Integrating a modern light rail transit (LRT) system into an historic city centre

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Abstract

In June 2002 construction of the LUAS light rail system began in the historic city centre of Dublin. For this initial stage of the Dublin Transportation Office master plan, three lines are to be constructed consisting of on street, segregated and reserved track alignment. Within the city centre, this has meant the introduction of a 21st century track structure and highway design standards into a cityscape that dates back to the 18th century.

While the city has a wealth of rich architecture and historic streets, this has left a legacy of obstructions and uneven roads that the track alignment must navigate. To overcome these problems, the latest track design and computer modelling techniques have been utilised to integrate the track alignment into the existing city infrastructure.

The authors have used extensive CAD, vehicle motion software and 3D modelling techniques to develop the optimum alignment for the transport corridor. This has produced an integrated alignment for the LRT designed to accommodate all highway users.

This has culminated in the production of an innovative integrated 3D model that has been used extensively for the systems design, visualisation and construction. This paper describes how the 3D model is developed from the initial 3D survey to its use on the construction site.

Keywords: LRT design, Dublin LUAS, horizontal and vertical alignments, highway integration, 3D modelling.

1 Introduction

In recent years LRT systems have been considered a useful tool in the arsenal to combat inner city congestion. Routes are selected to maximise the customer
potential and often require the tram to pass through the busiest areas of a city. This can be a street that dates back hundreds of years or a new housing development. In all areas, integration of the LRT infrastructure and the existing environment is critical.

As well as limited space, the design of the LRT route has all the difficulties of highway design combined with those of railway alignment. For example, whilst it is possible for the alignment of low speed highways to change frequently, the smooth operation of a tram is dependent on a smooth horizontal and vertical rail alignment. Likewise, a street running LRT must be designed to be walked on by pedestrians unlike a segregated railway where you would expect only trained staff. In this ever increasing litigation society we live in, it is essential that everything is done to minimise the potential for injury to staff, customers and pedestrians.

With multiple stakeholders’ interests to consider and different design criteria for the rail alignment and highway, what approach should a designer take? Is it possible to produce a route that satisfies both the highway and rail authorities? How can the impact of design changes be minimised to ensure the successful delivery of the design? This paper explores these questions and provides solutions based on experience that has been gained from designing the LUAS, Dublin’s LRT system.

By following a structured approach to the design and harnessing the latest software, the designer can optimise the LRT route. By asking the right questions and agreeing each stage of the design in a systematic way, it is possible to produce a design that balances all stakeholders’ interests and minimises the risk of design changes.

2 Starting the project – the building blocks of the design

Normally, an LRT route consists of a rail alignment integrated within a highway. In a city centre the highway already exists and the LRT’s route is highly constrained by existing buildings and other structures such as bridges. Using Computer Aided Design (CAD) software and accompanying applications it is possible for the designer to create a digital representation of the existing landscape and LRT route. Within this virtual environment the designer can change and amend the design until the optimum rail alignment is found. This is done without the need for excavation or opening up a site.

2.1 The three dimensional model

The LRT route is designed through the creation of a three dimensional computer model. In its most basic form, the model will consist of a 3D survey of the landscape overlaid with the LRT route design. Using specialist software, the LRT route design can be integrated with the 3D survey to create an accurate scale representation. This is known as the 3D model.
2.2 The model components

The model is created by the designer using a 3D survey of the site, design criteria and standards, software and experience. Figure 1 illustrates the main building blocks of the 3D model.

![Diagram](image)

Figure 1: The model components.

From the very start, the designer must be fully aware of these building blocks and have a clearly defined strategy for design.

2.3 Survey

If the design of an LRT was likened to a bottle of wine then the survey would represent the grapes i.e. it is the essence of its taste. If the grapes are substandard then it doesn’t matter what the vineyard does as the wine will never become a vintage. Likewise, if the designer receives incomplete and inaccurate survey data regardless of the designers experience and software, the design output will be potentially unworkable.

