Connected Places Catapult

Intelligent Gateline Phase 2 & 3

October 2019

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V0.2	Final	Second draft for external review	APM			

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Introduction

Intelligent Gatelines is an innovation project developing and operationally demonstrating a gateline that can automatically self-reconfigure to manage throughput and prevent overcrowding at stations. The project is a partnership between Cubic Transportation Systems, Arriva UK Trains (AUKT), Transport for London (TfL) and the University of Portsmouth (UoP).

The project was awarded funding under the Rail Safety and Standards Board (RSSB) Train Operator Competition 2016. The fund is designed to encourage greater collaboration between train operating companies and the rail supply chain and enables the winners to move their projects into the delivery phase, subject to contract. The project title is "Intelligent gatelines; using situational awareness to improve customer experience, gate throughput and increase gateline staff effectiveness at mainline and metro stations".

The project started in September 2017 and has had a duration of just over 2 years, finishing in October 2019. The Connected Places Catapult (CPC) has been appointed as an external party to review and validate the innovation's design methodology and evaluation method.

The present report follows on the Phase 1 report "Intelligent Gateline: Review of project methodology and TRL level", issued by CPC in November 2018.

The Phase 1 report reviewed the project's proposed methodology, what the project was developing and how the project team were proposing to execute trials to observe the expected benefits. There was also a high-level review of existing technologies and further considerations for the project team. Based on the methodology chosen the CPC assigned a Technology Readiness Level (TRL).

The present report combines Phases 2 and 3.

Phase 2 (December 2018 to September 2019) - During Phase 2 CPC followed up on how the trial was being set up, visited the trial site at Black Horse Road underground station and discussed early outputs with the project team.

Phase 3 (October 2019) - Phase 3 reviews the final outputs and findings of the trial, assesses whether the outputs have delivered the expected benefits and whether the trial has resulted in an up-lift of the Technology Readiness Level established in Phase 1.

Phase 2: Early assessment

1.1 About this Section

This section captures observations as CPC followed the Intelligent Gateline development process and setting up of the project test trials from December 2018 to September 2019. It includes visits to the laboratory tests at Cubic's London Innovation Centre and the trial site at Black Horse Road underground station, together with a record of issues encountered while trying to set up the trial at Marylebone train station.

1.2 Development Methodology

Cubic and partners have developed the Intelligent Gateline innovation following the methodology laid out in the project schedule in Appendix B.

The project team planned to test the Intelligent Gateline system in two trial sites in London: a mainline station (Marylebone) and a metro station (Blackhorse Road).

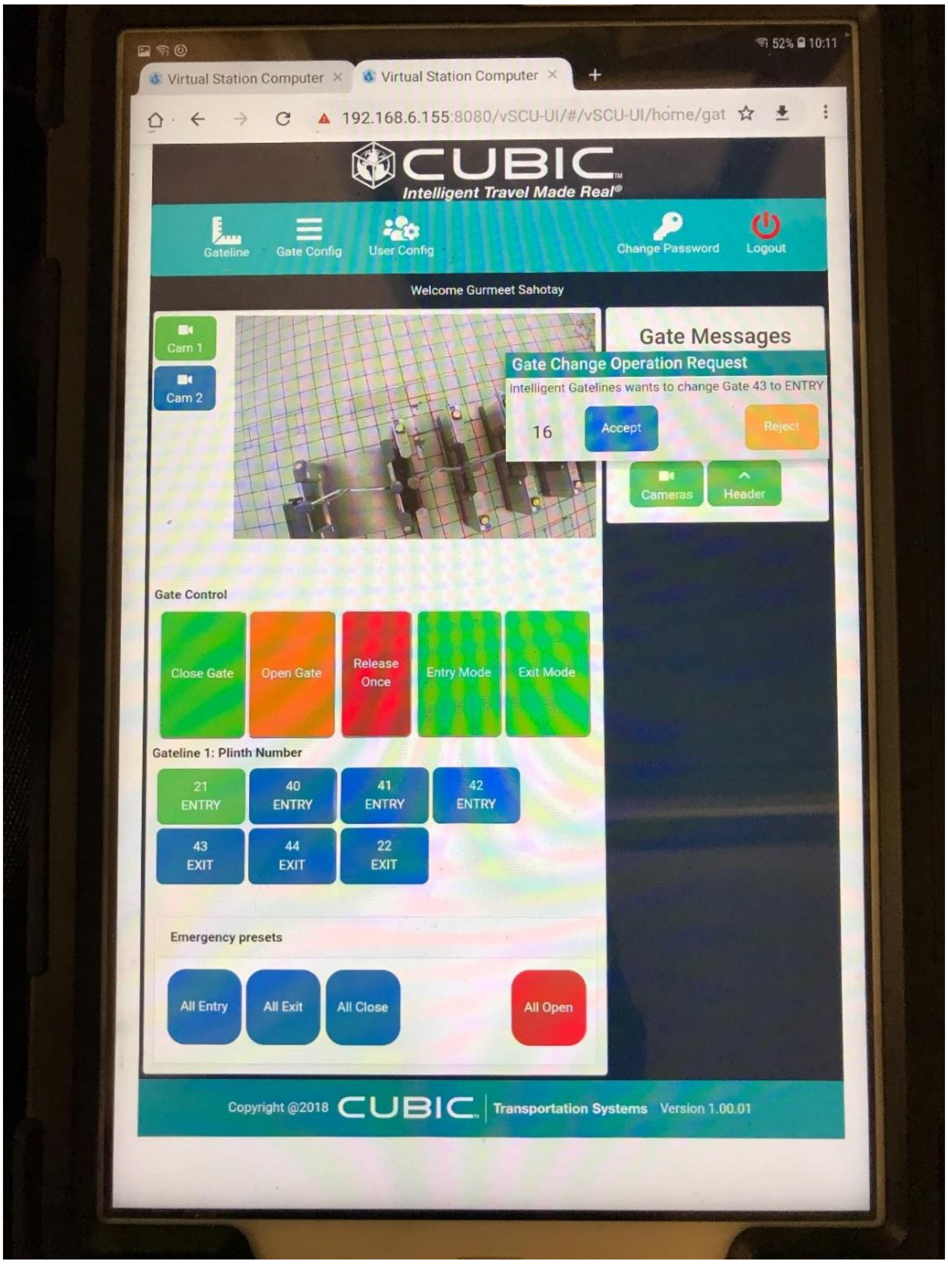
Issues with setting the trial at Marylebone station (discussed in 1.5.1) meant that the live trial took place at Blackhorse Road station only.

