

Traffic and Trams – The Edinburgh Experience



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Abstract

Several challenges arise in implementing a new tram system into any city and its transportation network. This paper will provide an overview of the impacts of running trams through the city, and includes a background of the project, the constraints and assumptions of the modeling, the methodology and models used, and finally report on the results of the complex modeling process and how it was effectively integrated into the design.

The model outputs provided good validation of the results from previous stage models, giving confidence in the process and providing a good check on the prior work completed. The outputs also provided an indication of the issues arising, and when viewed together, provided a map to the mitigation measures to be implemented and their potential carry on effects.

After completing the model runs and applying the various mitigation measures, an increase to the tram travel time of approximately 15% in the southbound direction and approximately 24% in the northbound direction occurred during in the AM peak. More significant impacts to tram travel time were seen in the PM peak, with increases of approximately 25% going southbound and nearly 30% heading northbound.

Introduction

The Edinburgh Trams project represents one of Scotland's most ambitious transport and infrastructure initiatives. Currently under construction, the £500+ million tramway is due to be up and running some 65 years after the last tram trundled through the city's streets. The 18.5 km route will carry passengers from Edinburgh Airport to the city centre and major development areas along the Waterfront and docklands (see Figure 1).

Funded by the Scottish Government and City of Edinburgh Council (CEC), the tram is seen as a preferred way to provide a comprehensive, high quality public transport network to help create sustainable development and economic growth. The tram system is also intended to encourage a modal shift from car to public transport and complement the city's bus services.

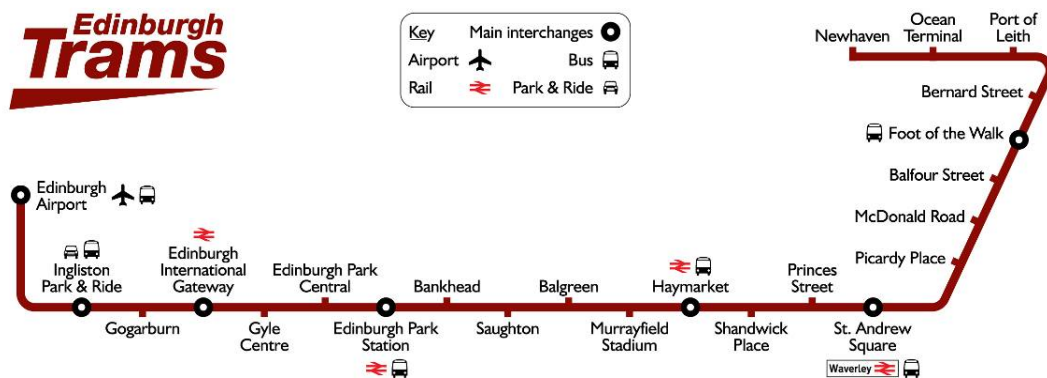


Figure 1. Line Diagram of Edinburgh Tram Network

This paper will focus on the design development of the Edinburgh Tram Network, highlighting the complex nature of the light rail design integration, the traffic modeling methodology, and the effects to run-time of operating trams through mixed traffic in the City Centre. It will provide a background of the project, the constraints and assumptions, detail the methodology and models, and finally report on the results of the complex modeling process and how it was effectively integrated into the design.

Background

The tramway will pass through many different urban and rural contexts. This includes city centre streets, business parks, existing transport corridors, farmland and former industrial areas. Approximately 7.1 km of the route runs on-street mixed with other traffic. There are 23 stops proposed as part of the initial construction, with 9 of these located within the mixed traffic area.

The tram system runs off-street from Edinburgh Airport in the west to Haymarket, where, at this key transport interchange, the tram route enters the existing roadway network. The route then moves east through Shandwick Place to Princes Street before turning north into St. Andrew Square. Once through the square, the route then turns abruptly east to Picardy Place, where it then shifts to a more northerly orientation along Leith Walk and Constitution Street. Once

reaching the waterfront, the alignment turns west, and travels along Ocean Drive, where it interfaces with much of the on-going and planned redevelopment of the port area. The alignment terminates after a short section of off-street running just east of the new Western Harbour development access on Lindsay Road. A future off-street section will also run along the disused railway corridor to Granton on the western side of the city. These alignments are shown in Figure 2.

