Living Lab

Transport Infrastructure Efficiency Strategy

TIES LIVING LAB PROGRAMME

Automated design for cable routing, using the digital twin method (IP2)

October 2022

INTRODUCTION

Cable routing design currently takes months or even years if the task is particularly complex and requires numerous iterations. It is a laborious manual process that puts people in difficult, dangerous, inhospitable environments – often at anti-social hours – and disrupts the public transport network.

This information paper explains the rationale and steps involved in developing and testing a “digital twin” modelling technique and intelligent design software to alleviate some of those difficulties. The work was one of the four TIES Living Lab Programme’s physical asset demonstrators (project title: Cable route management system (CRMS) automated design).

The design automation technology developed for this project, known as ARC (automated routing for cables), makes the process of cable routing for underground tunnel cabling upgrades more efficient, and considerably safer, because it enables remote survey and design development. That reduces the number of site visits needed, reduces design development time, and has the added benefit of generating fully realised building information management (BIM) data that can be carried through to the maintenance and end-of-life stages.

BACKGROUND

The tunnels in the London Underground network are notoriously tight and cluttered. Plotting the most effective route for new cabling currently involves a detailed on-site survey of the existing tunnel surface, and then meticulous planning to take full account of a wide range of complex variables – from the state of the tunnel wall surface, to the physical properties of the cables themselves.

Transport for London (TfL) is upgrading the Piccadilly line with new rolling stock and also plans to upgrade the signalling systems. In support of these works substantial amounts of power, control and communication cables will need to be installed over some 70 km of railway.

Traditional cable route management systems (CRMS) are a disproportionately time- and cost-heavy aspect of introducing new signalling or communication systems in the London Underground owing to the following constraints:

- The cramped environment and limited space because of narrow tunnel gauges, existing cables and track-side assets
- The need to ensure that electromagnetic compatibility (EMC) is maintained

- Limits on minimum bend radii
- The need to provide maintenance access
- Structural weaknesses and water ingress.

All these constraints mean that, historically, workers have needed to undertake hundreds of night shifts in dirty and cramped environments to select the best cabling routes, and that any change in requirements can lead to substantial amounts of design rework. It also makes it very hard for contractors to accurately predict costs or impacts when selecting or modifying signal designs.

The purpose of this demonstrator project was to show that it is possible to reduce time, financial cost and risk (especially delivery team safety risk) by using customised CRMS design software.

Specific requirements of the project included:

- Creating a user interface to read, compare and modify automated designs
- Providing the client with greater up-front access to and control over materials and labour
- Demonstrating reductions in survey hours and costs and design development time
- The capacity to produce BIM data
- The capacity to optimise cable routing systems in existing Underground tunnels.

CHALLENGES

The ARC design automation technology was developed specifically for TfL and the TIES Living Lab project. However, the overarching digital methodology that underpins ARC was developed by Bryden Wood, and had previously been used in automating motorway design (with National Highways) and automating rail network design (with Network Rail).

The cable routing system described in this paper features a number of enhancements as well as modifications to overcome past limitations and to tailor the system to the needs of the Underground environment, including:

- Improvements to object classification, such as differentiating between long elements (e.g. beams) and cables
- Variations to cater for other types of sections of tunnels, for example by fine-tuning the algorithm for curved-line sections and open-sky or rectangular sections, or for very busy areas such as next to stations
- Creating a new user interface (a web app solution instead of a desktop solution) to make it easier to read, compare and modify an automated design.

DELIVERING A NOVEL DIGITAL DESIGN TOOL

The ARC system is a rules-based platform for optimising the routing of cables in tunnels. Developed in close collaboration with TfL, through regular workshops and project meetings, it brings together existing systems management software, geographic information systems (GIS) and other information tools.

Preparation

A large amount of data was needed from the outset. The data-gathering and analysis process started with the fundamentals – assessing the standards that TfL works to, to establish a vast set of machine-readable rules. This information, which had already been gathered before the project began, was used to tune Bryden Wood's existing methodology to the specific circumstances of the London Underground tunnel network.

A "digital twin" of an existing tunnel was created using two sources of information: data collected from a "laser point cloud survey" that was carried out using a series of fixed survey stations in the physical tunnel; and classification of the data points to differentiate between the assets installed in the tunnel and the tunnel surface (using customised object-classification scripts).