1.3 System under test

The main innovations of the Intelligent Gateline system are described below, with the entire Intelligent Gateline System Design illustrated in Appendix B.

1.3.1 Virtual Station Control Unit (vSCU)

Staff mobility is a key component of the Intelligent Gateline concept, and the vSCU (Figure 1) has been developed as a conduit for the Intelligent Gateline system and interface for staff to monitor and control the gateline remotely. The vSCU allows for a supervised mode which requires staff to accept changes requested for a gate's direction; also functionality to change open the entire gateline in case of emergencies.



Gate Change Operation Request

Intelligent Gatelines wants to change Gate 43 to ENTRY

16 Accept Reject

Figure 1 Intelligent Gateline user interface (vSCU)

1.3.2 Intelligent Gateline Controller

The Intelligent Gateline Controller interprets multiple camera and sensor inputs to evaluate the need to alter the gateline to optimise passenger flow. The controller sends requests to the vSCU and logs decisions and requests sent.

The controller has two goals. One is to identify and predict clusters of people before they reach the gateline and the other to equally react when crowds start building up around the vicinity of the gateline.

The idea is to predict the optimal configuration of the gateline and what should be the configuration in 20, 40, etc secs for example, before customers reach the gateline.

The project is using two different controller designs:

- A simple damped feedback controller
  Sensors are added to the area around the gatelines to monitor waiting times, the average throughput in each direction and crowding.
- Controller with predictive analytics
  In addition to the current queue length at the gates, novel predictive analytics provided by the University of Portsmouth predict the length of the queue in advance.

Logic is added to the Intelligent Gateline controller to combine the solutions from both algorithms and calculate the gateline configuration that achieves maximum throughput while balancing the queuing times in both directions.

1.4 Laboratory Simulations

Cubic has implemented a medium fidelity replica of the Intelligent Gateline at their London Innovation Centre, encompassing a real gate, the user interface that the gateline operator would be using remotely, the two controllers under development and data sets provided by the stations planned for trials.

1.4.1 Testing of sensors

The laboratory environment has also been used to experiment with four different counting methods to feed data into the reactive and predictive algorithms.

1) **XOVIS system**: These top down sensors can measure people height and track them through a station.

2) **BLE sensors:** Low cost Bluetooth Low Energy sensors connected to a Raspberry PI were programmed to capture all individual phones up to 100 metres around. By using triangulation measuring strengths from numerous sensors around a station, the technique could sample a large number of people moving in a given direction, although was less accurate than XOVIS.

3) **Existing CCTV:** Work has been undertaken to integrate a third-party software (ULTINOUS actionable video analytics) to allow people counting from processing real-time CCTV feeds.

4) **Webcam counting method:** The University of Portsmouth and Cubic developed a simple in-house version of ULTINOUS as a further backup. The system uses a top-down algorithm for shoulders and head. It can then track passengers in a similar way to XOVIS but is less versatile.

1.5 Setting up live trials

The effort and stakeholder management to set up live trials at both stations is not to be underestimated and the project team spent considerable amount of time getting the buy in from all the stakeholders required to be able to sign off a live trial.

In the case of Marylebone train station, there were further complexity and cost issues to do with the listed building.

1.5.1 Marylebone

Initially a similar installation to Blackhorse Road was planned for Marylebone station. Unfortunately, the quotation to install the XOVIS sensors required listed building consent and presented a too significant cost.

As an alternative, BLE sensors were investigated. This solution required both power for any platform installation as well as landlord consent for listed building. After a survey the power access was deemed to be risky to station operations and extra risk management would have been required.

Then existing CCTV cameras were investigated to count people from processing real-time CCTV feeds but there were GDPR issues.

The issues above led to start exploring other stations along the London Marylebone route, such as the new Bicester Village station, where overcrowding has developed as a result of travellers moving from using Bicester North to the new Bicester Village station.

The station could provide an excellent test site for the Intelligent Gateline system. However, timelines of a trial fall however outside of the scope of this project.

1.5.2 Blackhorse Road test site visit

CPC visited the test site at Blackhorse Road underground station in August 2019.

The project team explained the different elements of the system on site. The pictures below were taken by CPC during the visit. Figure 2 shows the gateline, consisting of 7 individual gates, with one at either end being wide aisle, and the overhead 3D sensors (Figure 3) installed to measure passenger flow. Superimposed lines allow throughput and waiting times to be fed into the Intelligent Gatelines combined algorithms (Figure 4).