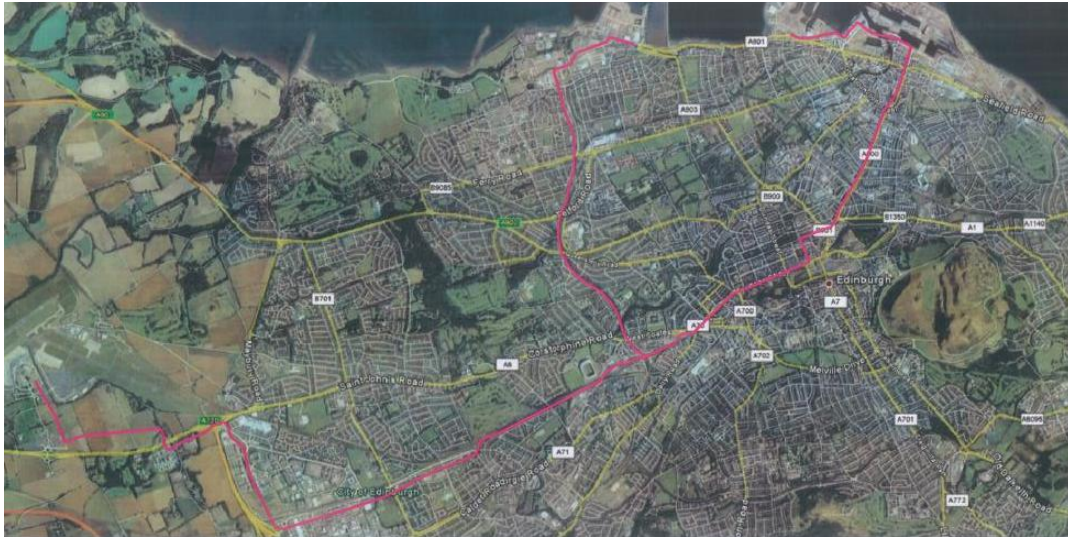


Figure 2. Map of Edinburgh Tram Network

The total length of the route required the modeling of 57 junctions and 10 pedestrian crossings.

Existing Conditions and Constraints

The on-street section sees tram running under a number of operating conditions. The aim was always to give as much priority to trams over junction to junction ('link') sections and at the junctions themselves. In theoretical terms, the tram has priority over buses, which in turn have priority over general traffic. In practical terms, the situation is more complex and requires a balance since additional time may be required to alleviate some side-road queues to keep buses in those side-roads moving.

In most of the city centre trams, buses and taxis will use the same running lanes and general traffic is excluded, giving 'transit' a level of priority. Pedestrians are given high priority as pedestrian volumes are so high in some places that normal signal operations have to be adjusted to prevent dangerous build-ups of people waiting to cross. In other parts of the city centre, where roads are wide enough, 'trambahns' (slightly raised sections within the road) are provided to give trams their own running lane. These lanes would only be used by other traffic in emergencies.

Leith Walk is a good example where the road is wide enough for two lanes in each direction. Trams run in the centre lanes and general traffic and buses run in the kerbside lanes, with buses allowed to pass general traffic by crossing over into the tram lane. Leith Walk has many

side roads and with the tram, right turn accesses into and out of many will be prohibited due to the geometric design, including the requirement to place the overhead line power poles between the tracks.

Where right-turn access is retained, the junctions will be signalised for safety and operational reasons. Traffic making right turns will move over from the kerbside straight ahead and left turn lane, to the centre (tram) lane, at a designated location prior to the junction, meaning a queue can form in the tram lane ahead of the next tram. In order to maintain tram priority, the queue must be cleared out before the tram arrives. As trams approach each junction, they pass over detector loops which tell the traffic signals to start the change sequence ready to give the tram a green light. These loops must be set further back than normal to give enough time for the right turners to clear.



Figure 3. Rendering of Centre Poles on Princes Street

There are two further complicating factors which made the traffic modelling more complex:

1. First, because right turners are not allowed to cross in front of a tram coming from the opposite direction, all traffic from the opposite direction including that going straight ahead and turning left must run at a different time in the traffic signal cycle (a different 'stage' of the traffic lights). Since the overall amount of cycle time in the traffic signal sequence is fixed (as discussed below) introducing the extra stage reduces the overall capacity of the junction and so brings many junctions closer to or over congested conditions on one or more arms of the junction.

2. Second, for safety reasons the Council would not allow traffic signal stages to be skipped when a tram is coming, that is, there must be no 'Hurry Call' for tram and every stage in the sequence must always be called¹. Some junctions are complex and need 5 or 6 stages in the cycle to allow all possible pedestrian, traffic and tram movements to be made.

