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Crossrail Integration Facility and Test Automation – improving resilience with automated testing

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This paper was originally presented at the ASPECT conference in Delft, Netherlands in 2019.

Systems integration has gained a higher level of importance as complex railway projects operate under tighter schedules than ever before and with limited access to tracks to run tests. This paper demonstrates how a fully automated off-site testing facility is extremely valuable to increase efficiency, cost-effectiveness and resilience of systems throughout a railway project life-cycle. The Crossrail Integration Facility (CIF) is a great example of this practice.

Systems integration facilities, such as Crossrail's, provide a means to perform thorough off-site interface, integration, timetable and transition testing, as well as simulation of faults to understand the system's behaviour under degraded and emergency situations. It is a cost and time-effective approach to de-risk the later stages of the project, which brings real benefits to the delivery of railway signalling systems.

Introduction

The railway is a very complex system, involving – in the UK – numerous stakeholders such as: end customer, government, service operators, rolling stock owner, rolling stock supplier, infrastructure owner, infrastructure supplier, infrastructure maintainer – each with individual corporate objectives. Within each category there are potentially several different organisations that consider each other as market competitors. There is also a complexity in technology, with various intricate signalling systems worldwide. A single line might operate under distinct systems in different areas, requiring complex transitions for safe operation of trains. Contemplating these facts makes it clear how systems integration is key for a railway line to work reliably, and how complex the system integration process can be, as it depends on stakeholders with distinct objectives working together. Successful systems integration also relies heavily on system-level tests; however, urban areas are getting bigger and denser, and service hours are getting longer – some railways run 24 hours a day. The real railway is not as available for system testing as would be desirable, which leaves a lack of infrastructure supporting system integration.

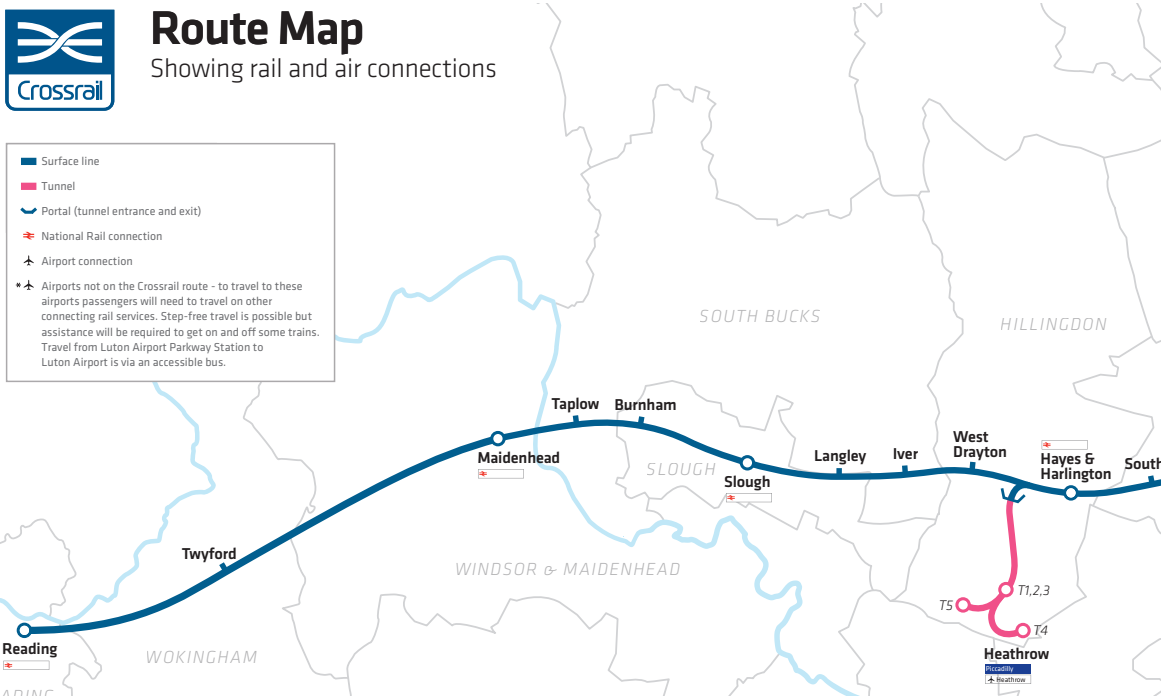


Figure 1 – Crossrail, the future Elizabeth Line, showing rail and air connections. *TfL/Mayor of London.*

The signalling system's main purpose is to optimise train movements whilst keeping them safe at all times and under all circumstances. Therefore, the system must be proved to be resilient, meaning that it must behave safely and reliably even under unintended operation or under the influence of external faults. It is very challenging to test the system's response to unintended scenarios in the field, even if longer access to it were granted, because to be able to put the system under certain complex situations, a lot of negotiations between stakeholders and risk assessments would have to be undertaken. The difficulties mentioned can be lessened with the use of system integration facilities. A great example of this practice is the CIF.

Crossrail (the future Elizabeth Line in London – Figure 1) is a major railway project that connects one of the largest urban areas in the world. It is currently Europe's largest infrastructure project and it is estimated that 200 million passengers will use it each year. It operates under three distinct train control systems – ETCS, CBTC, TPWS (UK train protection system), with high capacity throughput. To be able to deliver a robust operational railway with limited access to test tracks and the physical railway, the CIF has been implemented to provide early off-site interface testing and integration of critical systems.

The CIF

As already highlighted, the need of a system integration facility for the Crossrail project was identified early in the Crossrail programme due to the restricted access to the railway, the ongoing complex civil works and fact that the Elizabeth Line service will run across existing Network Rail infrastructure. An intricate signalling system, encompassing three distinct train control and protection systems, and the pressure for minimum disruption to the existing operational services add to the complexity. Thus, the CIF was designed and implemented in phases, planned according to the development of the products used within the system.

The objective of building the integration facility is to test and prove the functioning of system interfaces prior to their installation and deployment. It is not intended to replace any steps of the test and commissioning phase of the project, but to support it by identifying and mitigating defects early.