If the designer is not directly responsible for the survey then care should be taken to accurately specify what is required. An LRT is not the same as a railway or a highway, therefore different survey information is required. Without prior experience this is not always known and to have an area resurveyed and subsequently redesigned, can be very expensive.

2.4 Design criteria

Following on with the wine analogy, design criteria are represented by the fermentation process. This clearly defines the length of time allowed for fermentation to take place and the temperature it should be stored at. The design criteria will define the LRT’s route and how it will integrate into the city streets.
2.5 Rail alignment design requirements

At concept stage, a tram vehicle can be chosen to suit a proposed rail alignment. However, once the design develops the alignment must be defined by the chosen tram vehicles size and motion characteristics. Changing the tram vehicle once design has begun can be a very costly exercise as the entire route must be checked to ensure it remains compatible.

2.6 Highway design requirements

The highway design criteria can be less clearly defined and are usually at the discretion of the local highway authority. It is advisable that the criteria is specified and agreed prior to commencing the design as it has a significant impact on the LRT route. Table 1 identifies the highway features that will impact the LRT route.

Table 1: Highway design criteria and the aspects of the LRT route affected.

<table>
<thead>
<tr>
<th>Highway Aspect (minimum and maximum values)</th>
<th>Design Impact on LRT Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carriageway Widths</td>
<td>Horizontal Alignment</td>
</tr>
<tr>
<td>Footway Widths</td>
<td>Horizontal Alignment</td>
</tr>
<tr>
<td>Kerb Heights</td>
<td>Vertical Alignment</td>
</tr>
<tr>
<td>Footway Crossfalls</td>
<td>Vertical Alignment</td>
</tr>
<tr>
<td>Carriageway Crossfalls</td>
<td>Vertical Alignment</td>
</tr>
<tr>
<td>Drainage Criteria</td>
<td>Drainage Design</td>
</tr>
</tbody>
</table>

2.7 Software

Software is the fermentation equipment and is there to assist the designer optimise the LRT route. The client will nominate the base platform CAD package; this will usually be Microstation or AutoCAD. There are software applications available to run in both formats that can assist designers develop the LRT’s route.

The 3D model is created using specialist software for highway and rail design. These applications have been developed by industry experts and include many of the design calculations and routines required to produce rail and highway designs. Using their 3D functions the horizontal and vertical designs are combined to develop a 3D model. Also available are two-dimensional programmes that model the movements of trams and road vehicles. These are used to ensure that clearances between vehicles and structures are maintained and define delineation lines and kerb positions.
3 Design – creating the LRT route

The longitudinal nature of the LRT route means that design changes have an impact beyond the aspect that has been altered. For example, a change to the horizontal alignment has an impact on the vertical alignment which in turn has an impact on the drainage as the falls and low points may have changed. For this reason it is essential that a structured approach to design is followed to minimise the impact of any changes. The design sequence is driven by this and is illustrated in Figure 2. The dotted lines represent possible design iterations.

Figure 2: The LRT-route design hierarchy.

The designer must then consider what information the contractor requires to construct the LRT infrastructure. Typically, this will be an accurate rail alignment, a plan and a series of indicative cross-sections. This will assist the designer to develop a process that delivers the information required efficiently.

3.1 Horizontal alignment

The horizontal plan of the LRT system is defined by highway and rail alignment requirements and obstructions. Amongst others, these obstructions can be structures defining the LRT’s corridor a bridge pier or a manhole. The designer must identify all obstructions and categorise their importance. For example, whilst it is absolutely necessary to remain clear of a bridge pier, it may be possible to relocate a manhole.

The designer can then produce a smooth alignment for LRT operating speed that maintains all the tram clearance requirements while maximising the space available for the highway. This can be a difficult process as the highway and tram authorities can have differing opinions of where priorities lie. For example, a curve introduced to the rail alignment may increase the carriageway width available but could have a negative impact on the trams operating speed.

