Improving Urban Traffic Control with live multimodal data in Leeds

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Background

A competition win!

In 2018, Leeds City Council (LCC) entered, and were joint winners of, the National Infrastructure Commission-led Roads for the Future competition. The competition was focused on innovative ideas to create a road network ready for connected and autonomous vehicles (CAVs).

> National Infrastructure Commission announces winners of Roads for the Future CAV competition

The proposal submitted by the LCC Urban Traffic Management and Control (UTMC) team acknowledged that 'true' CAV data (i.e. sub-second position and object type data) was not currently available and would not be for the foreseeable future. Instead, it focused on whether it was possible to provide a signal control system with 'CAV-like' data in order to facilitate the development of new 'CAV-ready' systems. This was based on the premise that the provision of vehicle position data could improve the accuracy of traffic signal optimisation decisions.

The submission reported on the trial of two types of sensor, one radar and one vision-based machine learning (VivaCity) and demonstrated promising results in terms of the ability to track and classify vehicles (and, in the case of VivaCity, pedestrians and cycles) on the approach to a junction.

A public transport investment scheme

Around the same time, plans were being developed for a major public transport investment programme using funding originally allocated for an unsuccessful trolley bus scheme. These proposals were split into 'routes' (mainly arterial corridors) and 'gateways' (city centre regions).


Leeds' £250m trolley bus scheme rejected

12 May 2016

From an early stage, it was decided that the nature of the corridors meant that the traffic signal-controlled junction would, for the most part, be best suited to the Microprocessor Optimised Vehicle Actuation (MOVA) control strategy with some elements of Selective PRogramming in a UtmC Environment (SPRUCE) where sophisticated gating was required.

However, traffic signals across the city centre had historically been operated using Fixed-Time Urban Traffic Control (UTC), with little to no vehicle detection, to provide consistent coordination for large volumes of traffic. Telecommunications infrastructure across the city centre was provided by wireless networks using Asymmetric Digital Subscriber Line (ADSL) backhauls. As a result, there was very little existing ducting infrastructure.

An important decision

It was clear at this stage that there was a significant decision to be made on what method of control and associated vehicle detection to use in the city centre. There were some key points to consider as part of the decision-making process:

- The nature of the changes to the network (i.e. significant relocation of traffic out of the city centre) meant that an existing strategy such as MOVA could potentially have been used as coordination was to become much less important. Whilst recognising that above ground detection is used with MOVA and other existing control strategies, given the wholesale changes to the physical layout of the city centre network, it would have made sense to introduce inductive loop detection.
- High volumes of pedestrians and cycles were expected at the junctions and, in some cases, cycle movements were to be served in dedicated stages. Many bus stops, loading bays and the likelihood of pedestrians crossing away from formal crossing facilities meant that traffic flow was unlikely to be consistent on junction approaches. This meant that the ability to accurately distinguish between objects and track them through the junction was likely to be advantageous.
- At this point in time there was no commercially available optimisation strategy capable of fully utilising the data provided from the sensors trialled in the Roads for the Future competition.

Considering the successful trial and the richer data that it promised, it was ultimately decided to take the opportunity to implement a city centre-wide network of vision-based sensors covering 23 junctions and crossings. To complement the implementation of the sensors, a new traffic signal optimiser would be developed to make use of the rich data produced by the sensors and create a system capable of supporting the Connecting Leeds Transport Strategy ambitions.

Implementation of the new sensors would be supported by introduction of a high bandwidth, low latency private fibre-optic communication network.