The CIF is a testing facility with 112 interfaces between a mix of real products – the same as the ones used in the railway – and simulators. The products therefore can be categorised under "constituent domain items", which are the subsystems under test, and "test execution domain items", which allow for the integration and operation of the whole system under the integration facility environment. As far as the subsystems under integration testing are concerned, they are part of a system controlling a real railway.

A number of products are integrated in the overall system, including constituent domain and test execution items supplied by Siemens Mobility, Bombardier Transportation and Knorr Bremse.

Key constituent domain items

The list that follows covers the key sub-systems within the CIF that are identical to the ones used on the real railway. They comprise the sub-systems that are under test.

Automatic Train Supervision (ATS) – Controlguide Vicos – is the Central Operating Section (COS) control system, responsible for monitoring and controlling train movements. It is equipped with Automatic Route Setting (ARS) and Automatic Train Regulation (ATR), and is capable of adjusting individual train times to optimise traffic.

Interlocking – Trackguard Westrace Mk2 – provides point, route, Platform Screen Door (PSD) interlocking functions and secondary train detection functions from axle counters. The primary train detection function in the COS is train position reporting.

Platform Screen Door (PSD) Control Unit – Knorr Bremse Platform Door Controller (PDU) – which connects to 27 individual simulated Door Control Units (DCUs) of the platform screen doors as in Bond Street station.

Trackside Automatic Train Control (ATC) System – TrainGuard Mass Transit (TGMT) Communication Based Train Control (CBTC) Wayside Control Unit (WCU) – is the main trackside element of the ATC system used in the COS of the Elizabeth Line.

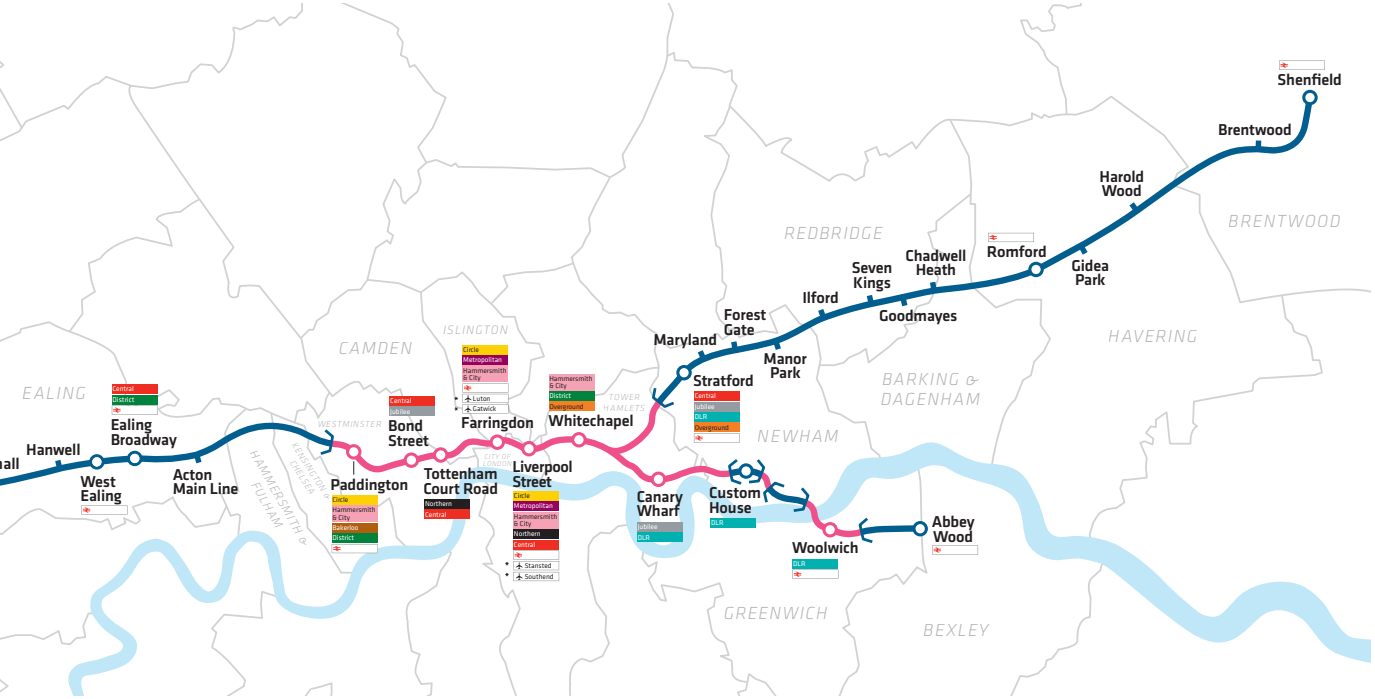


Figure 2 – The class 345 train driving desk and visual software in the integration facility – with Covid-19 precautions in place. *All photos Siemens Mobility.*

Train-borne Automatic Train Control (ATC), which is composed of:

- European Train Control System (ETCS), Bombardier Transportation (BT) European Vital Controller (EVC);
- Communication Based Train Control (CBTC) Trainguard Mass Transit (TGMT) On-board Control Unit (OBCU), which is equipped with Automatic Train Operation (ATO) and Automatic Train Regulation (ATR) within the CBTC area;
- Automatic Warning System (AWS) and Train Protection & Warning System (TPWS) Train Module – Mors Smitt UK Ltd AWS & TPWS Specific Transmission Module (STM).

Key test domain items

It is not possible to test the constituent domain items without a real railway unless test domain items that simulate a railway system with trains running are provided. For this reason, the key test domain items listed here are included in the CIF. With the test domain items working correctly, the constituent domain items can be tested, as if they are operating a real railway.

The Railway Environment and Trains Simulation (RETS), at the very centre of the system is a PC-based software application that provides the trackside equipment simulation for signals, points and axle counters; and provides the interlocking I/O for those objects. It also provides fully simulated trains, which are capable of communicating with real CBTC and ETCS wayside equipment, and one simulated train that hosts the real train-borne automatic train control equipment, including representative train interfaces.