This is where complex modelling of tram detector loop positions was carried out.

The 'prepare' loop, the first loop the tram passes, tells the junction that a tram is coming. It must be located the distance it takes for a tram to travel through all of the junction stages. This is calculated by adding the time it takes for each stage to run to the legal minimum amount of green time plus the time between greens which is called the 'intergreen' period. The latter varies depending on junction's geometry. The second loop the tram passes (the 'demand') is located at the distance it takes for the signals to change from the stage prior to the tram-related stage to the tram-related stage itself (plus any additional time to clear out the right turners referred to already). The stage prior to the tram-related stage is held until the tram passes the second loop. The tram-related stage can be cancelled by a third loop after the tram has crossed the junction stop line, provided that enough time has passed to clear out any traffic.

Assumptions

The modeled year for the basis of the study is 2010, in which two time periods are modeled: AM peak – 08:00-09:00; PM peak – 17:00-18:00

Two distinct tram frequency times have been used. Through the majority of City Centre, the model assumes 16 trams per hour in each direction (approximated to 120 passenger car units or pcu). The exception is to the west of Ocean Terminal where there will be 8 trams per hour in each direction (approximated to 60 pcu). This equates to the peak operating scenario for the system.

A cycle time of 225 seconds has been used for all junctions in City Centre. This has been done to account for 2 trams arriving (one in either direction) within this time period. All stages appear twice, so in theory it is a double cycle of 112.5 seconds. Off-street junctions where trams are only due to appear every 450 seconds (one in either direction); have been optimised for best performance.

On the approach to each junction there are four distinct traffic combinations. These are:

1. Traffic lanes only;
2. Tram only lane;
3. Tram, bus and taxi lane (combined); and
4. Tram, bus and traffic lane (combined)

In cases where a traffic phase ends and another traffic phase begins the intergreens were calculated as per the vehicle collision points method outlined in *DfT Traffic Advisory Leaflet 01/06*. The only exceptions are intergreens between a tram and vehicle phase were calculated

¹ The only exception is if the stage is for a tram only and the tram is not approaching.

by the same method outlined above with the addition of 20m (half the length of the tram) to clear the conflict point. Similarly, tram minimum greens in City Centre were calculated using the tram speed and distance.

The default minimum green time for any phase in all scenarios is 7 seconds, excluding a tram only approach which can have a 5 second minimum. *DfT Traffic Advisory Leaflet 05/05* timings were used to calculate leaving pedestrian intergreens and minimum greens. The saturation flows for each turning movement were calculated using the *Transport Research Laboratory Research Report (RR67)*. Models have been optimised around the required lengths for tram stages. These stages are sometimes extended to let traffic through after the tram if required for optimum junction performance.

As CEC criteria required no stage-skipping, the stages in the first half of the double cycle mirror the stages in the second half of the double cycle, although the lengths of either half of the cycle may differ as this is dependent on tram arrival times. In some instances it is not physically possible to run through a minimum cycle before required tram green time and thus the tram is delayed.

Many local bus services will be altered with tram implementation. The main operator, Lothian Buses, will also operate the trams. They plan to curtail many of its cross-city routes, especially those that currently use Leith Walk. These routes from the west and south will terminate at the bus/tram interchange proposed for St Andrew Square. Through customers towards Leith will transfer onto tram. At the other end of Leith Walk, another major interchange point will be created for reconfigured bus routes to meet with trams. Buses would then be re-distributed to other areas in the city to improve the feeder service network.