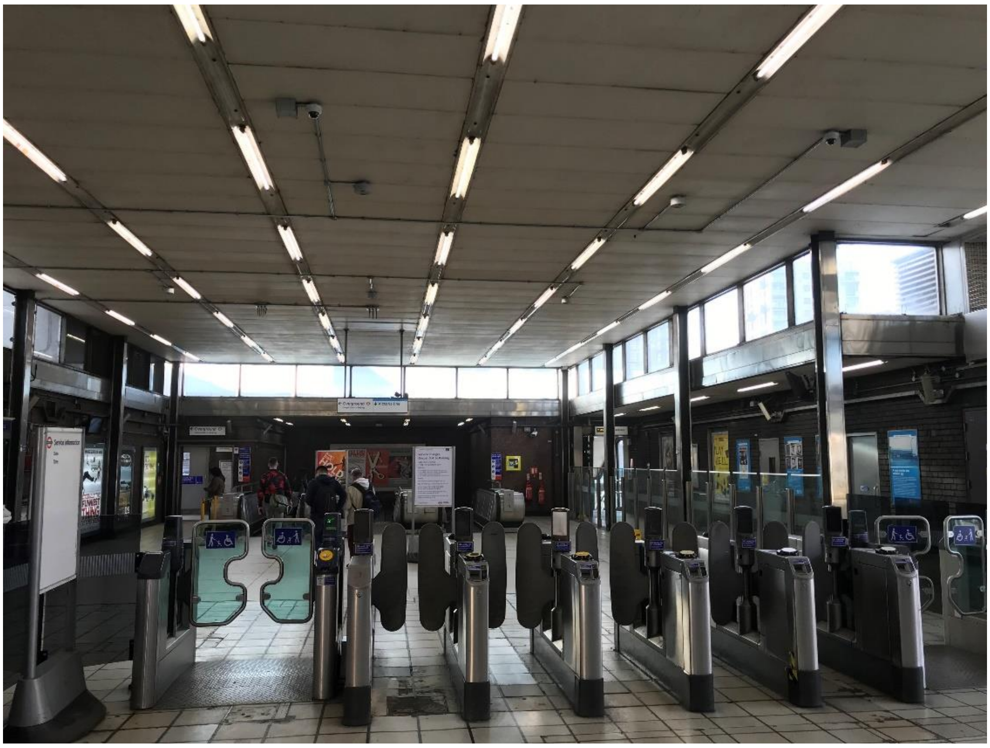


Figure 2 The gateline at Blackhorse Road station

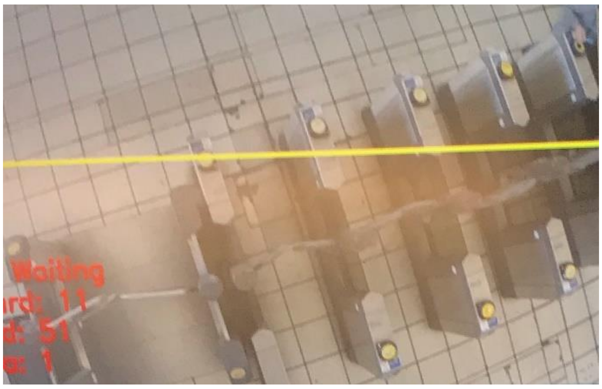


Figure 3 Camera view of half of the gateline

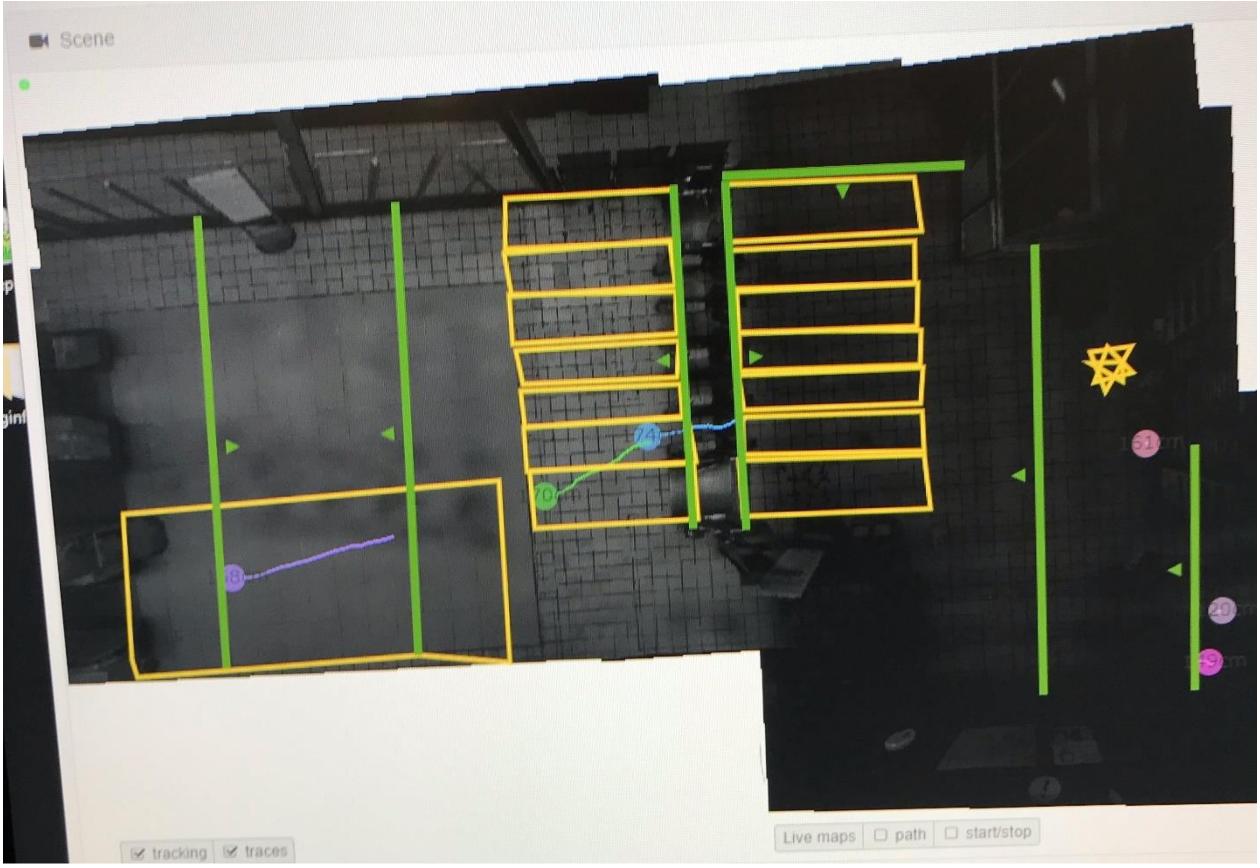


Figure 4 Predictive algorithm sensor measurement lines and zones

The project team had also familiarised themselves with the passenger movement that characterised the station, with a morning peak (6h30 am to 9h30 am) and an afternoon peak in the opposite direction (4h pm to 7h pm) (Figure 5).

The first 4 days of the week were the busiest, with the average waiting times per minute projected to be higher than when the station was less busy.