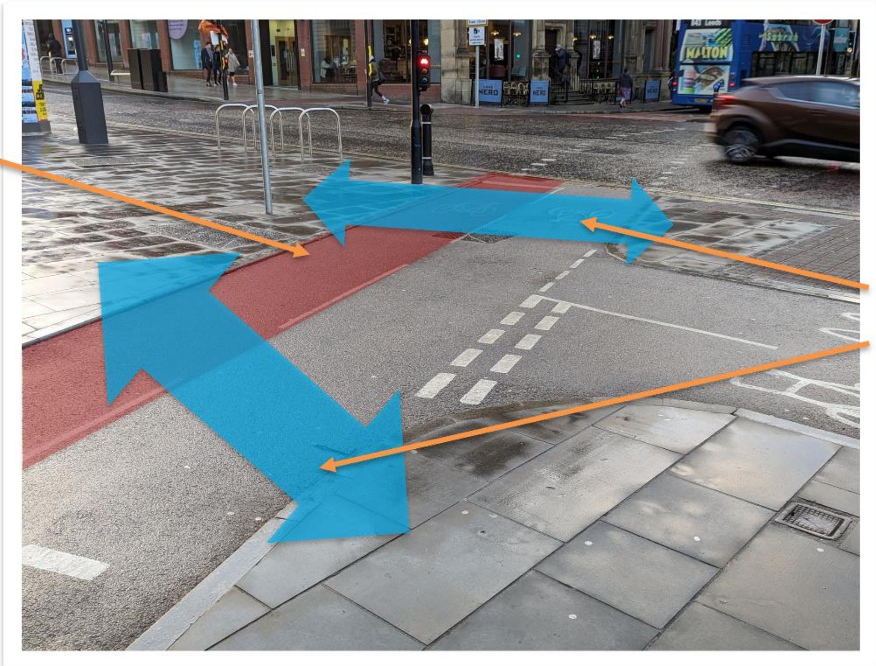
Development

Traffic signal controller integration

The medium to long term aim for the project was to develop a centralised optimisation strategy using anonymised data streamed from the VivaCity sensors to a central database. However, it was recognised early in the process that there was also the potential for the sensors to replace conventional local pedestrian, vehicle and cycle detector functionality. For example, if the sensors could also provide kerbside and on-crossing capability then it would become possible to provide all the detection requirements of a junction from the sensors.

VivaCity worked with Swarco and Telent to integrate the sensors directly into the PTC-1 and Optima controllers as opposed to conventional I/O through an interface card. Some of this work was driven by other Local Authorities (such as Sheffield City Council) at the same time which provided useful additional impetus. This successful piece of work added zonal occupancy and object classification (up to 13 road user types) to the controller capabilities and thus enabled the sensors to be used as a replacement for conventional inductive loop and pedestrian detection.

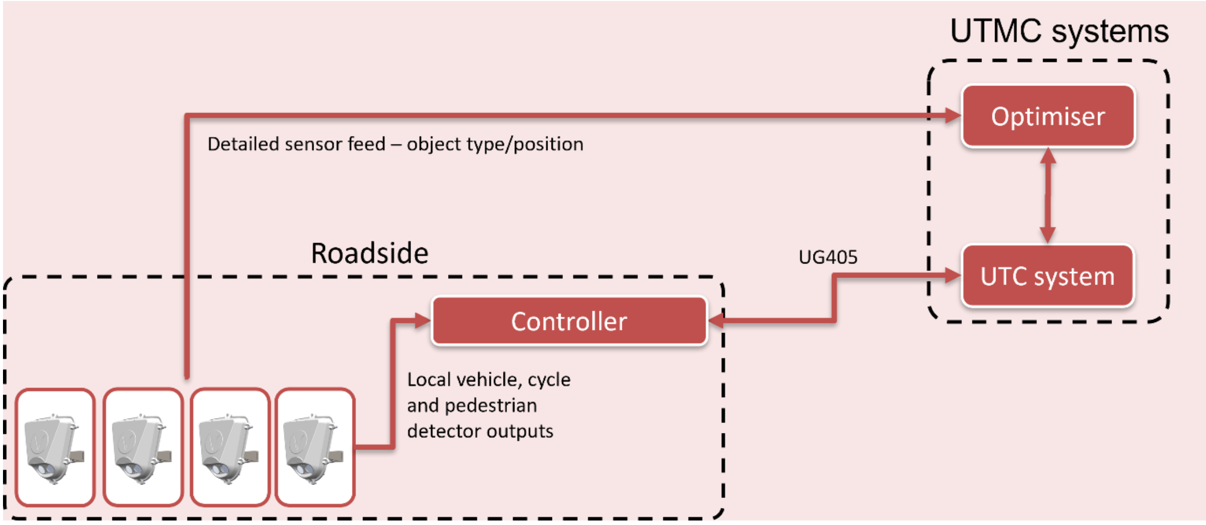
A single unit can replace multiple legacy detectors since any number of detection zones can be placed across the wide field-of-view. It also creates new possibilities within controller conditioning as the volumetric demand for each phase and mode can be used to configure a response based on demand level. For LCC, this integration was an important step in enabling junctions to be operated in Vehicle Actuated (VA) mode until a new optimiser was ready to deploy.