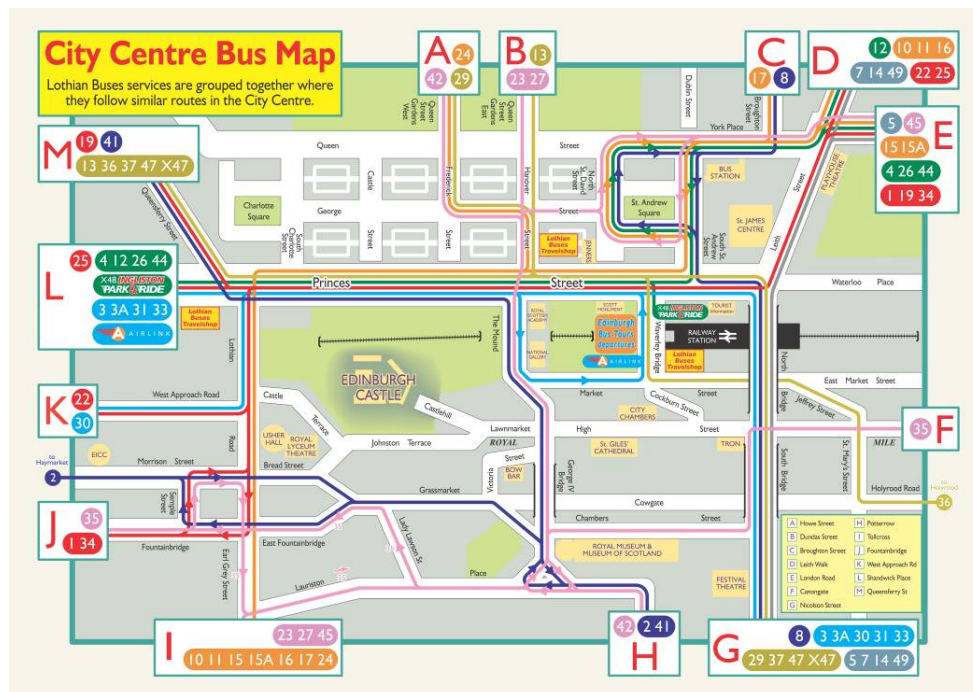


Figure 4. Lothian Buses through City Centre

Approach to Design and Modeling

Design

It was recognised at an early stage of the project development that significant changes to the geometric and operational characteristics of the City would be required in some areas upon implementation of the tram scheme to achieve the maximum benefit to the City, including improved traffic operations and benefits to the surrounding urban environment. As the traffic models and detailed designs developed in parallel, discussions were continually held between the Council and the designers related to the possible options at various key sites. Advanced traffic modelling, utilising limited design and traffic data, was completed on many options to give a high level initial indication of appropriate layout considerations in terms of traffic operations, which could then be moved forward at an early stage for consideration and with the geometric design and planning considerations to determine their viability.

The team worked together to outline the requirements of traffic movements. A key principle for consideration was the priority established for the various users of space, as this would have a fundamental impact on the traffic modelling work. After long discussion, including strategic planning charettes, the Council agreed on the following priorities in terms of integrating the new tram into the spaces of Edinburgh in a safe and efficient manner:

- Pedestrian movements / urban space requirements;
- Tram movements (fixed guide way);
- Bus requirements and interchange;
- Access and delivery requirements;
- Parking provisions;
- General traffic movement.

The Council also provided their inputs and lessons learned from previous projects with respect to the concepts put forward. Additionally, discussion with bus operators ensured that the integrated solution met the overall transportation needs for the area. The integration of the work was continually discussed throughout the design development through various forums such as working groups, meetings, and ultimately through the design approval process.

Traffic Modeling

Traffic modeling of the project was progressed in parallel with the geometric designs. This included reporting results through the preliminary design and the detailed design stages. Additionally, as various change works were being introduced through the planning process, the traffic modeling approach was adapted to accommodate the necessary information requirements of the project

In order to meet the requirements of the tram project, five separate models were required to analyze this complex implementation of the trams. These models included:

1. Tram Journey Time model
2. VISUM
3. VISSIM
4. LINSIG
5. TRANSYT

The approach to using these models required that work was undertaken in series, as the results of one piece of work fed directly into the next stage of modeling. This required that a strict schedule be developed and the design development be closely coordinated with the model development such that the various inputs and outputs were retrievable in the required order.

In the early stages of development, several key junctions were modeled, designed and discussed with the client in an iterative process. Early traffic flow forecasts from VISSIM were taken into individual junction LINSIG models for testing and amending different proposed junction designs.

Tram Journey Time Modeling

A traditional rail model was utilized to work out tram journey times. The model accounted for geometric features such as gradient, speed limits, and curvature of the track, however it could not account for the effects of traffic on tram journey times through shared running sections. Therefore, to see how running in traffic would likely impact on idealised tram times, the outputs from the rail model were needed to be used in another traffic model. This model provided a tram run time of 21 minutes 9 seconds for northbound vehicles, and 21 minutes 41 seconds for southbound vehicles, and represents the 'best' or minimum travel time that could be expected with no other influences from traffic.