Two tunnels were analysed: initially a short tunnel (Liverpool Street to Moorgate) was used as a test case; then another iteration was tested on a second tunnel (Bayswater to Notting Hill Gate).

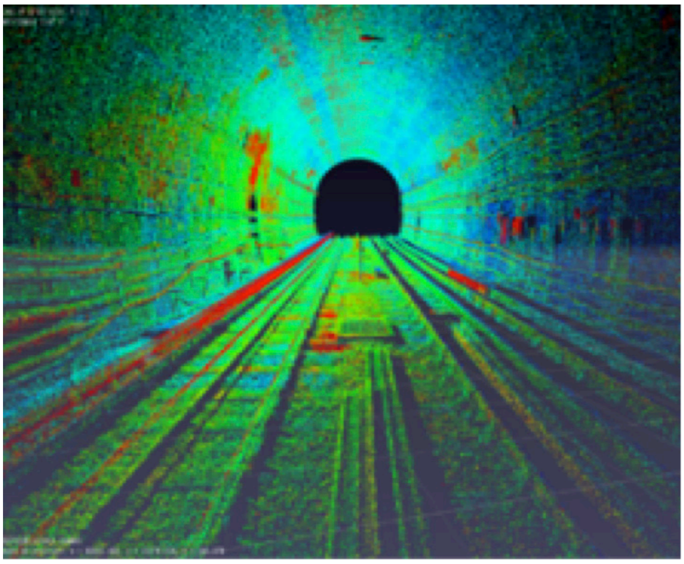
That dataset was combined with data on the built alignment of the tunnel, and then analysed to separate the tunnel surface from the various assets, such as existing equipment, cables and other objects. (The process is similar to the object analysis required for autonomous vehicles.)

The Python coding language was used for this project, with Rhino and Grasshopper for the computational design.

Automation

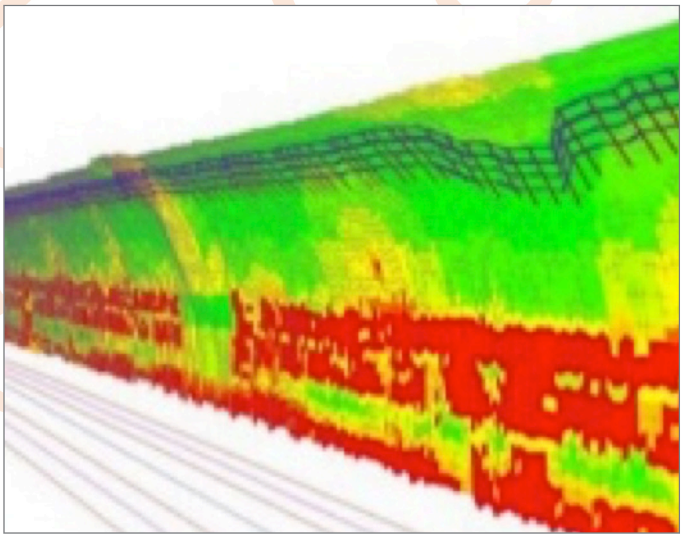
The design automation stage starts with applying the established rules that describe the optimal routing of cables in tunnels, for installation, operation and maintenance, as follows:

- The digital twin tunnel is divided into small sections (tiles of 125 x 125 mm: roughly the dimension of a one-way hanger) so that the design tool can assess every tile against the rules (from the TfL standards) and the data gathered from the current real-world status of the tunnel. This step checks the suitability of each tile in terms of, for example, height in the tunnel, or proximity to the rails or other objects.
- Each tile in each section of the tunnel is evaluated and ranked as to its suitability to host a new cable (or cable hanger).
- The "shortest path" algorithm then uses the combined results to plot the optimal route for a new cable through the tunnel section.



Output from an algorithm used for "distance comparison", which uses pure geometry to calculate the relative distances between points.

This analysis can also be adjusted to account for other priorities and variables, such as environmental considerations, cable type (e.g. because different cables have different bending properties) or new products.



Output from an algorithm used for identifying the positions of existing cables.