3.1.1 Software

There are several CAD applications available to assist in designing the horizontal plan. Firstly, all obstructions are located. A horizontal alignment is then...
designed using rail alignment and tram vehicle motion software. An output of this process is the tram’s swept path that is used to define the kerb lines adjacent to the tram route. The remaining highway is then developed in coordination with the local highway authority. Road vehicle motion software can be used to determine the radii and widths of complicated road junctions. Figure 3 demonstrates this process.

3.2 Vertical alignment

As defined within the ‘design hierarchy’, the detailed design of the vertical alignment should begin when the horizontal has been fixed. The design can be completed in two parts:
- Stage 1: Development of a zone wherein the alignment can lie.
- Stage 2: Accurate placement of the alignment.

Although not desirable it is acceptable for a speed restricted highway to have a certain amount of undulations within its longitudinal profile. This is common within historical city centres that have been developed over many years and do not comply with modern design standards. Curves within a rail alignment must be smooth and are governed by minimum acceptable curve radii. Therefore the addition of a rail alignment to a historic city centre is a balancing act of meeting the highway and rail alignment design criteria.
3.2.1 Software
Using standard highway design software, we have developed a method for optimising the rail and highway vertical alignments. Firstly, a ‘roadway modeller’ tool is used to develop a ‘zone’ that an acceptable vertical rail alignment can fall within to meet highway criteria. This is based on the maximum and minimum allowable tolerances for the highway and footpath cross falls and kerb heights. This rail alignment is developed by running a series of cross-sections along the LRT route that lock onto the back of footway levels defined by the 3D survey. By allowing the cross falls and kerb heights of the cross-sections to vary it is possible to obtain a lower and upper level of the vertical alignment. An example of this is detailed by Table 2 and Figure 4.

Table 2: Examples of highway design tolerances.

<table>
<thead>
<tr>
<th>Template zone</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerb height</td>
<td>135mm</td>
<td>100mm</td>
</tr>
<tr>
<td>Road cross fall</td>
<td>1:40</td>
<td>1:60</td>
</tr>
<tr>
<td>Footpath cross fall</td>
<td>1:40</td>
<td>1:60</td>
</tr>
</tbody>
</table>

The final stage of this process is to represent the ‘zone’ in a longitudinal profile and design a vertical rail alignment that fits within its limits. Provided the rail alignment meets its design criteria, the 3D design should meet both the rail and highway requirements.

Using this process, it is clear where it will not be possible to meet all the design criteria. Where this is the case it may be necessary to request a dispensation against the highway design criteria, for example decreasing the
minimum kerb height requirement may allow the rail alignment to be higher. A section of the 3D model in the form of a few cross-sections and longitudinal profile is usually sufficient to present a case to the local highway authority.

3.3 Drainage design

The drainage design is a function of the catchment areas, longitudinal profile and cross falls of the highway and LRT tracks. This information is best represented in a series of cross-sections and a longitudinal profile. The highway and rail alignment modelling software can be programmed to annotate sections and profiles automatically. At complicated locations such as road junctions the direction of falls is not always clear, particularly the roads crossing the tram route. Using the modelling software it is possible to produce a contoured plan that clearly shows the directions of falls (perpendicular to the contours). Using this information gullies can be located at low points and to prevent the flow of surface water over pedestrian crossing points.

For drainage purposes it is undesirable to have level sections of the LRT route. At these locations all efforts should be made to maximise the longitudinal gradient within the vertical alignment zone generated by varying the cross falls and kerb heights. Where it is still not possible to attain a sufficient longitudinal gradient then other drainage strategies should be considered such as false channelling and cambering the surface between the rails.

4 Outputs – using the 3D model

All outputs will come from the 3D model and will be represented in one of two formats depending on the requirements of the client.