The interlocking of the Great Western Main Line area is a Trackguard Westlock, being used to emulate the Alstom Smartlock for the purposes of the CIF only.

The interlocking for the Great Eastern Main Line area is simulated.

The driving desk (Figure 2) is designed to represent the Class-345 Bombardier train cab. There are two of these to simulate the actual train twin cabs. These interface with the real on-board train control systems. The controls and screens in the driving desks interface with the visual display software, which provides a driver's eye viewpoint when driving on the Elizabeth Line. Providing the functionality of a twin cab added another level of complexity both in the hardware and software, which involved the duplication of hardware and their associated interfaces while developing the software to enable control of the changeover between the two cabs for the system simulations in the various scenarios that were required. All of this was done to a tight delivery schedule by the team based in Chippenham.

The train hardware simulation software simulates the train wiring and train relay logic using the inputs from the driving desks and their associated on-board ATC equipment, and provides the necessary outputs in response. It also performs the train dynamics calculations for determining the speed and acceleration of the train, the output of which is used to provide simulated Doppler radar and tachometer inputs to the on-board ATC equipment. Furthermore, it simulates balises and energises the AWS magnet and TPWS antenna in the Mors Smitt AWS & TPWS trackside module.

Testing

To be able to prove that the system performance aligns to the expected behaviour and that the system integration process is successful, system-level tests need to be undertaken. The integration facility provides the means for thorough off-line testing of a diverse nature, such as:

- Interface testing: test the interfaces between all systems and applications.
- Integration testing: test that products work together to provide the desired emergent properties of the system.
- Timetable testing: Introduction of as many trains as a real railway timetable will run, plus testing the movement of trains in and out of the sidings.
- Transition testing: Run trains between Great Western Main Line (GWML), COS and Great Eastern Main Line (GEML) to test the transitions between CBTC, TPWS and ETCS.

- Stress testing: test the performance of the system and interfaces under overloaded conditions.
- Faults testing: Introduction of faults to understand the system's behaviour under degraded and emergency situations.

Stress testing and fault testing are related to system resilience – these two types of test put the system into abnormal situations due to external factors. An example of a stress test would be to create a timetable with more throughput of trains than the system was initially designed for. A real example of this test is detailed later in this article. One can easily understand the advantages of having a controlled factory environment to perform such a test, as the conditions required can be readily orchestrated in an inexpensive way without the need to negotiate access to the client and other shareholders of the system. It would be very difficult to test the system under this scenario in the real railway – there would be several safety implications and necessary agreements. This highlights the benefit of the CIF to test and consequently improve the resilience of the system.

Test automation

To increase the utilisation of the rig without the need for continuous human interaction, and to facilitate the execution of repetitive tests – while also making the system integration tests more consistent and reproducible – the CIF is equipped with an extensive system automation library. The test automation is designed to interact with the key software components to enable complete testing, with most tests being completely autonomous.

A possible consequence of running automated tests is that the behaviour of the system might be different than when being operated by a human or by a script command, depending on how the automation is designed. Some functionality might not be available for the end user, but it is available for the system integrator writing the test automation. As an illustration, the signaller's workstation is designed so that if a user wants to set a route for an approaching train, they would click the entry signal, followed by a click at the exit signal of the route, and then click request route button. If the same operation is requested by the automation through a "backdoor" command, even though the route appears to be set the same way, the signaller's workstation was not designed to be used in that manner, and the operation might have skipped a crucial check step in its execution. Therefore, it is important to make sure the automation does not affect the result of the test. For this reason, in the CIF, the freeware software AutoIT was chosen for most of the automation functionality. It provides the ability to manipulate mouse moves and key stroke inputs in Windows environments, so that the system sees no difference in the input provided by the automated tests and the input provided by a human user operating the system.

The test automation permits 24/7 utilisation of the rig, enabling robustness tests to be executed without human interaction for long periods of time. Therefore, full utilisation of the facility's time can be achieved without the need for staff working on a shift basis. Logging is also provided by the automation for debugging purposes, in combination with product specific logging.

An extensive system automation library has been written, which enables complex set-ups to be achieved, health checks to be accurately performed, endurance testing to occur over extended periods and the implementation of tests of repetitive nature.

Test automation structure

The test automation is composed of a scenario controller application and test clients. The scenario controller runs in a dedicated automation computer in the CIF. The test clients run in the computers that hold software applications of the CIF