The practical benefits of using machine learning are already being demonstrated at various city centre junctions. The example above shows a cycle track approaching a junction where Cookridge Street meets The Headrow and the cycle track demands an additional stage. The ability of the VivaCity sensors to accurately distinguish between objects and accurately discriminate direction of travel significantly reduces instances of the additional stage being demanded unnecessarily.

Integration with UTMC systems

It was decided at the beginning of the process of developing the new control strategy that the system platform would be centralised. A centralised system removes the need for additional hardware at the roadside and can support any optimiser architecture, whether centralised (e.g. SCOOT), hierarchical (e.g. SPOT/UTOPIA) or fully distributed (e.g. MOVA), as long as it is supported by a low latency telecommunications system.



In addition to the local data transfer described in the previous section, object position and class data from the VivaCity sensors is also streamed to the optimiser database at sub-second frequency. The second data feed bypasses the controller and is output directly to the central system platform.

Close working with the Council's corporate IT department was necessary in order to segregate the network and provide the required access through the UTMC firewall. Fortunately, work had already recently been undertaken with the IT department and Swarco as part of the implementation of a hosted UTMC environment which meant that relevant relationships were already in place.

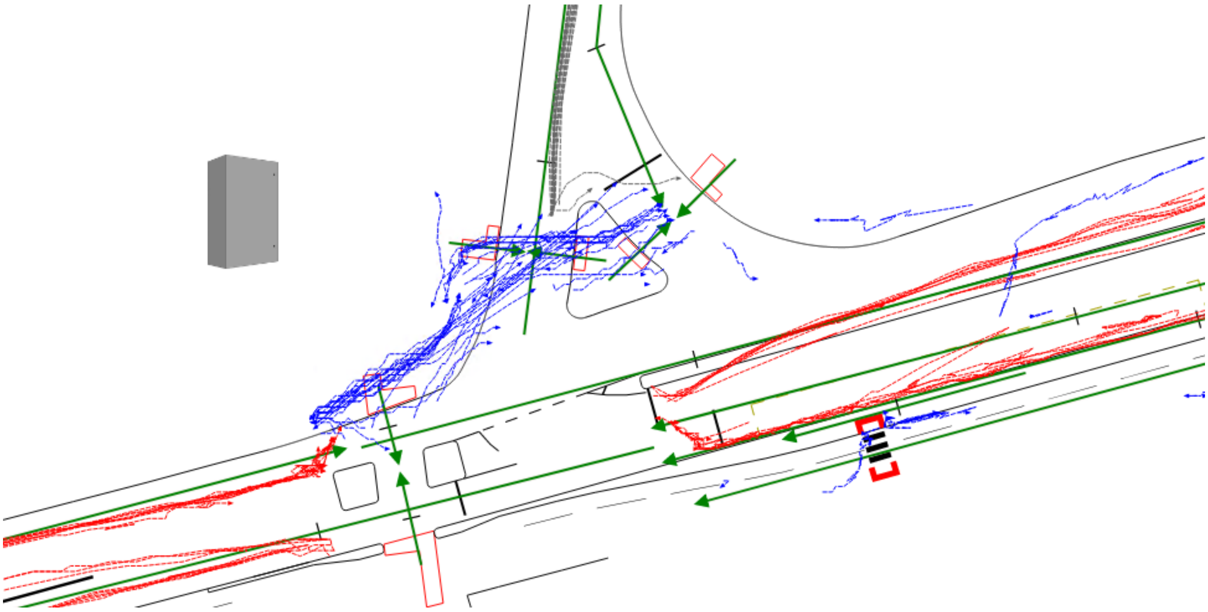
For the purposes of developing a proof of concept, the versatile SPRUCE system has been utilised given the existing integration with the UTC system. This enables the new control strategy to control and monitor traffic signal sites through the UTC system using SPRUCE as an intermediate step.