VISUM

VISUM is a multi-modal traffic and public transport model suite which was used to develop a strategic model for Edinburgh and the region. It was developed by others, with the outputs provided to the team for use on the tram design development. The model represents more or less the whole of Scotland, however the closer one gets to Edinburgh the more refined the model becomes until, along the tram route itself, nearly every junction is modelled. Trams, buses and general traffic are included which means it was possible to predict how many car and bus trips will transfer to tram.

The model's primary purpose was to produce the business case for tram; however it was also an appropriate tool to provide peak time traffic flows through major junctions and at almost every junction along the tram route. These flows were taken into the VISSIM model.

VISSIM

VISSIM had a very detailed representation of the road and public transport network in the city and because it is a very 'visual' tool it is possible to see how the model assigns vehicles through the network, with the graphics making it possible to physically see cars, buses and trams moving along the roads.

By adjusting traffic signal settings in VISSIM it was possible to see how efficiently individual junctions would operate and where queues might build up. It was also possible to see how well trams were likely to progress through successive junctions and provided an indication of times between those junctions. Getting these 'off-set' timings correct between adjacent junctions is important to maintain tram priority and giving trams a 'green wave' along its route.

LINSIG

So whilst VISSIM is an excellent tool, it did not provide all of the required information. For example, the model is not very effective at optimizing the detailed operation of traffic signals, something which was required by the CEC. For this, individual junction LINSIG models were developed. These show precise timings for green, red and amber signals including any 'phase delays' (things like filter-turns). Detailed information from LINSIG can be taken into road side traffic signal controllers.

The outputs from the models are provided in the form of practical reserve capacity (PRC). PRC indicates whether an individual junction is working satisfactorily within its capacity. Each individual approach to the junction has degree of saturation ($\text{effective green time} \times \text{Saturation Flow} / \text{Cycle time}$) and the worst of these is used to define the PRC. A positive PRC indicates a junction is working within capacity; a negative figure indicates it is over capacity. The PRC does not show how queue build-up can affect upstream junctions, so queue lengths are also assessed where junctions are densely located and where junctions are close to capacity.

The conclusion of the LINSIG modeling revealed that most junctions work within capacity, with significant spare capacity available at the pedestrian only crossings. Eight junctions were revealed to not be working within capacity.

Below is a summary of some of the more interesting results of junctions that did not function well:

- Ocean Terminal South: Required a high number of signal stages and the large area and relatively long distances through the junction from stop lines to leaving the junction meant that intergreen times were longer.
- Baltic Street/Bernard Street and Leith Walk/Great Junction Street junctions: Both have large volumes of west/east/west traffic passing through. The first tends to act as an informal northern ring road for the city. The second is in the centre of Leith. Because the latter is central to a major shopping area it also acts as a public transport hub. The Council and Lothian Buses wanted to reinforce the hub by making interchange between buses and trams easier. To do this meant removing capacity through the junction for general traffic. This increased congestion and some traffic also moved across to the Baltic Street/Bernard Street axis. As a result this too was predicted to be very congested.
- Picardy Place and York Place/Elder Street: A major hub for general traffic and buses. Already congested prior to trams the situation was expected to worsen with tram. For tram the situation was less serious since it runs segregated through the area, however it must still cross major traffic volumes at traffic signals.

The recommendations arising out of this modeling were to revise the relevant stage orders from what is was proposed in some detailed design drawings and to review CEC criteria of no stage skipping at key locations. In working with CEC and taking on these easily implementable recommendations, the design was able to mitigate the majority (about 5 out of 8) of the issues arising through the LINSIG modeling and improve the results of subsequent stages of modeling.

Alternatively, it was determined that the designs for three locations (Bernard Street/Baltic Street, Palmerston Place and Manor Place junctions), although over-capacity, should remain unchanged despite as they had been optimised for tram progression to the degree possible.

TRANSYT

LINSIG also has its limitations, for it does not show how queues at one junction can affect the operation of an adjacent junction². For this, a TRANSYT model was developed. TRANSYT is usually used to calculate the exact timings of one set of signals relative to another set close by ('off-set' times referred to above). However, in the case of Edinburgh, as the timings between adjacent junctions along the tram route were to be governed by the green wave, TRANSYT instead used to adjust timings for the side-road arms to stop too much traffic from blocking the tram route itself.

The recommendations from this model were to use TRANSYT stage timings in configuration of individual junction arrangements, as it offered improved performance. Similarly, the model highlighted where improvements should be considered for individual junctions to improve overall network performance.

