. This would need to be flush with the surface of the carriageway. There is already mounting concern in the UK of the effect of rails in the highway and like tram rails themselves, the strip will be a further hazard to other road vehicles. Consequently, an *APS* system may only be truly acceptable for a segregated section of route.

UK street track is typically based on rails being set within a reinforced concrete slab. To provide the *APS* duct within a conventional UK slab may necessitate increasing the depth of the slab to maintain its structural integrity. This is not a significant technical constraint and more of a costing issue.

The Bordeaux climate and the local terrain may be more accommodating than that of Edinburgh. Having a live electrical surface between the rails may encourage leakage of current in wet weather and this may be compounded by the British habit of salting roads in winter. Irrespective of climatic effects, the issue of stray current and electrical protection is one that would need considerable investigation.

The cost of *APS* is also unknown, but there are suggestions that it will be more expensive than conventional OLE, some reports suggesting by as much as 2 – 3 times. Such information will only truly be available once the Bordeaux system is completed and operational.

Finally, *APS* is a proprietary system. This would mean limiting the scope of supply to a consortium that can offer *APS* or, at least, the payment of a royalty for use of the design in addition to its installation cost.

Intermittent OLE

The use of intermittent overhead line equipment is unproven, such systems are probably not in operation anywhere in the world except on short sections to overcome an obstacle e.g. for lifting bridges in Holland.

- Overhead wire would be placed in short lengths sufficient for acceleration and braking either side of stops and at gradients and tight radii.

- The trams would coast between stops.

- Such a system does not allow tram to brake between stops, for example due to traffic conditions – onboard traction batteries would be required to cater for unscheduled stops which would also heat and light vehicle between powered sections.

- Guides at ends of wires would be required to bring pantograph and wire into contact. Which could result in a complicated and obtrusive arrangement to safely accommodate moving pantographs.

- Not suitable for a line built up of long sections, hence unlikely solution to the OLE issues to be addressed in Edinburgh.

C.10.4 Conclusion

The Edinburgh Tram is likely to be procured in the next 2 to 3 years. Of the traction and power collection systems discussed in this paper it is unclear whether any of these will constitute a viable alternative to traditional OLE or whether these could be proven during this time frame.

Consequently, it is recommended that the scheme is developed on the basis of a traditional OLE format.

This traction and power supply method as the most widespread and has been in use for in excess of 100 years and provides a suitable basis on which to develop the outline feasibility design, allowing it to be accurately assessed and costed.

The accommodation of OLE apparatus requires a relatively conservative system cross section compared to other possible alternatives. A OLE based design should ensure that land take requirements are sufficient to accommodate other traction options, which could be re-evaluated at a later stage in the procurement process without prejudicing the route.

Of the alternative power collection technologies discussed, the APS system being developed for Bordeaux holds the most promise. However, as outlined above, there are a number of technical and approval issues that need to be addressed, taking account of UK conditions. It is recommended that the implementation of the APS system is reviewed in the lead up to Edinburgh Tram's procurement.

C.11 Construction

C.11.1 General Principles

Code of Construction Practice

It is intended that a "Code of Construction Practice for Working on or Near to Edinburgh Tram Line One" will be developed in conjunction with Edinburgh City Council. The Code of Practice will address the environmental and safety aspects of the project affecting the interests of local residents, businesses, the general public and the surroundings in the vicinity of the works, and will be additional to statutory regulations. It will apply to both the construction and maintenance of the works throughout the whole period of the Concession Agreement. The Concessionaire, his servants, agents and employees will be required to comply in full with the terms of the Code and to incorporate it in any contract or sub-contract relating to any aspect of the scheme.

Constraints

Construction will need, where possible, to take account of and minimise the effect of the works on major events at venues within and in the vicinity of the City.

Construction Within the WHS, Conservation Area and Site of Special Scientific Interest

These works will be carried out in accordance with the guidance and codes of practice identified in the Environmental Statement.

C.11.2 Construction Appraisal

General

In sections where the tram runs on-street, the works required to support the tramway will generally consist of a reinforced concrete slab at an appropriate depth to support the rails while allowing for whatever surface finishes are required. For deep road surface construction and construction on bridge decks, the rails may be set on plinths above the slab. The concrete slab could be of insitu or precast construction, and be founded on a base of cement bound or compacted granular material with an overall excavation depth of between 0.56m and 1.2m, the depth of construction being dependant on the capacity of the subgrade. In the section running on the existing disused railway embankment without road traffic, the tramway will consist of a 'grasscrete' slab on similar foundations as that for the on-street sections.