Optimiser development

The reason for developing a new optimiser was to provide a system capable of fully utilising the richer data provided by the VivaCity sensors in the absence of an existing commercially available product. The Connecting Leeds Transport Strategy ambitions include a significant increase in modal shift towards active travel and public transport. To support this, it was decided that the new optimiser should focus on minimising person delay – rather than conventional vehicle delay – as its primary objective function. To capture this shift in focus, and for the purposes of development, the project has been named INclusive TRaffic signal Optimiser (INTRO).

Development of the optimiser algorithm is continuing in parallel to a web-based graphical user interface (GUI). It is recognised that, without an intuitive GUI, a new system will be difficult to engage with, however good the optimiser itself proves to be.

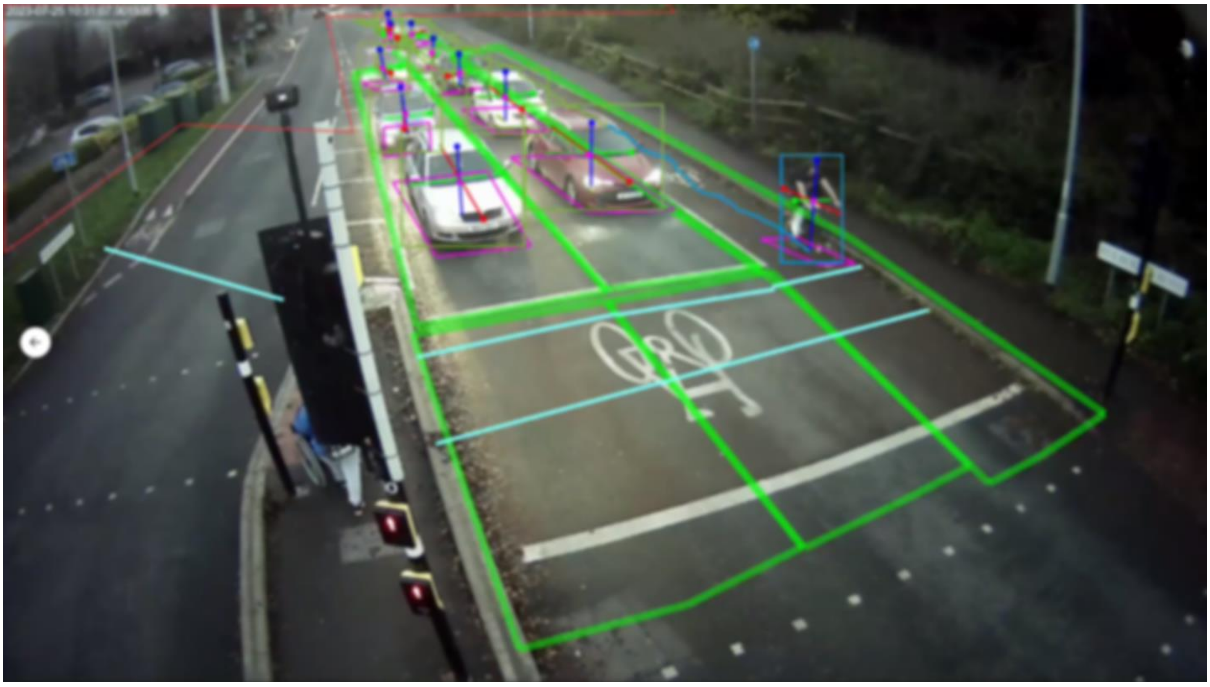
The image below shows object track data from the sensor plotted onto a simplified layout of the junction (buses in red, pedestrians in blue). The vehicle tracks largely follow the lanes shown in the drawing but with some exceptions, the cause of which is explained in the following section. The GUI allows users to create links (shown by green arrows) over the top of the plotted data – accounting for deviations – which are then used to 'snap' objects ready for use by the optimiser. Visualisation of the data has proven invaluable in ensuring accuracy of this process.