Results

Each model provided individual outputs which were used in the subsequent stages of modelling. As the results were received, these were fed into the design development to determine the overall impacts and acceptability. This iterative process resulted in various outcomes for the key regions throughout the city centre.

The VISUM model showed how those trips that do not transfer onto tram could divert elsewhere around the road network. This happens because trams running on-street use up valuable capacity which in congested conditions especially, means some vehicles that can divert away do so. Not surprisingly VISUM showed the most popular alternative routes were ones that roughly parallel the tram corridor. Some junctions along the parallel routes were predicted to become congested and work was done to re-optimize traffic signal timings through those alternative junctions. A combination of LINSIG and a new traffic signal modelling suite called Fast Answers (not yet an industry standard) was used for testing purposes. In a few cases some wider area junctions were re-designed altogether to cope with significant increases in traffic.

The on-street section of tram runs through some heavily used junctions increasing the pressure on traffic capacity and, without careful mitigation, resulting in significant congestion. These include Haymarket (to the west of the city centre), Picardy Place - an important 'hub' for traffic at

² Newer versions of LINSIG now have this capability, albeit not to the same extent as TRANSYT

the north east corner of the city centre, and at two intersections in Leith, at Foot of the Walk / Great Junction Street, and at Bernard Street / Constitution Street.

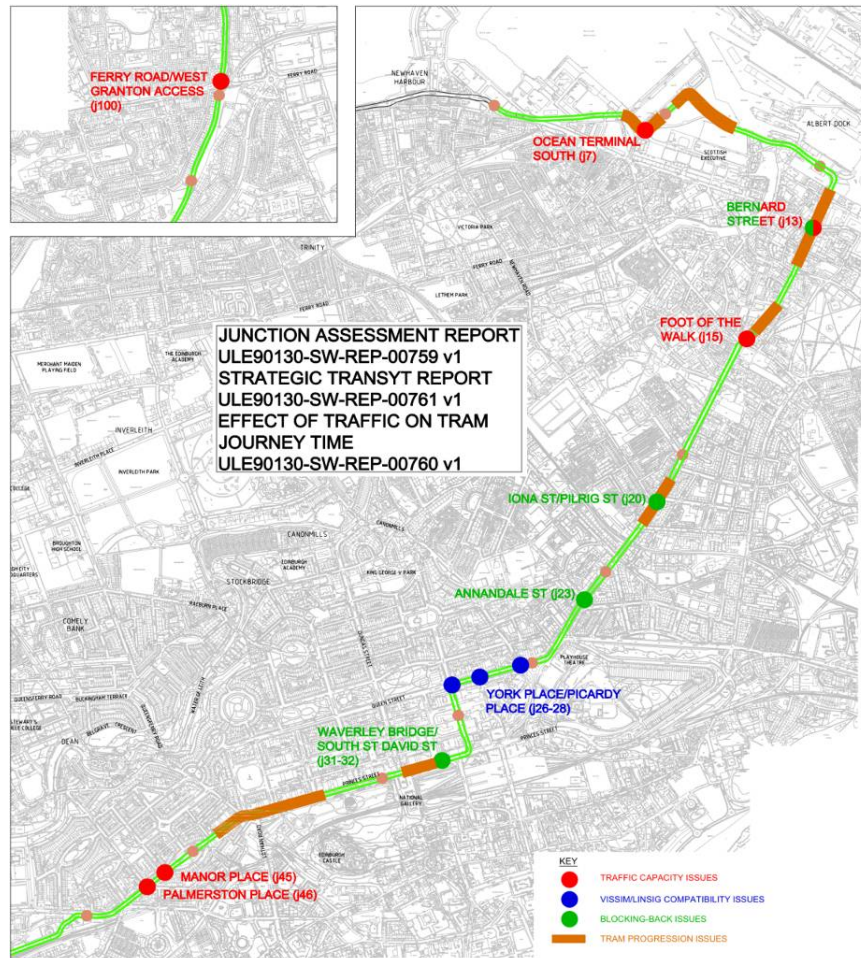


Figure 5. Summary of Modeling Results through City Centre

VISSIM provided the modelers with first indications of those junctions likely to be over-capacity. Where trams were proposed to run in traffic, the model also showed how tram progression would be affected. The stage lengths were also defined by the VISSIM model and were defined as the time required for the tram to progress through the junction, including clearing out any traffic in front of the tram. Because VISSIM is so visual, it was also an excellent tool for showing how different junction designs would likely work in practice.