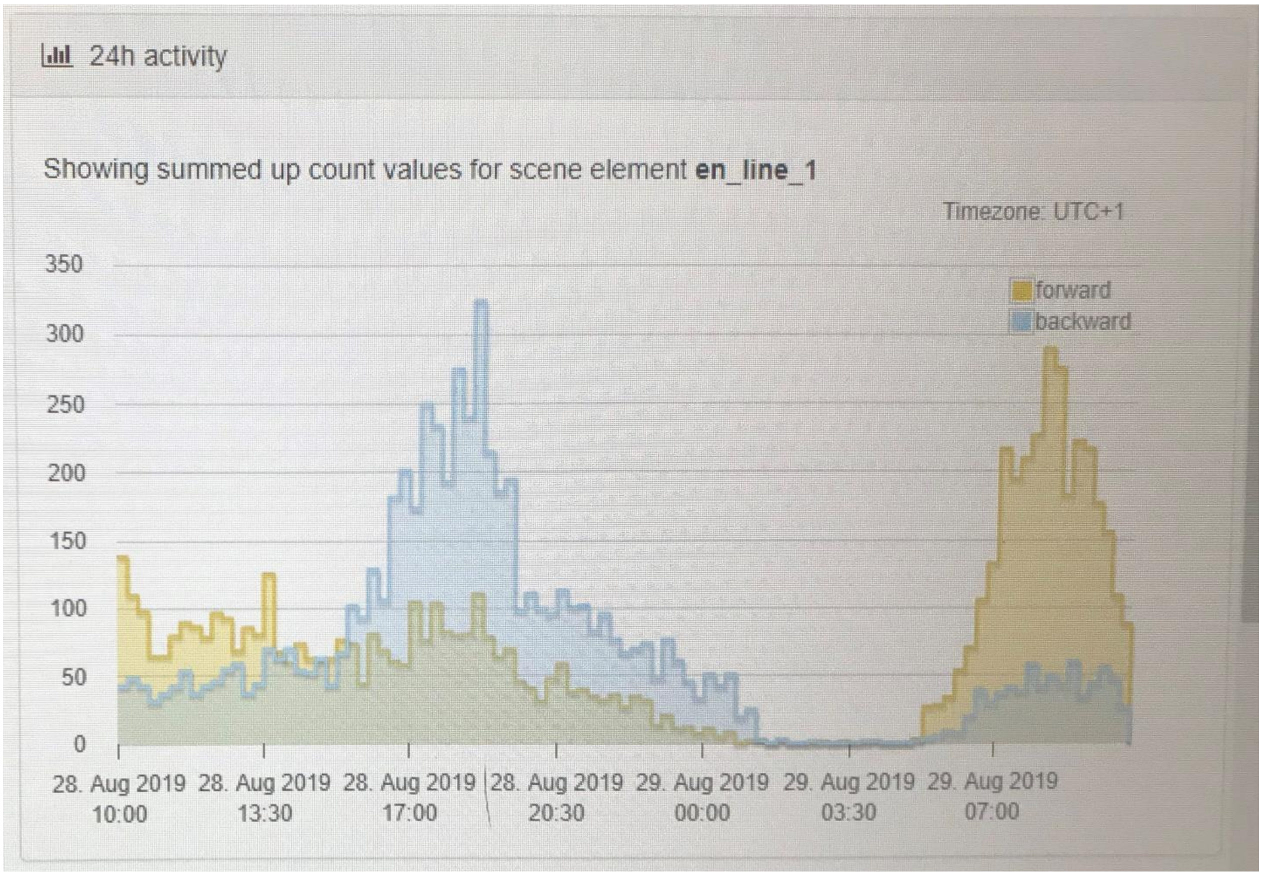


Figure 5 24h count values flow in both directions

1.6 Review of Key Performance Indicators

The project team put together a list of Key Performance Indicators (KPIs) at the beginning of the project (Appendix A). The list was reviewed later on the project, considering the specifics of the trial site at Blackhorse Road. The measures of average throughput, waiting time and number of gate changes were chosen as measures to evaluate the trial. Results can be found in the next section.