Challenges

Sensor development

A common limitation of computer-vision based detectors is the 2D bounding box around detected objects and drawing appropriate virtual detection zones such that this box (or a point on its boundary) is “within” the zone. During the deployment of the system the VivaCity sensors were enhanced with a “3D-pose” model, allowing the sensor to position a 3D bounding box around the detected object which provides a full estimate of its size, position and orientation. In this way, even at oblique camera angles the “ground centre” of detected vehicles (or cyclists and pedestrians) can be used to determine occupancy of the virtual zones - as well as more accurately determine their position in GPS coordinates.



The image above shows 3D-pose for detected objects. Even partially occluded vehicles and cyclists have an accurate representation of their footprint in 3 dimensions.

The 3D-pose enhancement has proved particularly beneficial where the sensors are being utilised for pedestrian kerbside and on-crossing detection. A 2D bounding box can lead to pedestrians incorrectly being observed outside a defined zone when actually inside and vice versa. The 3D-pose enhancement was therefore a key development to enable the sensors to replace conventional pedestrian detection.

Commissioning

The transport investment programme that led to procurement and implementation of the VivaCity sensors included significant remodelling of the city centre road network. As is often the case with major works, ducting for the fibre telecoms was not available until very late in the programme which delayed commissioning of the sensors.

Furthermore, to produce the GPS-space location of the detected objects used by the optimiser, the sensors must first be calibrated. This requires the GPS location of several known points within the field of view. This is challenging with brand new sites as satellite imagery is not up to date, and as-built drawings may not be available until months later.

Although feedback from signal contractors on the functionality of the sensors themselves is positive, the unfamiliarity for signal contractors has led to lengthy commissioning times. This is decreasing over time as signal contractors gain more experience. However, allowing installation engineers to perform basic functions such as adjustments to zone extents and basic network diagnostics could significantly decrease the time required on site.

VivaCity is currently working toward Traffic Open Products & Specifications (TOPAS) registration. VivaCity sensors currently perform all conventional detector functions but conventional on-crossing detection is still being used in parallel. Initial observations suggest the VivaCity sensors perform well and it is intended that the conventional sensors are removed once TOPAS approval is gained.

Optimiser

To build an optimiser from the ground up requires development in several areas. This includes:

- Processing the data received from street;
- Provision of a configuration tool for engineers to enter the optimiser controller model data (e.g. stages, min/max interstages etc);
- Provision of a configuration tool for engineers to create the link structure;
- A mechanism to control sites; and
- Compliance checking.

Each of these elements has provided its own challenges and has required in-depth knowledge of the various systems involved. Support and advice during development has been provided by BR Hallworth Ltd.