There was a high degree of validation between the LINSIG and the VISSIM models. In other words, individual junction LINSIG outputs (basically lines of data) corresponded closely with what could be seen on the screen when VISSIM was run.

The TRANSYT results also validated well with the LINSIG and VISSIM. Alternatively, they also highlighted a number of issues which did not come through the other models. For example, in a couple of locations, queues were shown to develop on parts of the tram corridor between

‘staggered’ signal junctions. Examples included Iona Street/Pilrig Street and Annandale Street/Brunswick Street junctions. For example, large volumes of traffic would leave Iona Street, turn left for 50 metres along Leith Walk and then right into Pilrig Street. Queues would be seen to form at the Leith Walk/Pilrig Street junction blocking back to the Leith Walk/Iona Street. By careful manipulation of the signal timings, these queues were relocated back to Iona Street, leaving a relative free run for tram and other traffic on Leith Walk itself.

Traffic signal timings at all the on-street junctions were pivoted around the times that trams were scheduled to pass through and in this way tram priority was maximized around a ‘green wave’ through successive signal junctions. Modeling showed that the green wave should be sustainable over long sections. However at a handful of critical, congested junctions, the green wave is likely to be interrupted. This is because there is more demand from the total amount of traffic and trams during tram-related traffic stages than can be satisfied in the maximum amount of green time available. If time for the tram-related stages was to increase further, the consequences for other vehicles trying to get through other approach arms to the junctions would be significant and unacceptable.

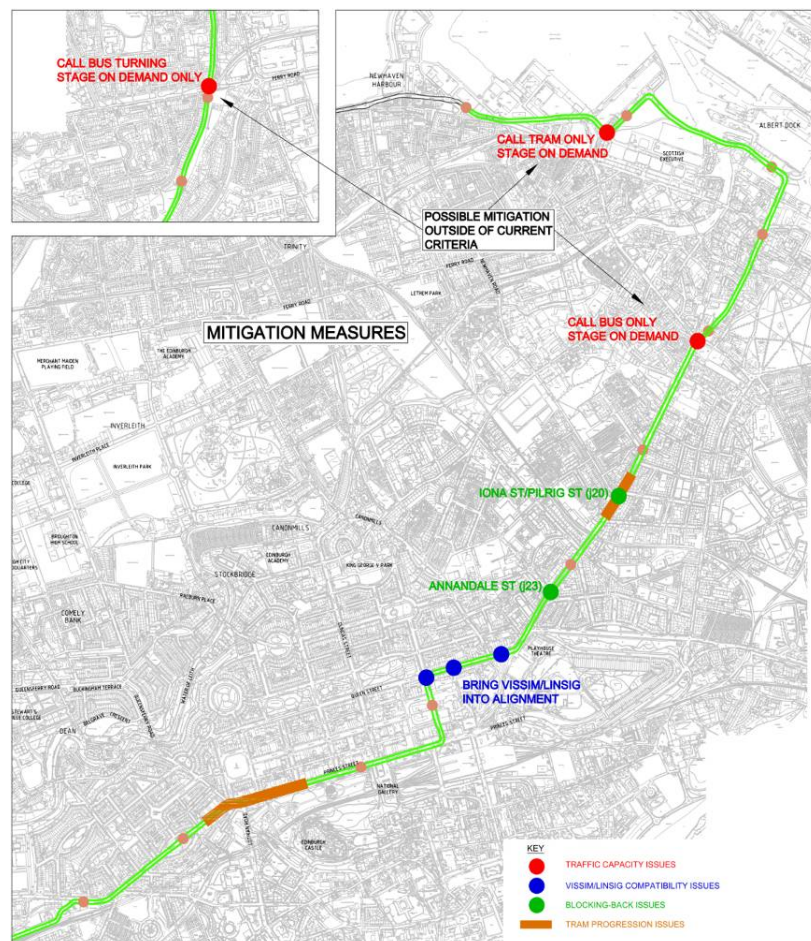


Figure 6. Proposed Mitigation Measures to Identified Problem Areas

Taking all of the above into account, the combined final modeling revealed the expected tram run times during peak hours to be:

Northbound AM Peak: 26 minutes 15 seconds (+5 min 6 sec)
Southbound AM Peak: 24 minutes 56 seconds (+3 min 15 sec)

Northbound PM Peak: 27 minutes 30 seconds (+6 min 21 sec)
Southbound PM Peak: 27 minutes 06 seconds (+5 min 25 sec)

This showed that the effect of running the trams through traffic had an impact of increasing the travel time for the trams of 15%(SB) and 24% (NB) in the AM peak, with a more significant impact to travel time in the PM peak, with increases of 25% (SB) and 30% (NB) expected.