Phase 3: Review of final outputs and findings

1.7 About this Section

This section reviews the final outputs and findings of the trial, assesses whether the outputs have delivered the expected benefits and whether the trial has resulted in an up-lift of the Technology Readiness Level established in Phase 1.

1.8 Trial findings

This section reviews quantitative results of the analysis of the waiting times and the throughput of the Intelligent Gatelines system, considering data for a 2 week period of trials from the 19th September to the 3rd October 2019.

1.8.1 Gateline Configuration

During the trial period the configuration of the gateline at Blackhorse road station was set in a semi-autonomous mode (Figure 6), whereby gates 21e and 20x are fixed to entry and exit respectively. Gates 40, 41, 43 and 44 are set to supervised mode - meaning that any request sent to these gates needs staff approval before being executed. Finally, gate 42 is set to automatic mode. That is, no staff approval is needed for this gate to be changed.

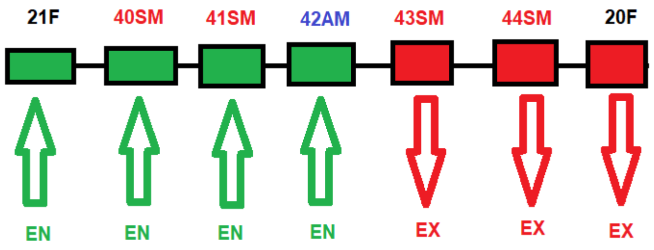


Figure 6 The Intelligent Gateline in semi-autonomous mode

The values obtained are compared to the prediction scenarios fully autonomous (Figure 7) and baseline (Figure 8).

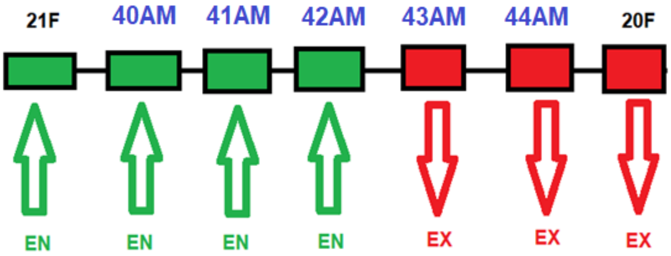


Figure 7 Fully automated gateline configuration

Figure 7 illustrates a fully automated gateline configuration scenario, whereby gates 21e and 20x are fixed to entry and exit respectively, with the remaining gates 40, 41, 42, 43 and 44 set to automatic mode.

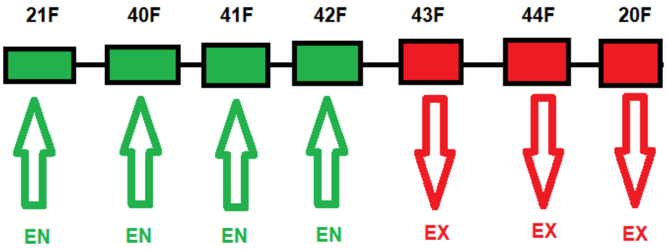


Figure 8 Baseline, morning gate configuration default setting at Blackhorse road

Figure 8 depicts a baseline, morning configuration default setting scenario at Blackhorse road station. In this scenario, it is assumed that the gateline configuration is static with 4 gates (21e, 40e, 41e and 42e) set to entry direction and 3 gates (43x, 44x and 20x) set to the exit direction.

1.8.2 Gate change requests

For the results of gate change requests, the morning peak from October 3rd (6h30 am to 9h30 am) has been considered. Computations were made every 60 seconds. A total of 366 computations were logged, of which 106 required Gate changes. 1 was okayed by staff and 1 double gate request was made.

Total number of Computation	366
Gates Changed	1
Gate Requests	106
Dbl Gate Request	1

From the above table, the project team concludes that:

- Gateline efficiency (in terms of passenger throughput) can be increased by approximately 30% using Intelligent Gateline in a typical station with rush hour peaks. For that potential to be fully materialised, staff need to act on all the gate requests made.
- A spike in passenger numbers will make the Intelligent Gateline suggest a change in gate direction (one or more walkways) which will reduce queuing and congestion. Staff need to act on the gate change requests made by the intelligent Gateline to fully capitalise on the benefits of the IG system.

1.8.3 Average Waiting Times

In the bar charts shown in figure 9, a comparison is made between the waiting times obtained using the baseline scenario and the fully automated scenario.

The predictive model uses queueing models to produce waiting times at the vicinity and at entry/exit points. The queue model is developed based on live stream passenger timestamps accessed through overhead sensors, a given constant service rate and a fixed number of service gates. Then, the model predicts in advance the queue lengths and the waiting times in the queue.

The project team observes a reduction of waiting times at the gateline vicinity and entry/exit points of 75.6 % and 89.63 % respectively when the gateline is working autonomously with only gates 20e and gate 21x fixed to entry and exit respectively and the remaining gates (40, 41, 42, 43, 44) set to automatic mode.

This indicates that if passengers are picked farther away from the gateline, there is potential to reduce the waiting time even more.