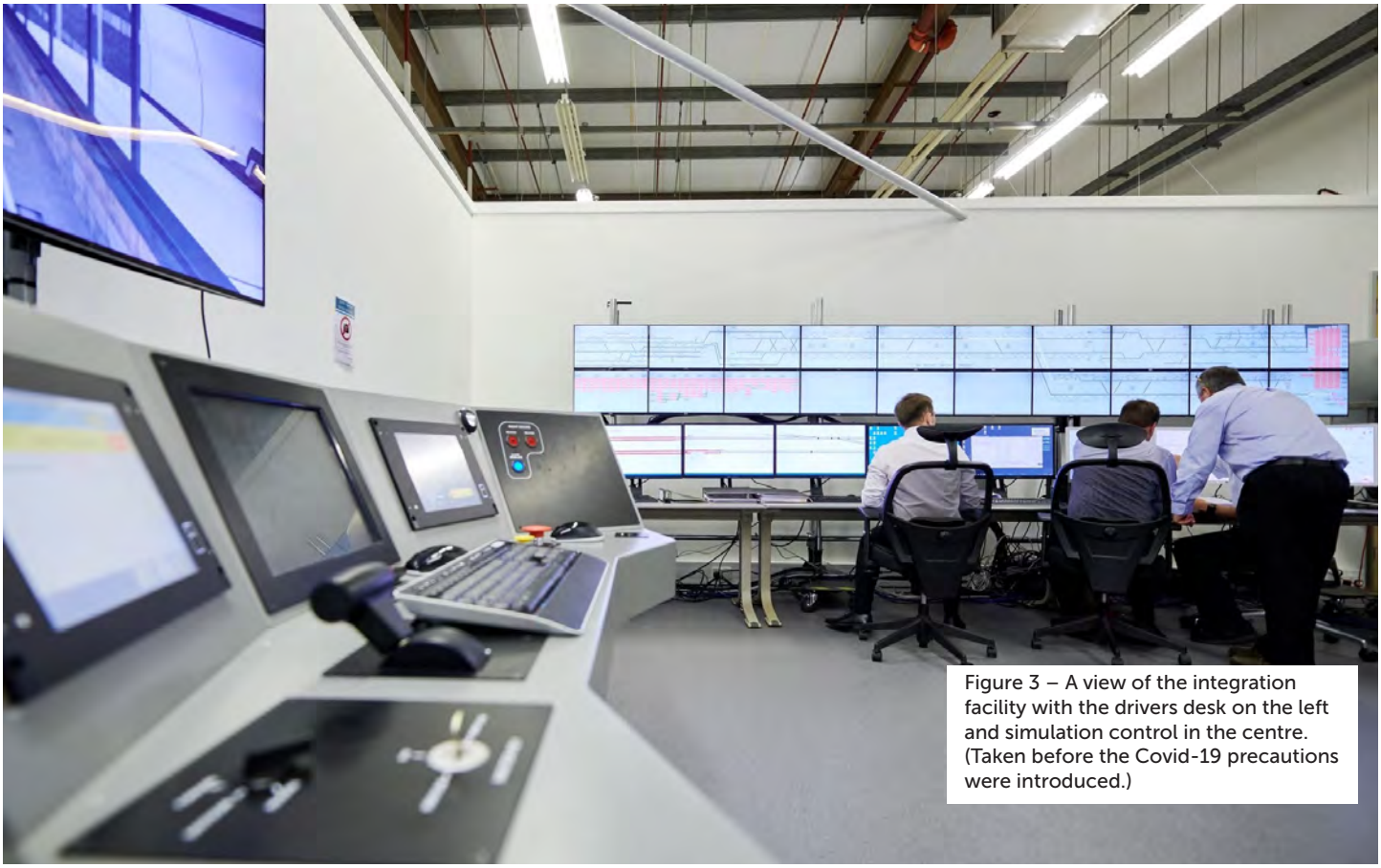


Figure 3 – A view of the integration facility with the drivers desk on the left and simulation control in the centre. (Taken before the Covid-19 precautions were introduced.)

that require automation. The connection between the scenario controller and the test clients is via a TCP interface.

Figure 4 illustrates the automation network (for simplicity purposes, not all client nodes are represented in this diagram). As one can see, the scenario controller can send and receive messages from all applications holding test clients; however, the clients are not able to communicate between themselves through the automation. The clients only send messages to the controller of the nature of health checks or function execution results.

The scenario controller application was developed in-house at the CIF based in Chippenham. It is composed of a Graphical User Interface (GUI) as shown in Figure 5. On the left, the GUI displays a list of test scripts. Tests can be run repeatedly, or different tests run sequentially. The result of the execution of the test is populated as the tests finishes. The middle of the GUI holds the list of sent/received messages. On the right, the GUI displays a list of test clients to which the scenario controller PC is connected. Through this connection, the scenario controller is able to request the execution of the specific automation functions in each product of the system.

The request to execute an automation function can be sent from the scenario controller to a test client either using the debug functionality or test scripts. The debug functionality sends a request to execute a single automation function to a single test client. The test scripts are simple text files with a sequential list of automated functions, which are assigned to different clients.

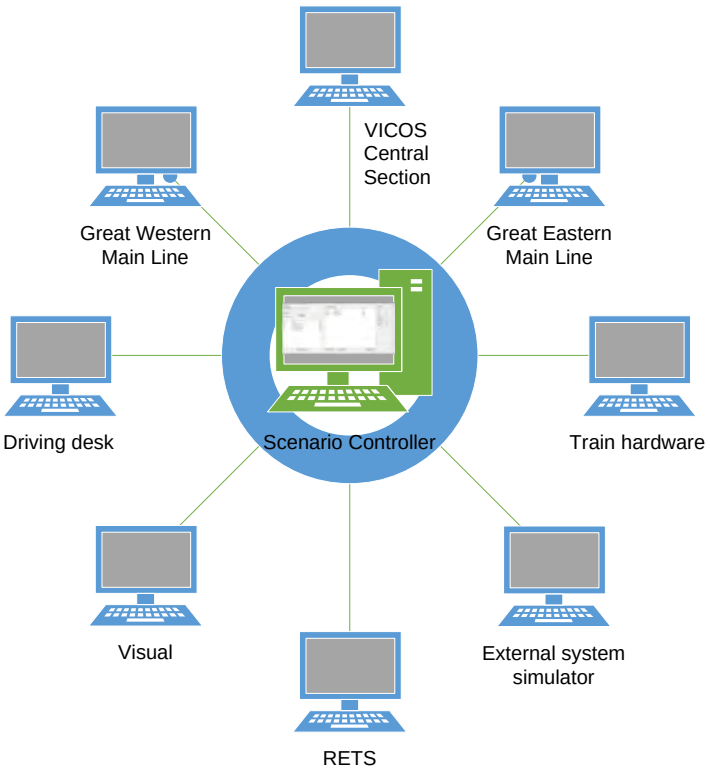


Figure 4 – The automation network structure.