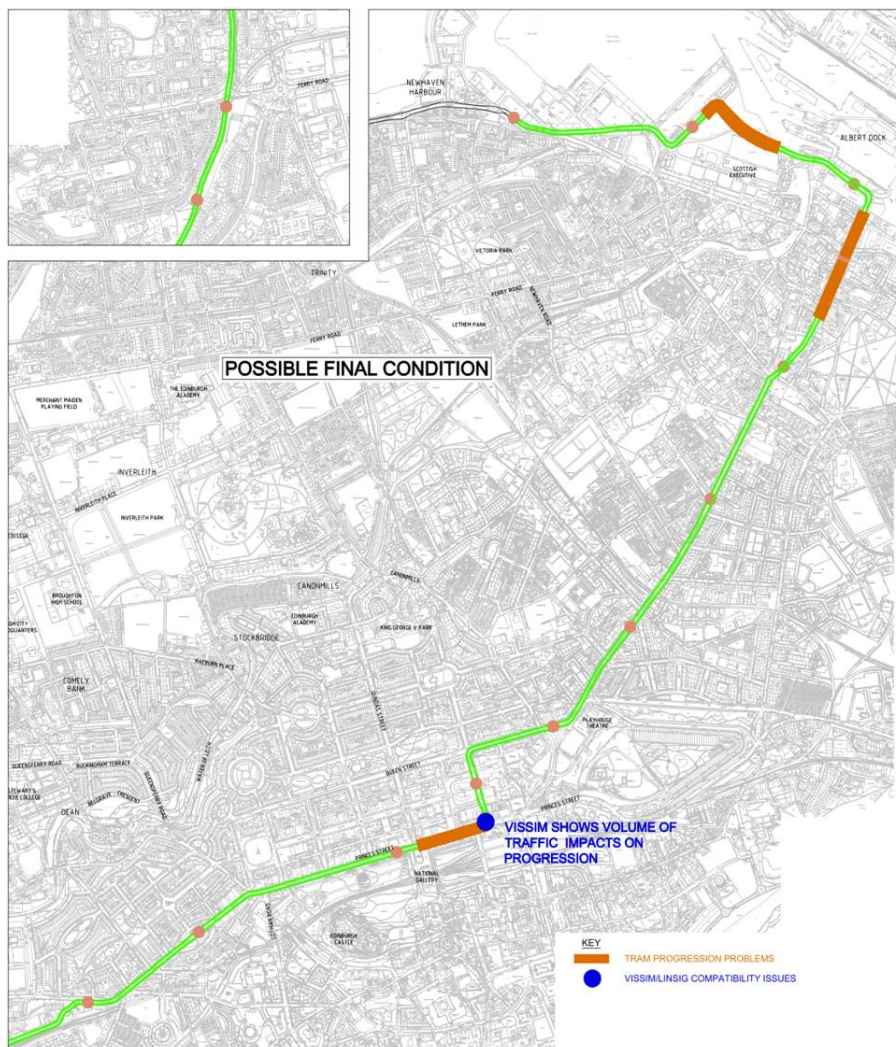


Figure 7. Final Solution to Traffic in City Centre, including Mitigation Measures

Conclusions

There are difficult challenges in implementing new tram systems into any urban context. In this paper, we have given an overview of the procedures and challenges which we were confronted with in Edinburgh for the traffic modeling, highlighted some of the key results, highlighted the value of the various model outputs, and described the expected impacts to the tram travel times due to traffic. .

The overall design work has not meant only meeting the complex technical and operational challenges of providing a new tram system for the city, but also sympathetically integrating the system into the historic streetscape and balancing the various requirements, including traffic operations, while providing an overall benefit to the city of Edinburgh and its citizen through an improved transportation network with the re-introduction of trams.

Great success was achieved by working in close partnership with the CEC, heritage organisations and other stakeholders to achieve a sympathetic and robust overall design solution for the City and its citizens. The integrated design approach overcame various traffic operations, urban planning and design challenges to meet the fine balance of requirements to achieve a viable re-introduction of trams to Edinburgh.

References

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