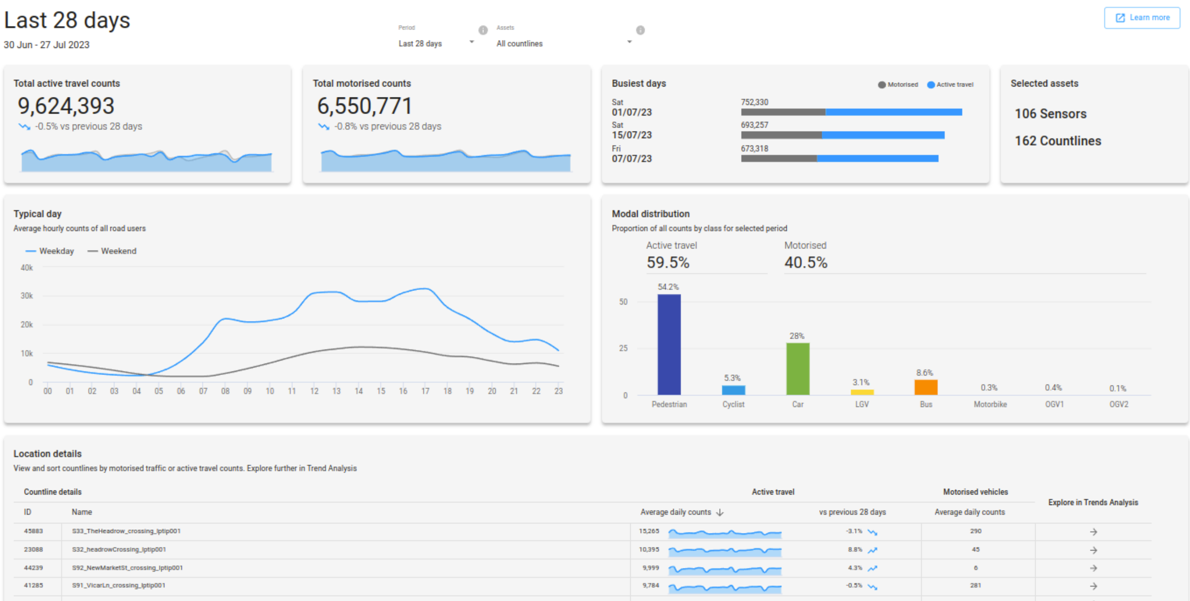
Cost and funding model for support

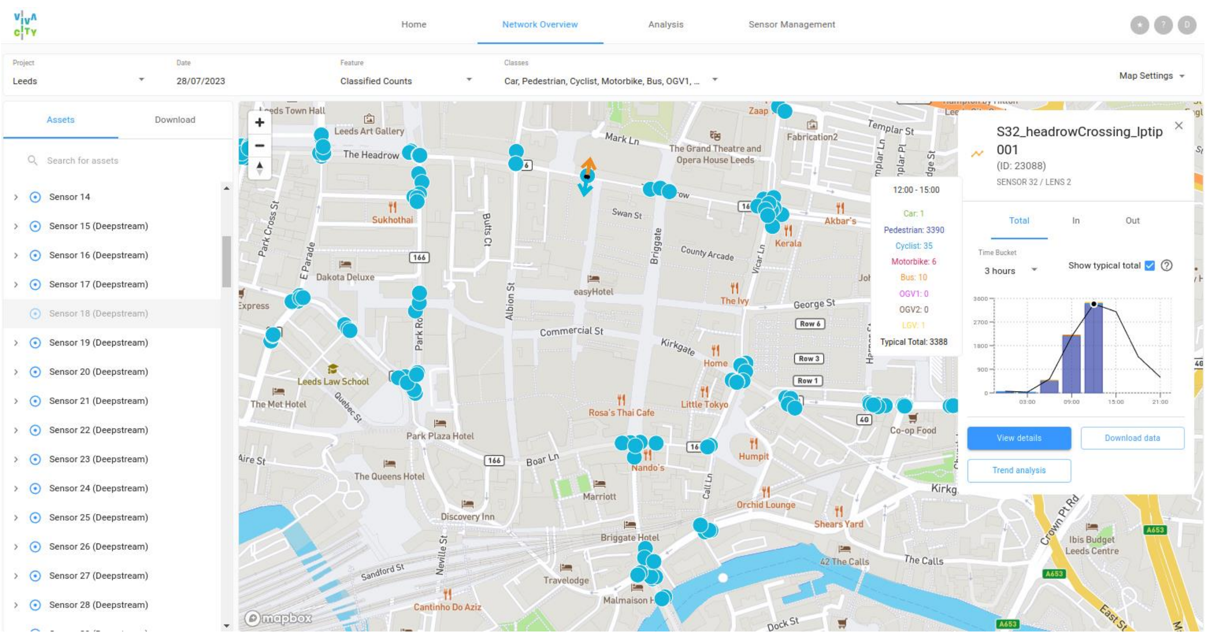
Even with multiple detection zones per sensor the total amount of hardware required is relatively large, given the need to detect all modes in all areas of the junction. However, despite this, the cost is comparable to inductive loop detection where, as in this case, new ducting would be required. The next generation of VivaCity hardware, with up to 6 independent cameras per unit, aims to significantly reduce the total amount of hardware required.