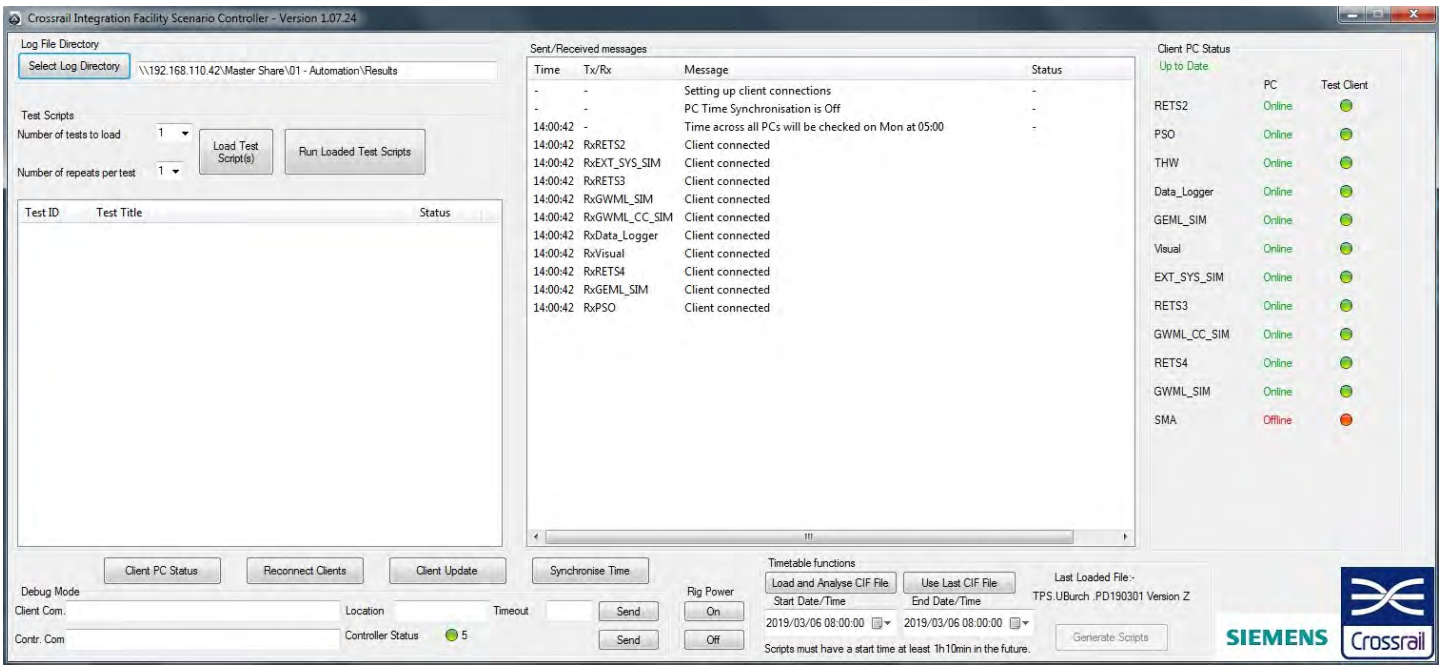
Test clients

The test clients hold the specific automation functions for each software application that is automated. They stay on standby until receiving a message from the scenario controller. Then, they execute the requested function and return a value depending on the outcome of the execution – in most cases it is either a "pass" or a "fail".

All functions are developed by the supplier of the CIF and are bespoke to each product within the rig.

All functions include checks to ensure that its execution was successful. If a failed, or an unknown or unrecoverable scenario is found, the test client returns a "fail" message in response to the scenario manager message that requested the execution of that function. A "fail" message then interrupts the test and makes the scenario manager proceed to a clean-up process, which includes saving logs and taking screenshots of all test clients, so the facility user understands the state of every product at the time of the failure.

Figure 5 – Scenario controller application.



Automation logging and debugging

The CIF is equipped with comprehensive logging. Most software applications have specific built-in logging functionality. The automation provides extra logging.

Each test client logs its activities locally into an activity file. This file registers both commands received individually – sent through the debug mode functionality in the scenario controller – and the specific commands received through a test script. All messages received (automation functions) and sent (outcome of the executed functions) are logged with a time stamp.

There is also central automation logging, which is only used when executing a test script. Its location is determined by the user. In the case of a test failure, debug screenshots would be taken of all clients and added to the log folder for the specific test. The latest messages exchanged with each client, including the test client debug failure message, and a copy of the step result displayed in the controller would also be stored in the same location.

Resilience of the test environment and the test automation system

It is important to consider the resilience of the test environment itself when performing tests in the integration facility. The purpose of the CIF is not to test the test domain items' behaviour. Those components are there merely to enable the testing of the system composed of the constituent items. Hence, a lack of resilience within a test domain item does not reflect the resilience of the system under test, even though it affects the result of the tests that are run within the CIF.

Furthermore, the test automation system's resilience can affect the result of automated tests. Since it is a pre-programmed system, it can only deal with known scenarios. If the system finds itself in a state that was not anticipated, the automation will not have been programmed to cope with that, and will, consequently, fail the test, even though the system itself might have exhibited correct behaviour for that specific scenario. It is up to the user to determine if a "fail" result in the automation test is an automation failure or a system failure.

In addition, not all automation functions are resilient to user interaction. For example, if a user changes the view in the signaller's workstation, the automation will simply change back the necessary screens if requested to set a train's head code – in this case, the automation is resilient. However, if the user simply closes a software application mid-test, the automation will fail the test. Therefore, some measures have been introduced into some test clients to avoid a user induced failure, such as blocking all user inputs in some computers while a test is being executed. That way, only the test automation system can interact with the software application during the execution of the automated tests.