Statutory Undertakers' plant and services lying within the excavation zone beneath the tram alignment will be diverted or lowered where required in order to reduce future disruption to the operation of the tram resulting from service repairs.

Sequence and Continuity of Construction

The sequence of the works at any one location will be governed by the detailed layout of the street/area and its buried services and any structural works required. For the majority of the route, services would normally be diverted in advance, and one by one, as a co-ordinated process under the provisions of the New Roads and Street Works Act (NRSWA). Work on the track bed and street/finished surface, in well-defined sections, would follow.

In areas where significant structural works are required, the sequence of working is likely to be more complicated. Access for construction to the structure(s) and to the route generally is likely to be the determining factor. This is particularly significant for the section of track running on the disused railway embankment and that along the sea wall.

In constructing the track the Concessionaire/Contractor will want to provide continuity of work for the resources at his disposal, this will require track construction to be as continuous as is practically possible or permissible from one end to the other. In order to optimise construction output, therefore, within each Work Section, the Concessionaire will want to open up as many areas of the alignment for construction of the track as the constraints allow. Inevitably, this will involve some areas of work remaining open while the different construction activities catch one another up. It may appear to the public in such circumstances where no construction activity is evident, that disruption is being caused unnecessarily.

On-Street Sections

For the on street sections the length of alignment that can be constructed in a continuous length will be defined by the requirement to maintain access and compliance with restrictions imposed by the Emergency Services, especially the Fire Brigade. Experience on other LRT schemes has shown that in narrow streets within city centres or in wider streets where access has to be maintained, the lengths of continuous track construction rarely exceed 100m because of the constraints and restrictions imposed. In these circumstances, the track will have be constructed in pre-defined bays with construction joints between adjacent bays. Within the WHS and City Centre core it is likely that restrictions on the construction process will be extensive and that the use of ‘Slipform’ procedures (as in Sheffield) or a paving train will not be practicable. Outside the City Centre core and WHS however the use of ‘Slipform’ techniques may be practicable.

New drainage collection will replace or supplement the existing surface drainage, but with the addition of outlets for track drainage at the low point of vertical curves and occasionally in between. Drainage pipes and connections away from the track bed or at an adequate depth beneath it will continue in use.

As a result of the likely disruption to the street surface caused by the diversion of Statutory Undertakers’ Plant and construction of the track slab, it is likely that the whole width of street will need to be reconstructed at some time. The benefit should be an improvement in the appearance of the general 'streetscape'.

Off-Street Sections

For the section of track running off-street on the disused railway embankment the sequence of construction will be determined by the available access to the embankment and the structures along this section of the route. It is likely that access will be limited and that the works to the structures including any utilities diversions will have to be completed before track construction proper can begin.

General Sequence of Construction

Bearing the above in mind, the general sequence of track construction following diversion of the services within each area will be as follows:

1. Site clearance.
2. Demolition if required.
3. Removal of hard landscaping, etc if required.
4. General excavation.
5. Installation of drainage, ducts and stray current protection beneath track formation.
6. Lay granular capping material if required.
7. Lay sub base/blinding.
8. Fix reinforcement.
9. Lay first stage concrete.

10. Install rails and complete stray current protection.
11. Complete drainage/ducting above first stage concrete.
12. Lay second stage concrete around rails.
13. Construct Stops where required.
14. Install main cabling.
15. Complete highway/accommodation works and final surfacing where possible.
16. Install OLE supports.
17. Complete final surfacing.
18. Install OLE wiring and complete cabling.
19. Energise and commission.

Construction of Substation and Connection of Main Power Supply

Construction of substations and connection of the main power supply cables will be carried out to suit the requirements of the power supply company and the programme.

C.11.3 Construction Activities

The following sections briefly describe the general construction activities for the project and their anticipated effects on the local community.

Site Clearance

Site clearance will consist of the removal either to tip or to store of trees, bushes, fences, street furniture, signs, lamp columns, bus stops, bus shelters, advertising hoarding and the like. The site clearance required along the proposed route will vary depending on location. In some areas it will be extensive and in others where areas have been cleared for development it will be only minor.

Removal of Existing Hard Landscaping to Store for Reuse

Where hard landscaping areas are present especially within the WHS, it is likely that wherever practicable the materials will have to be taken up and stored for reuse.

Demolition

The partial or complete demolition of some existing structures will be required to accommodate the construction of additional structures, or modifications to existing structures, required to accommodate the tram. Demolition is an especially dangerous "construction" activity and should only be carried out by qualified personnel experienced in the type of demolition being carried out. The Concessionaire will almost certainly employ a specialist demolition sub-contractor to carry out these works. The general public will need to be excluded from the vicinity of any demolition works.