"We took advantage of the accuracy, reliability and flexibility of NI hardware and software to implement an innovative system to reduce the lost customer hours experienced on the Victoria Line. The system is forecast to reduce lost customer hours by 39,000 per year—an estimated £350,000 savings per year in passenger disbenefit."


The Challenge:
Predicting London Underground track circuit failures that cause disruption to the travelling public, to increase signalling asset uptime and schedule appropriate maintenance, and completing the project within a compressed timeline of one year.

The Solution:
Designing, certifying, and installing a large-scale distributed system to simultaneously monitor 385 deep Tube track circuit assets in real time on an operating railway from a central location. Development time and cost was reduced by using commercial off-the-shelf (COTS) tools, maintainers can proactively respond to potential failures and management has a better insight into asset lifecycle.

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London Underground serves 1.7 billion passengers per year and the Victoria Line accounts for 213 million of those journeys. The line carries 89.1 million passengers per year in the peak service, offering the most intensive service on the underground network. Over the past eight years, a £1 billion investment programme upgraded and replaced the Victoria Line’s rolling stock and signaling and control systems to deliver a service capable of running more than 33 trains per hour. The new signalling system uses 385 Jointless Track Circuits (JTCs) to detect train position, maintain safe train separation and deliver train headways capable of meeting an extremely demanding timetable. Track circuits are the sole means of train detection and play a critical role in the safe and reliable operation of the railway; however, no provision was made for any condition monitoring during the design and installation. Because of the critical nature of the asset, a failed track circuit has a major impact on the service and constitutes the biggest cause of passenger disbenefit on the Victoria Line, amounting to £1.5 million since their introduction (London Underground CuPID database for Track Circuit failures since 2012).

The Victoria Line Condition Monitoring Team, made up of six professional engineers with rail, software, electrical, mechanical, network and engineering backgrounds, delivered the solution. National Instruments Silver Alliance Partner Simplicity AI supported the project by providing additional software consulting services. We used the company’s enormous breadth of expertise to deliver the system onto an operational railway within one year of the concept design.

The scope of this project consisted of designing, integrating and installing an intelligent remote condition monitoring system that could perform real-time analysis of voltage and frequency for all 385 JTCs across a 45 km of deep tube railway to predict and prevent failures and subsequent loss of passenger service. We took advantage of the accuracy, reliability and flexibility of NI hardware and software to implement an innovative system to reduce the lost customer hours experienced on the Victoria Line. The system is forecast to reduce lost customer hours by 39,000 per year—an estimated £350,000 savings per year in passenger disbenefit.

Application Overview

Read the Full Case Study

London Underground Improves Reliability for 200 Million Annual Passengers with Remote Condition Monitoring
The Victoria Line deploys variable length frequency-driven tuned electrical JTCs. The circuits energise and de-energise as trains traverse the line. Each JTC includes an electrical receiver unit matched to the frequency of the track circuit (4 to 6 kHz frequency shift keyed), which processes the incoming signal and provides a sample to a monitor point that can be used to check the health of the track circuit.

Prior to the introduction of this system, we had to periodically monitor the condition of every track circuit manually on-site with a digital multimeter. Following the installation of the NI CompactRIO (http://www.ni.com/compastrio/) system, we can now simultaneously acquire the JTC monitor point samples remotely from all track circuits on the line, which means the maintenance teams can proactively predict and prevent equipment failures before they occur.

We looked at various suppliers of data acquisition products and concluded that, although other products may have met the initial requirements, no other product offered the flexibility, scalability and performance of the CompactRIO platform. The diverse range of input modules and the ability to easily customise the onboard software using the NI LabVIEW (http://www.ni.com/labview/) platform also meant that we could deliver further condition monitoring projects using a common platform, which would reduce the time to design and develop the hardware and software for a wider range of data inputs.

Due to the Safety Integrity Level (SIL4) of the track circuit system, we needed to introduce an independent isolation barrier between the receiver unit and the CompactRIO device. We collaborated with Dataforth, based in the United States, to design a SCM isolation module to provide galvanic isolation between the CompactRIO device and the track circuits being monitored. The SCM range of isolation modules could pass the stringent test equipment requirements of the receiver and also provide an accurate and compatible replica of the output signal for the CompactRIO acquisition. The isolation layer coupled with the low failure rates of NI hardware ensured that we could install the system without compromising the SIL4 safety integrity of the Victoria Line signalling system. We pursued an extensive engineering safety analysis on the hardware in accordance with the CEN/IEC railway application standards and approved by the relevant safety authorities to assure and validate the design.