Observed benefits of the Test Automation

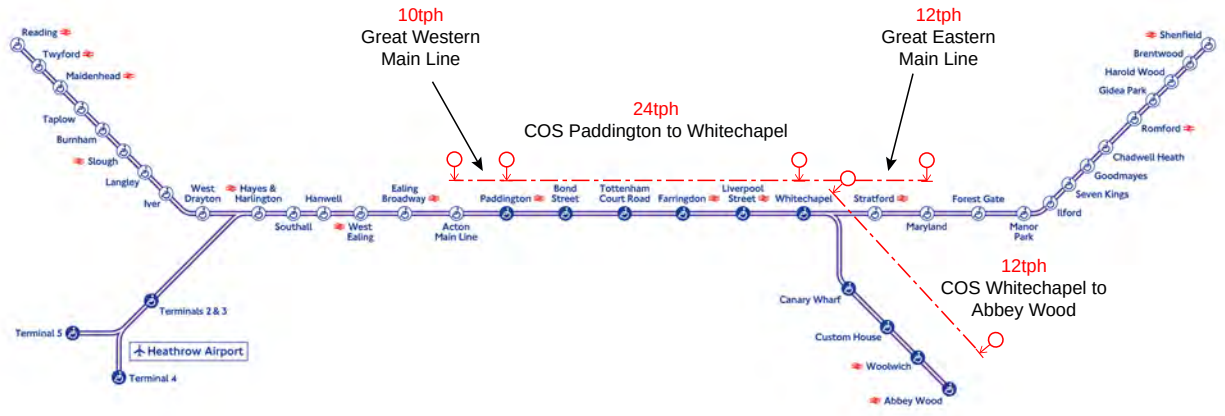
Besides increasing the utilisation of the rig and facilitating the execution of repetitive tests, the test automation has brought other benefits. Firstly, it is very useful to have a tool that provides top-level logging of a test. Usually each product will provide its specific logging, and when a fault occurs, the system integrator must analyse and link logging from the different applications to understand the sequence of events and find the root source of the fault. This becomes more challenging if the time and dates between applications are not synchronised. Having top-level logging provides the system integrator with a reliable record of the sequence of events. Moreover, since the automation's logging is also performed locally, it gives the user a reference, in case of faulty time synchronisation between the applications. This information can then be combined with the specific software logging performed locally, to more easily and readily identify faults of the system.

As the CIF has been built in parallel with the development of the key constituent items, the automation has also proved to be very helpful in allowing advanced system functionality testing whilst the product software itself was still undergoing product testing. The reason for this is that the automation can provide workarounds for known issues quicker than waiting for the next release of the products – therefore, further development can continue to be made with the system, decreasing project execution time. An example of this scenario was found during timetable tests. When a train is entering the COS from either Great Western Main Line (GWML) or Great Eastern Main Line (GEML), the Vicos-ARS is responsible for setting a slot request into the COS area, as soon as the head code (UK's main line network train description) of the incoming train is recognised as having a route through the COS. However, it was known that, at that stage of the Vicos development, this functionality was not working correctly. To work around this issue, automation specific functions were written to set both GWML and GEML slot requests when it identified that a train was meant to be routed into the COS. These functions were incorporated into the automated test scripts, so that the timetable tests could already run reliably.

Example of an automated test

As an example of an automated test, consider the following timetable test. The requirements for the peak frequency of trains in the real railway is represented in Figure 6 for the area covered by the CIF.

Figure 6 – Peak frequency of train service pattern on the Elizabeth line.
Modified diagram from TfL/Mayor of London Crossrail website.



The objective of the timetable resilience test in the CIF is to stress the system by timetabling more trains than the real system would run in reality. To be able to test this scenario, the system integration team has developed its own timetable, with frequencies – trains per hour (tph) – that exceed the peak frequencies showed in the diagram. The frequency of trains in each area in the resilience timetable test is shown in the following table.

Railway Region (as defined in Figure 4)	Frequency (tph)
Great Western Main LIne	10
COS – Paddington to Whitechapel	30
COS – Whitechapel to Abbey Wood	15
Great Eastern Main Line	15

A Common Interface File (CIF file) – the industry standard file format for Network Rail's (the owner and infrastructure manager of most of the railway network in Great Britain) timetables – has been generated for this test by the system integration team, so that it can be loaded into the system.

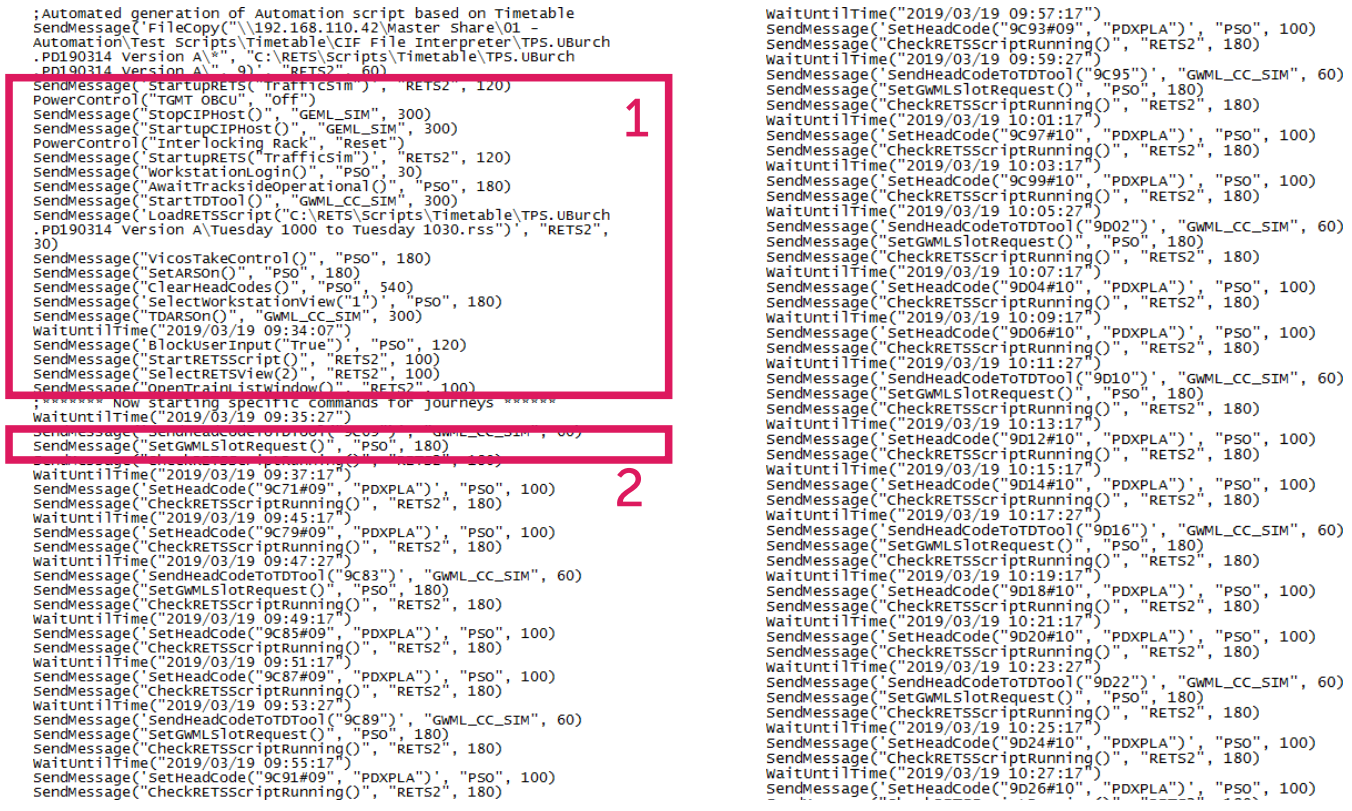
In contrast to other automation tests, which require the user to write their own automation scripts, timetable tests have a specific functionality in the scenario controller. The timetable automation test script can be generated automatically, once a CIF file is loaded into the automation system. The user only needs to specify a date and a time to run the test.