Verification

The system was tested on sections of tunnel in London from Liverpool Street to Moorgate, and from Bayswater to Notting Hill Gate.

Output data was provided in various formats, such as visualisation metrics and dashboards, 3D models and 2D information, offering several options for installation, and flagging any potential issues or particular points for consideration.

The parameters set for the project were that the demonstrator would be considered a success if it could be shown that the ARC tool could:

- Provide a single viable end-to-end cable route on a section of tunnel that had been manually designed previously
- Allow for a "live" manipulation of constraint hierarchy to produce alternative routes, and generate metrics for each option (e.g. number of hangers, length of linear cable)
- Show that by manipulation of the constraint hierarchy the software would produce a route selection that nominally matched the manual design.

It is important to note that there can be no "perfect" cable route design, just an optimum one based on specific priorities (e.g. minimum length of cables vs number of assets to be relocated).

Confirmation

Results from this project show that once the point cloud survey is complete, the first stages of the evaluation take just a couple of days, and generating design options takes a matter of hours. In this way, using ARC reduces potential travel network disruption, and health and safety risks for the workforce. Further, ARC design automation outputs also give the client much more up-front visibility and control over material, labour, capital and maintenance costs.

It is also worth emphasising that the overarching methodology here is transferable, with (already proven) applications across multiple sectors and scales.

Suggested cable design plot, based on the "shortest path" method.

LEAVING A LEGACY

As it stands, the ARC system can be used immediately by TIES Living Lab Partners when initiating projects to help develop and assess likely out-turn costs based on a variety of constraint hierarchies. This would have a significant impact on the sector's capacity for driving and informing some of the hard decisions that need to be made during large-scale upgrades, and would bring a level of cost certainty at a much earlier life cycle stage.

The improvements shown through this project are fully subjective at this stage, partly due to a lack of historical data, but also because this was a prototype trial and is therefore not fully representative of an "in-flight" project.

But what it does is show how the smart application of digital methodology and design automation can drive progress and deliver tangible value, in the tunnels beneath London, and far beyond as well.

The algorithms that underpin the ARC system are fresh and relatively under-developed but there is considerable scope for further development to eliminate some of the limitations. In the short term with progression this software could benefit a project with some reduction in concept survey time for large areas and enable more accurate project cost predictions around CRMS and cabling quantities, but to get to a reasonable level of confidence in relation to its autonomous capabilities more development, comparison test subjects and scrutiny are recommended.

Further enhancements could include:

- Integration between the digital models and video footage to enable easier design reviews and issue resolution
- Introduction of a flag system, whereby the route designer is alerted to constraints
- Creation of an asset register/catalogue that will allow the software to better identify existing assets
- Expansion to allow for autonomous design in external areas.

In the longer term there is considerable potential for wider applicability among the TIES Partners, including Network Rail, National Highways, HS2 and many construction companies. Indeed, the ARC system could be used on any mass transit system that is entering overhaul or upgrade works – from Paris to New York and beyond.

The project has received several industry awards, including being named "Transport Infrastructure Champion" at the New Civil Engineer TechFest awards in 2021, and receiving the Best Application of Technology at the Digital Construction Awards in May 2022.

This work was coordinated by Transport for London and delivered by experts from Bryden Wood Technology Ltd and the TIES Living Lab under the project titled Cable route management system (CRMS) automated design, overseen by the Cost and Performance Benchmarking Steering Group.

Living Lab

Transport Infrastructure Efficiency Strategy

The TIES Living Lab is a transformative collaboration of 25 partners together with Government, i3P and the Construction Innovation Hub that use data, technology and Modern Methods of Construction within live transport infrastructure projects to deliver significant value-adding benefits across the transport infrastructure sector. The programme is funded via a grant from Innovate UK through the Transforming Construction programme, plus contributions from the Department for Transport, HS2, Transport for London, Network Rail and National Highways.

The four strategic outcomes of the collaboration are to:

1. Improve the way Transport Infrastructure projects are set up to maximise value
2. Achieve better assurance of project and programme value and what assets should cost (benchmarking)
3. Accelerate the wider adoption of MMC
4. Establish the TIES Living Lab as a catalyst for long term cultural change across sectors by making a compelling case for long term HM Treasury funding to scale this facility.

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