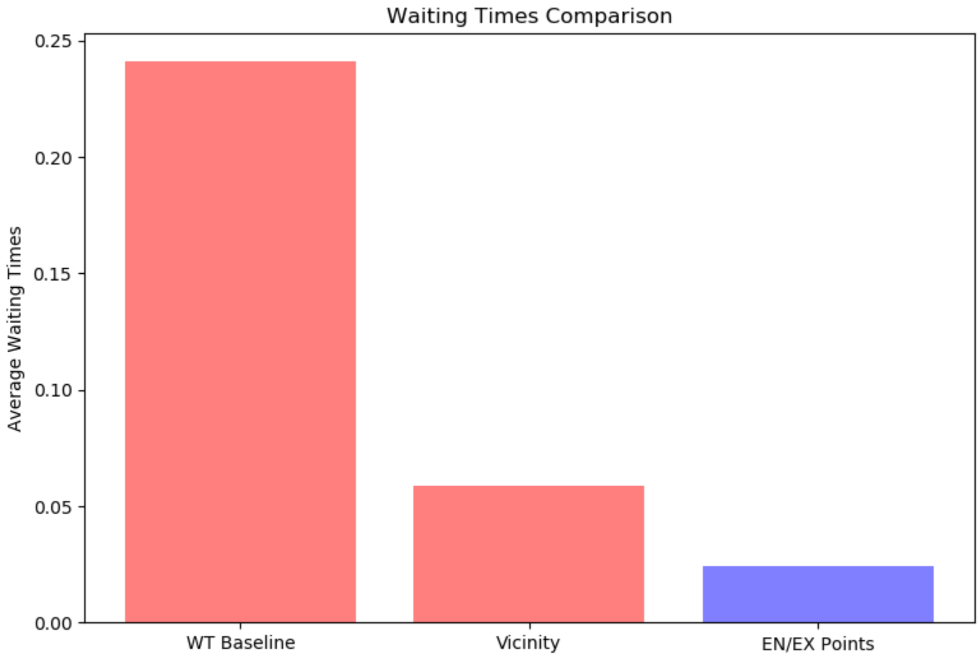


Figure 9 Average Waiting Times bar charts

1.8.4 Stakeholder on site demonstration of Intelligent Gateline

The project team organised an on-site demonstration of the Intelligent Gateline solution at Blackhorse Road station on the 16th October 2019, will all project partners and stakeholders.

The agenda consisted in:

- Introduction
- Presentation of the Intelligent Gateline
- Live presentation of the Virtual SCU
- Live demonstration of the Intelligent Gateline

The event was attended by representatives from RSSB, Transport for London, Chiltern Railways, Marylebone station, Cubic, University of Portsmouth and Connected Places Catapult.

Feedback collected from stakeholders during the event was very positive. The conversations have been captured below:

- The device that allows to operate the gate remotely is great since it will allow people more freedom of movement, e.g. sometimes staff have to stand in a place that is not safe. It also allows them to have more time looking after the passengers.
- The staff were confident enough to leave the middle gate in automatic. While here, it has changed a few times. After we forced it to in-flow it then reversed itself to outflow to let the people out that had just arrived on the train.
- The system allows to observe the flow around the station, how the space is utilised, maybe a sign is in a place where no one really sees it.
- Finances: The system displays and logs the error codes when people put the ticket in e.g. a ticket from the previous day. People usually would then direct themselves to the gate staff to be let through. Understanding all these cases and frequency can help understand how to manage them.
- There could be established pre-sets for types of stations. For instance, some stations have predominantly flow of people commuting into the city centre to work and coming back later in the evening. Others have more of a balanced flow in/out depending on whether the area has retail facilities etc.
- Feeds from timetables and live data from buses and trains could be integrated so the flow can be predicted in advance.
- For the future, artificial intelligence could be added so the gateline leans about behaviour during the week, seasonal behaviour etc.

Conclusions

1.9 Conclusions

The goal of the Intelligent Gateline project was to develop and operationally demonstrate a gateline that could automatically self-reconfigure to manage throughput and prevent overcrowding at stations.

CPC is pleased to confirm that this has been achieved. The report includes quantitative figures obtained through the trial at Blackhorse Road Station and predictions on the further improvements that the system can deliver, if it is to run in its automatic mode.

During the trial at Blackhorse Road the Intelligent Gateline run in semi-autonomous mode, which means a number of gates were set to supervised mode. This is perfectly understandable since deployment of any new technology usually requires building trust in the system.

The semi-autonomous mode possesses an element of human intervention hence can result in suboptimal decisions in cases where predicted optimal configurations are constantly being ignored.

In this case, the supervised mode acted as a check balance whereby staff needed to make sure that the system was doing the correct thing and that safety protocols were thoroughly followed. As the trust in the system develops, this should naturally shift to a more autonomous mode.

The results obtained also confirm that if passengers are picked farther away from the gateline (predictive algorithm), there is potential to reduce the waiting time at the gateline even more.

The Virtual Station Control Unit (vSCU) has also been very well received, as it allows staff to operate the gate remotely, gives them more freedom of movement and enables them to be more customer facing. The fact that the gate can still be operated manually from the vSCU if desired, allows staff to take ownership of the gate in situations of emergency or where specific management of the crowds are required, for instance.

1.10 Technology Readiness Level (TRL)

The project aimed to raise the TRL level of the resultant product to TRL 7 (i.e. a technology prototype demonstration performed in an operational environment). A definition of all the technology readiness levels can be found in Appendix D.

CPC identified the technology readiness level for the overall system at the time of writing the Phase 1 report at 5.

The reasoning for TRL 5 is that Cubic was at the time testing their system in a representative environment at their London Innovation Centre, with basic technology elements integrated with reasonably realistic supporting elements (e.g. a real gate).

With the trial at Blackhorse Road underground station the Intelligent Gateline system has been demonstrated in an operational environment, very closely to how it would be deployed operationally, with functions available for demonstration and test.