Even though all trains are simulated, the system only accepts trains being injected into the scenario from a limited number of locations. For this reason, once a date and time is specified, the automation system analyses which trains will be part of the test by working back when they would have to be injected at an allowed inject location.

After the timetable script is generated, the scenario controller will synchronise the time between the different applications in the CIF and the test is ready to be started.

The example of the automation test script in Figure 7 demonstrates how, in a timetable test, the automation does not need to set any routes for the trains, since the signaller's workstation is equipped with Automatic Route Setting (ARS). Therefore, the main focus of the automation is to set up all applications correctly and make sure that all injected trains have the correct headcode assigned to them. At the start of the script (box #1), one can see the necessary commands to set up the system, such as starting the RETS application; loading the appropriate test script in RETS for this test; restarting the interlockings, so that all routes in the layout are cleared out; taking control of all control areas in the signaller's workstation; clearing all headcodes left behind in the layout, and switching ARS on. After that, the system is ready to start the test. The commands after the message "Now starting specific commands for journeys" are executed while trains are running in the scenario. This part of the script mainly consists of assigning the correct headcode to each train, after its injection either in GWML area – using "SendHeadCodeToTDTool" function, which assigns a headcode to a train injected in Acton Main Line platform 3 – or in the COS area – using "SetHeadCode" function with "PDXPLA" parameter, as trains that are injected in the COS get their headcode in Paddington Platform A. The previously mentioned slot request workaround is visible here (highlighted in its first appearance in box #2) – the automation sets the slot request for all trains driving from GWML into the COS appropriately.

Figure 7 – Example of a timetable test.



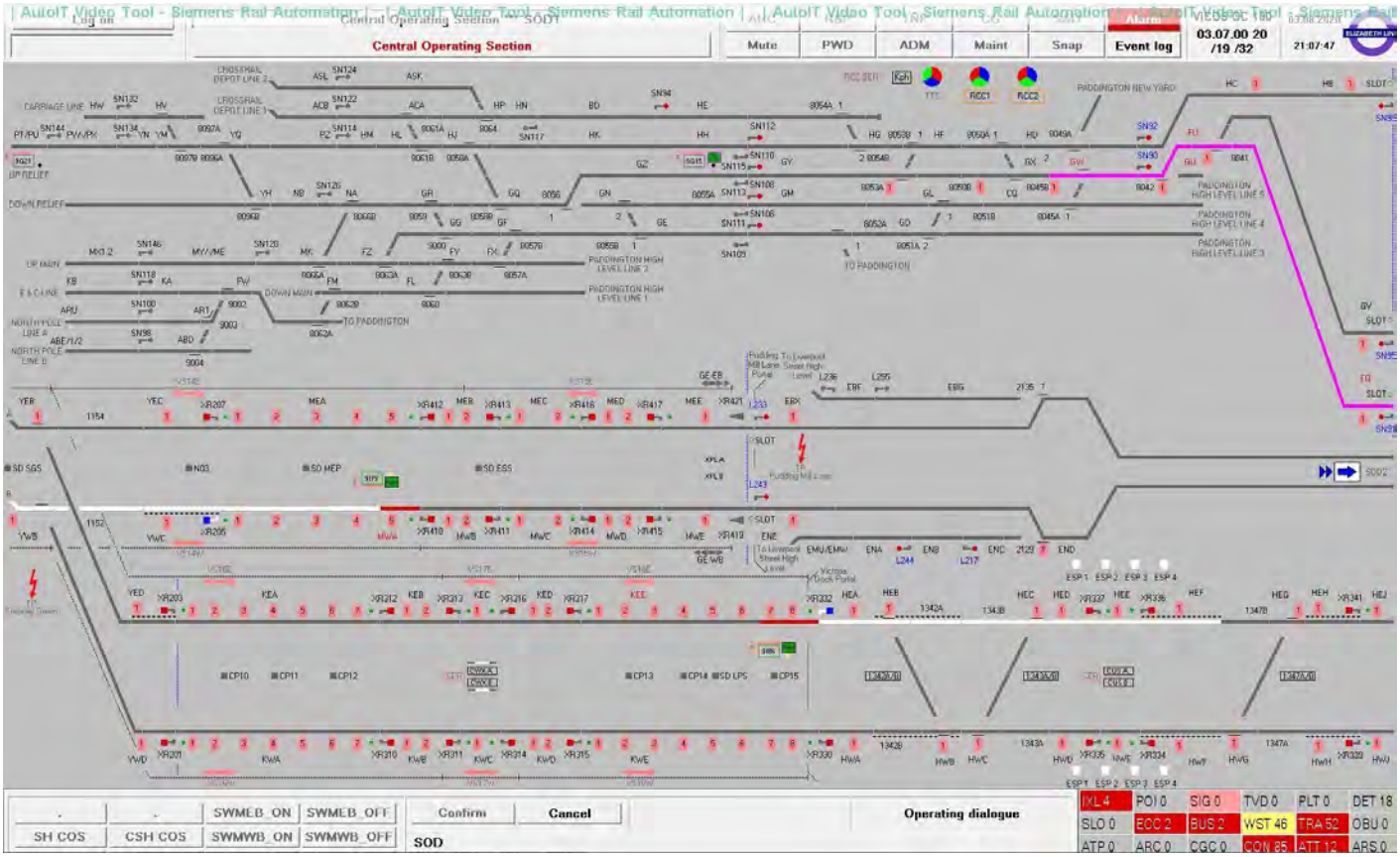


Figure 8 – Signaller's workstation display during an automated timetable test.