- **Drawings**: Usually used for approvals and seeking dispensations.
- **Excerpts from the 3D model**: Used by the contractors for setting out on site.

4.1 Drawings

Drawings are produced by placing a border around a section of the model. It is possible to include and omit information as required. For example the drainage drawings will require gully locations and sewers to be shown but the ducting runs should be turned off. A correctly set up project will enable this method to be used easily for the production of all drawings.

4.2 Model files

The 3D model is an accurate representation of what the LRT route should be when constructed. Therefore, it is possible to provide the contractor with information taken directly from the model that can be used by the surveyors for setting out the work on site. This utilises the same equipment used to collect the initial 3D survey and is demonstrated by Figure 5. Information for everything can be delivered in this format from the rail alignment and kerb strings to the...
location of the road markings. As long as the initial survey was accurate, we can have confidence that the design, when built, will integrate into the original infrastructure.

![Diagram of design information cycle]

Figure 5: The design information cycle.

### 5 Conclusion

The production of an LRT route combines the problems associated with railway and highway design. It can also be subjected to several major stakeholders such as the highway and rail authorities. Add the effects of a city environment and the design soon develops into an intricate balancing act of meeting design criteria and pleasing different stakeholders.

If the route is to be developed successfully and profitably then the designer must follow a structured approach and harness the software packages available. By doing this, the designer can reach the goal of optimising the integration of the rail alignment into the existing cityscape. Referring back to the ‘building blocks of the design’ the following questions should be asked at the start and throughout the design process.

**Table 3: LRT-route development questions.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey</td>
<td>What information is required and in what format?</td>
</tr>
<tr>
<td>Design</td>
<td>What are the design criteria for the rail and highway design?</td>
</tr>
<tr>
<td>Software</td>
<td>What packages are available and what assistance can they provide?</td>
</tr>
<tr>
<td>Outputs</td>
<td>What information is required for approvals and construction?</td>
</tr>
</tbody>
</table>
5.1 Summary of benefits of using 3D-model

The 3D model allows the designer to develop an integrated design within a virtual environment. This means that different solutions can be attempted without any impact on the construction site. As the model is a 3D representation of what the finished LRT route will be it is possible to provide this information direct to the setting out engineers for use on the construction site. Figure 6 shows a section of the 3D model from the LUAS along side a photograph of the same constructed section.

![Figure 6: A section of the 3D model and a photograph of the constructed LRT.](image)

5.2 Future improvements to assist design

Software applications and their functionality are improving all the time and many software houses are amenable to suggestions. This section describes how we envisage LRT route design software could develop based on the contents of this paper.

- **Horizontal alignment design:** This will be a combination of the rail alignment and tram motion software and will automatically develop a horizontal rail alignment with minimum track spacing based on one side of the routes swept path e.g. a footway kerb. The software inputs will be the trams motion characteristics, clearance criteria and rail alignment design criteria.

- **Vertical alignment design:** This will be an advancement of the 3D roadway modeller and will automatically create the zone for the vertical alignment based on allowable cross falls and kerb heights. The software inputs will be the maximum and minimum values of cross falls and kerb heights and the survey tie-in points either side of the LRT route.
5.3 Recommendation for the aspects of each design submission

To develop the LRT route efficiently the correct design sequence must be followed. This can be at odds with an agreed design process of preliminary, detailed and construction drawings. Time can be wasted attempting to develop a vertical alignment before the horizontal has been fixed. It is therefore advised that the preliminary design aims to fix the horizontal rail alignment as this is the single most critical item. At this stage only an indicative vertical alignment is required. The final vertical alignment will be developed during the modelling process and should be undertaken at the detailed design stage.

Acknowledgements

The authors are employed by Halcrow Group Ltd as sub-consultants to Sinclair Knight Mertz Ireland for the design of the city centre sections of the LUAS LRT system. The client for this project is the Railway Procurement Agency who is responsible for delivering the LUAS LRT system.

References