Appendix A: Intelligent Gateline Key Performance Indicators

Type	Description	Measurement
Gateline		
	Individual Gate Throughput	Baselining data. Log files, Operators numbers
	Gateline Throughput	Baselining data. Log files, Operators numbers
	Walkway Utilisation	Baselining data. Log files, Operators numbers
Rail		
	Train loading time efficiencies	Staff questionnaire, train delays, log files
	Platform overcrowding due to gate misconfiguration	Staff Questionnaires, log files to collaborate
Tube		
	Reduced Incidents requiring closure of stations	Staff questionnaires, log files
	Reduced incidents of overcrowding	Staff questionnaires, log files
	Increased capacity/throughput	Baselining data, operator numbers
Customers		
	Reduced queueing to exit platforms on arrival	Customer? Staff questionnaires. Waiting times baselined and compared
	Reduced queuing to get on a train after platform announcement	Linked to loading metric, waiting times baselined and compared. Staff questionnaire
	Improved customer service by enabling staff to be more customer facing	Staff questionnaire asking about role change?
	Waiting times reduced to be even for both sides	Delta between waiting times in both directions
	Did gate changes hinder staff at any point?	Staff questionnaire

Appendix B: System Design Diagram

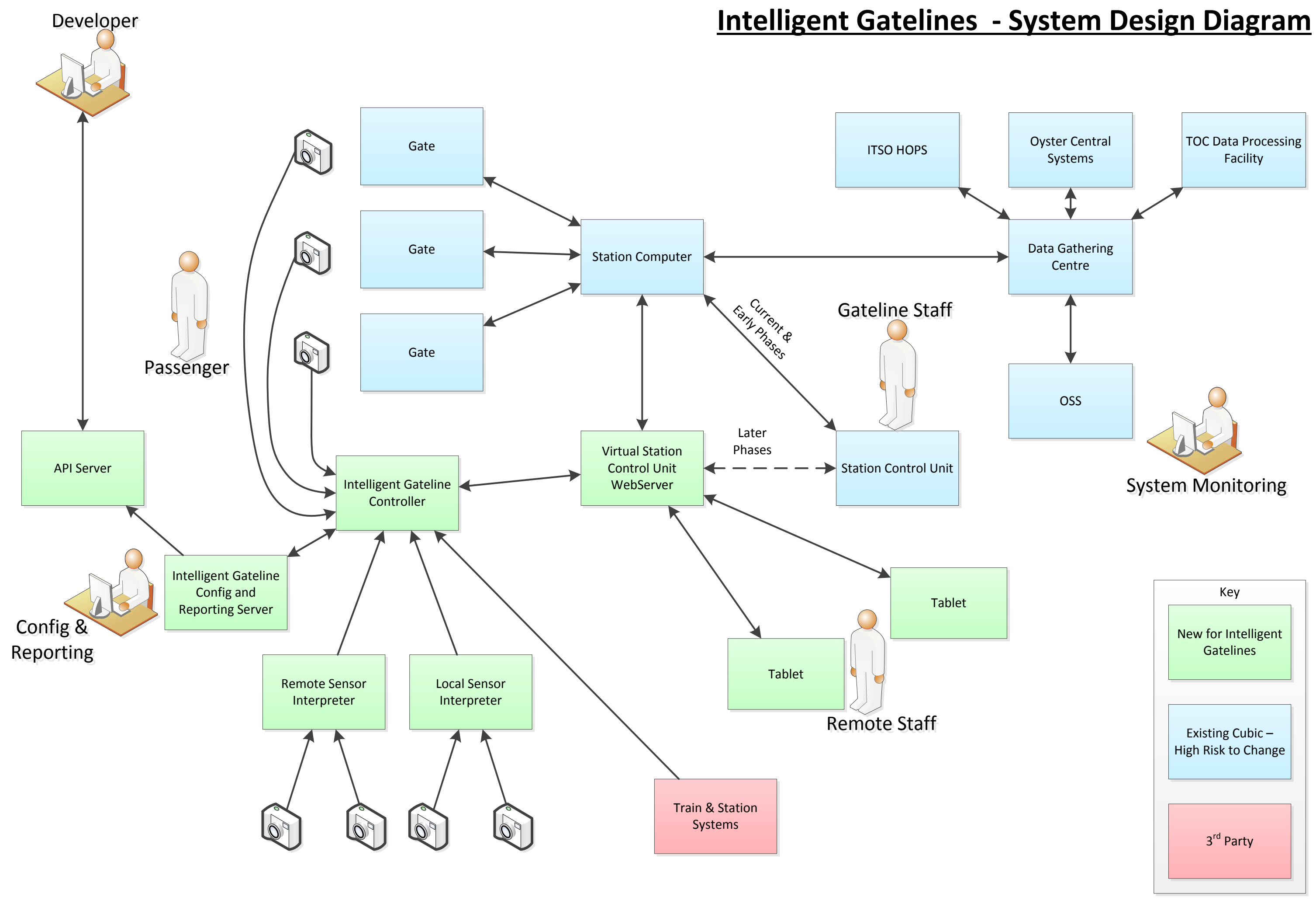
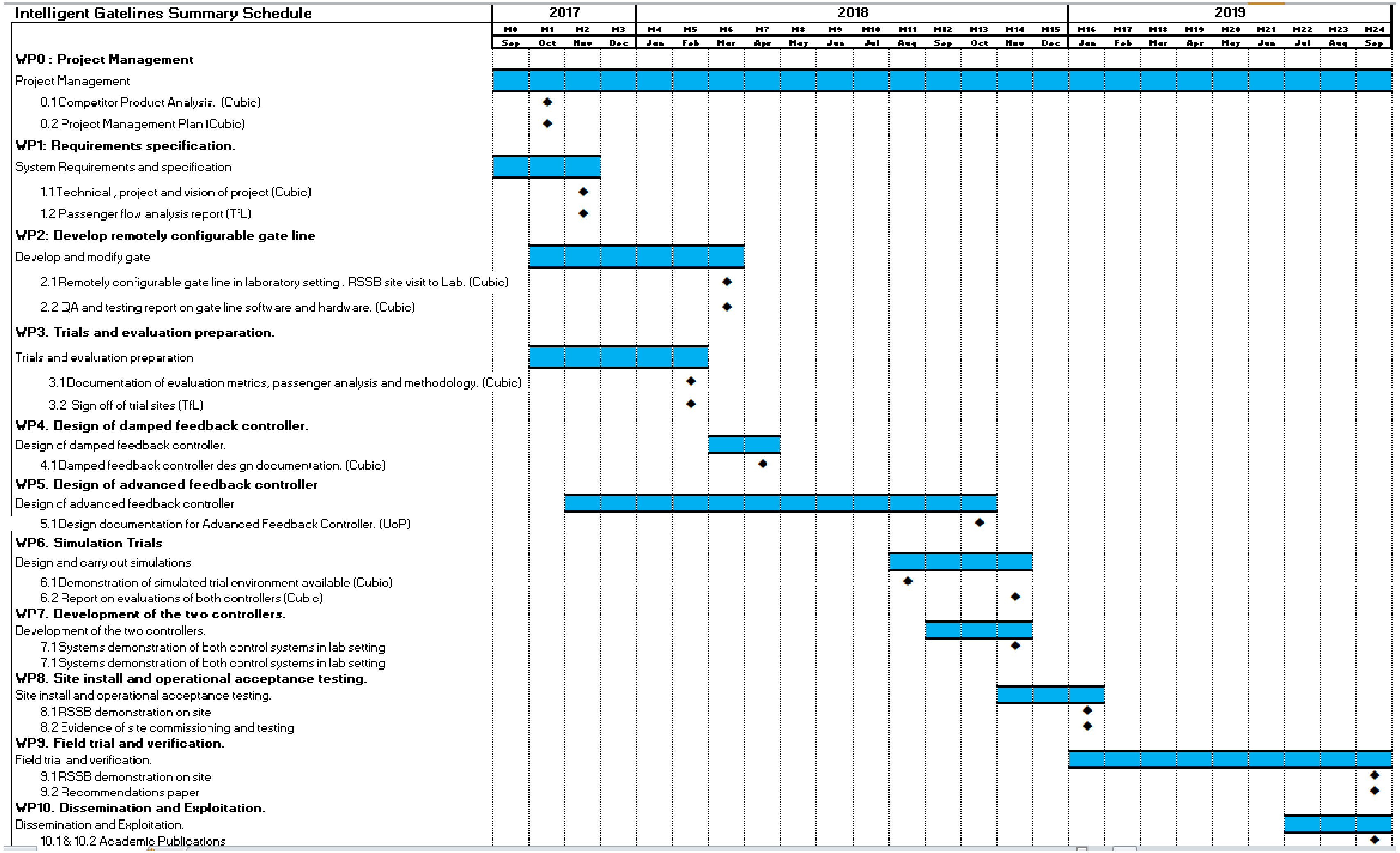