The CIF user can observe the movement of all trains through the signaller's workstation, in the same way as the operator of the real railway would. Figure 8 illustrates the signaller's workstation during a timetable test. The details of the layout are not visible; however, one can observe the occupied track (red) sections, which correspond to the location of trains within the layout. With meticulous observation, one can see that each red section is accompanied by a small box with green outline – this box contains the headcode of the train within that occupied track section. The white tracks represent sections of routes that are set and locked for the moving trains, which were set automatically through the automatic route setting functionality. Dark grey sections represent unoccupied tracks.

Observed impact of having an integration facility in the project

Since it replicates the core parts of the real Crossrail signalling and control system, the CIF is itself a very complex system. A team with a deep understanding of the system was needed to build this facility. The investment in building the facility is, however, essential in a complex project like Crossrail to facilitate early system integration. The cost and time necessary to run all tests that the CIF enables would be enormous in the real system.

It is possible to identify several benefits from having a system integration facility in the Crossrail project:

- Fault-finding and debugging in a controlled off-site environment are a lot easier than it would be with the actual live system.
- The detection of defects early minimises the cost and time necessary for their rectification.
- Working in a controlled environment allows the use of some workarounds for specific product faults until a new product release is received. This allows system tests to continue even with known product faults, accelerating further fault finding and correction within the system and the products. Many of these workarounds would probably not be possible in the real system, as thorough risk assessments would have to be performed before their implementation.
- It is an efficient way of de-risking the project, as an off-site facility provides the capability of executing tests that otherwise would be very impractical to perform in the live railway, such as stress tests, tests of how the system operates under degraded or emergency mode.
- Once in the operation phase of the project, the facility will provide the means to test planned updates off- site before being implemented on the real railway, so that general reliability is maintained during updates.
- It provides a means for the maintenance and operation teams to familiarise themselves early with the system, so they can provide inputs to the project early on.
- It can be equipped with extensive test automation, obtaining all the benefits listed above.
- Ultimately, in the long run, one of the best benefits that integration facilities can provide to the railway is the cooperation between the diverse stakeholders involved in running a safe and resilient railway. It is only through cooperation that we can work with complex systems in an increasingly globalised and intertwined world.

Figure 9 – The integration rig brings together a large array of target equipment and simulation systems which, together with extensive test automation, brings a wide range of benefits.

Conclusion

Complex railway signalling projects lack the time and infrastructure access to perform extended testing and integration procedures because of tight project schedules. A solution to this problem is to provide a system integration facility. The Crossrail project is no exception, hence the decision to build the CIF.

In this article I have explained how establishing a fully automated off-site testing facility is extremely valuable to the Crossrail project. The CIF is used to run interface, integration, timetable and transition testing, as well as to test the system's behaviour under the introduction of faults or stress. The benefits of being able to run autonomous test scenarios include increased utilisation of the system and ease of execution of repetitive tests, in combination with ease of implementation of workarounds and fault finding with the extra logging provided. In addition, the scenarios related to testing the resilience of the system are much less complicated to set up in a controlled environment. Generally, it is evident that the CIF has brought several benefits to the Crossrail project itself and has given a lot more in return than the financial and time investment necessary to build it.

I believe that all future major railway signalling and control projects should use a system integration facility to test their products and the emergent properties of their system prior to on-site testing. This additional step within their system engineering process will also be very useful when updating a system – all updates can be tested in a controlled environment prior to their implementation. Updates can go through thorough resilience tests that would probably not be available otherwise. Clearly though, to make the most out of the investment in a system integration facility, it is important to make sure that the facility is completely integrated within the system engineering process, which means that the time for tests within the facility and time for fault rectification need to be incorporated into project schedules.

What do you think?

Railway control command and communications are networks of very complex interconnected systems. System integration testing is therefore becoming increasingly important to deliver thorough off-site interface testing, as well as simulation of faults to understand all behaviour, including degraded and emergency situations, and to provide interoperability. Other industries do similar, with for example the ETSI Plugtest Programme provides an environment for collaborative testing and validation activities for products, and not just projects, among different telecoms organisations. The ETSI Hub for Interoperability and Validation (HIVE) interconnects participants' labs and allows for multi-party remote interoperability testing, proof of concepts and validation testing. Plugtests events allow the plugtest community (who may be commercial competitors) to meet and run face to face intensive testing sessions, with non disclosure arrangements in place. Could railway signalling systems benefit from similar arrangements? What is your experience of system integration testing? Who should lead and manage remote off-site integration testing? We would love to hear from you at **editor@irsenews.co.uk**.

About the author ...

Alessandra (known as Ale) is a systems engineer at Siemens Mobility, currently working on ETCS projects in Zoetermeer, Netherlands. Ale graduated with a Physics Engineering degree from the Universidade Federal do Rio Grande do Sul, Brazil, in 2016 having spent a year of her studies at the University of Sheffield. She joined Siemens Mobility in the UK as a graduate engineer in 2016, and was soon appointed as a systems engineer working on the Crossrail Integration Facility. She changed roles during 2020, moving to her current position in the Netherlands. Ale is committed to the promotion of science, technology, engineering and mathematics to younger people and has a long track record of developing and running activities in school and work environments associated with this.