Above-ground detection has, traditionally, been procured on a 'plug-and-play' basis with installation and on-going support provided by signal contractors via maintenance contracts. However, as sensors have become increasingly sophisticated, this model has led to instances of sensors under-performing leading to friction between manufacturers and signal contractors whereby one party blames the equipment and the other blames the configuration.

VivaCity installation and support is undertaken by the manufacturer which reduces the signal contractor requirements down to ensuring power and connectivity to the devices. This provides significant benefit in terms of the operation of the sensors as it ensures that they are working optimally for more of the time. It also enables new features to be added (e.g. the recent addition of an e-Scooter class). The downside is that it introduces a revenue budget pressure that is very difficult for Local Authorities to accommodate.

Although there are revenue implications and budget pressures, which Local Authorities need to reflect upon, there are potential signal maintenance contract savings available by adopting this approach. These could accrue through needing to investigate and diagnose fewer spurious faults, as well as through additional uses of sensor data, such as for transport planning and road safety purposes. The example VivaCity dashboards below demonstrate the insights, in this case classified count data from across the deployed sensors, that can be gained as a secondary benefit.





Privacy

Vision-based sensors inevitably attract attention with regard to use of personal data. A benefit of the VivaCity sensors is that all processing is done on-board, and no video leaves the device. The data leaving the sensors is anonymised and this has been a requirement from the start of the project.

A privacy notice was published on the Leeds City Council website at the start of the initial trial to explain the purpose of the sensors which was then updated as implementation expanded. Despite these precautionary steps, there has been some media interest.

The ability to remove all conventional above-ground equipment from sites has the benefit of significantly reducing equipment and associated bracketry. However, it is unlikely that public perception of above-ground sensors will ever be wholly positive and so conspicuousness should be considered in future product design.

Summary

This was a highly ambitious project to utilise emerging technology as part of a major transport investment programme. The simpler, low risk option would have been to implement an existing control strategy supported with conventional detector technology. However, it was considered that the Connecting Leeds Transport Strategy objectives demanded a more fundamental change. To achieve this, the INTRO project sought to reconsider how active travel modes are incorporated into traffic signal control systems to ensure a greater degree of equity.

The project incorporated innovative sensor technology, new telecommunications infrastructure, new traffic signal infrastructure and development of a new optimisation strategy. Any element of this in isolation would have been a challenge but the progress made is testament to the work undertaken by the various parties involved. From a Local Authority perspective, the sensors are performing exactly as had been hoped when the decision was first taken to pursue this approach. It has been proven that the use of machine learning technology for traffic signal control is not only possible but also beneficial in terms of the ability to track objects, accurately classify road users and provide various secondary benefits through insights from the data.

Next Steps

A small number of sites are still to be commissioned. Once this is complete, further work will be undertaken to fine-tune the perspective transforms at each site to improve the GPS coordinate accuracy. In parallel, development of the optimiser will continue with a view to an operational proof-of-concept running by the end of the year.