Figure 10 Intelligent Gatelines System Design

Appendix C: Project schedule



Intelligent Gatelines Summary Schedule

WP0 : Project Management
Project Management
0.1 Competitor Product Analysis. (Cubic)
0.2 Project Management Plan (Cubic)
WP1: Requirements specification.
System Requirements and specification
1.1 Technical , project and vision of project (Cubic)
1.2 Passenger flow analysis report (TfL)
WP2: Develop remotely configurable gate line
Develop and modify gate
2.1 Remotely configurable gate line in laboratory setting . RSSB site visit to Lab. (Cubic)
2.2 QA and testing report on gate line software and hardware. (Cubic)
WP3. Trials and evaluation preparation.
Trials and evaluation preparation
3.1 Documentation of evaluation metrics, passenger analysis and methodology. (Cubic)
3.2 Sign off of trial sites (TfL)
WP4. Design of damped feedback controller.
Design of damped feedback controller.
4.1 Damped feedback controller design documentation. (Cubic)
WP5. Design of advanced feedback controller
Design of advanced feedback controller
5.1 Design documentation for Advanced Feedback Controller. (UoP)
WP6. Simulation Trials
Design and carry out simulations
6.1 Demonstration of simulated trial environment available (Cubic)
6.2 Report on evaluations of both controllers (Cubic)
WP7. Development of the two controllers.
Development of the two controllers.
7.1 Systems demonstration of both control systems in lab setting
7.1 Systems demonstration of both control systems in lab setting
WP8. Site install and operational acceptance testing.
Site install and operational acceptance testing.
8.1 RSSB demonstration on site
8.2 Evidence of site commissioning and testing
WP9. Field trial and verification.
Field trial and verification.
9.1 RSSB demonstration on site
9.2 Recommendations paper
WP10. Dissemination and Exploitation.
Dissemination and Exploitation.
10.1 & 10.2 Academic Publications

Appendix D: Definition of Technology Readiness Levels[1]

TRL 1 Basic principles observed and reported

Transition from scientific research to applied research. Essential characteristics and behaviours of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated

Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of concept

Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment

Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment

Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space)

Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

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[1] ***https://esto.nasa.gov/files/trl_definitions.pdf***

TRL 7 System prototyping demonstration in an operational environment (ground or space)

System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.

TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space)

End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.

TRL 9 Actual system "mission proven" through successful mission operations (ground or space)

Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

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