We split data acquisition from the CompactRIO devices across 14 geographically separate sites that were all part of a new high-bandwidth fibre optic network specifically installed for this application. The flexibility of the CompactRIO hardware, combined with NI LabVIEW software meant that we could transport data to a central condition monitoring server in real time using a lightweight transfer protocol. This was a key requirement in the design and delivery of a true remote condition monitoring system.

The central condition monitoring server processes a live 10 Hz data stream from every CompactRIO device, which totals more than 7,000 data samples per second. The lightweight CompactRIO data transfer protocol ensures that the central server can rapidly analyze the data and monitor track circuits for deviations away from the ideal condition. The system compares each received frame of data to a defined standard frequency and voltage so the server can make an independent decision on the health of each track circuit connected to the CompactRIO input channels. In addition, the server stores all of the data in a near line and far line database architecture so we can analyse long-term trends on large datasets.

The central server can push asset condition alerts to a human machine interface (HMI). The HMI is a large touch screen device that displays an accurate scaled replica of the Victoria Line track circuit configuration. A user can intuitively navigate the information displayed with natural touch gestures, clearly identify line-side asset condition and receive predicted equipment failure warnings.

We plan to deploy two HMIs for faster response times—one in the Victoria Line control center and another in the maintenance control center. Both can be used by signaling maintenance staff. We can remotely interrogate each track circuit on the railway with a single touch, presenting the user with a live graphical representation of the root mean square (RMS) voltage, frequency and track state information using the data streamed from the line-side CompactRIO devices.

Figure 1. Overview of the Remote Condition Monitoring System

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Alongside the HMI, a suite of touch screen devices can display the CompactRio data in the line-side equipment rooms and through a smartphone or tablet. This means the data from the CompactRio devices is available anywhere on the Victoria Line through a connection to the new condition monitoring network.

**NI Deployment**

We selected Simplicity AI to develop the CompactRio FPGA and real-time software. Although London Underground has internal LabVIEW developers, we used Simplicity AI on this project because of the company’s high level of FPGA and real-time experience. The company provided full documentation, source code, and results from long-term stability and stress tests within three months to ensure that the CompactRio system could be assured to a level suitable for use in a safety-critical environment on London Underground’s infrastructure.

For each deployed unit, we paired an NI cRio-9025 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/208044) controller with an 8-slot NI cRio-9118 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/206767) chassis. We could use up to eight NI 9220 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/210836) analog input modules to provide a maximum of 128 physical inputs per CompactRio system. We selected this configuration because it offered the required processing power and provided dual network ports for redundant network operation to maximize system uptime. The CompactRio platform helped the team take a bottom-up approach in developing the system because the ever-evolving specifications were unknown until we acquired early asset data. This flexible platform accommodated rapid iterations in the development of application functionality, which saved a significant amount of time in project delivery.
Early on we faced the challenge of calculating frequency and RMS voltage simultaneously over all 128 channels on the FPGA. Simplicity AI addressed this by delivering a serial process architecture that uses the high clock rate of the FPGA to process data for each channel sequentially. The software builds up a 10 ms buffer for each channel then iterates through each buffer and calculates the frequency and RMS voltage.

A key feature for the deployment on London Underground was for the system to be installed, commissioned and maintained by rail technicians unfamiliar with NI software and the CompactRIO platform. Simplicity AI provided a common software package configured for each location via a simple external text file in the standard XML file format. We developed an application using the Replication and Deployment (RAD) utility, which automated the process of installing the system and application software to the CompactRIO device along with the correct configuration file.

The CompactRIO deployment tool simplified the rollout of the system, delivered installation efficiencies and allowed for CompactRIO devices to be remotely deployed, configured and updated from a centrally managed location. This remote one-click configuration also proved extremely beneficial during the development phase when London Underground and Simplicity AI engineers worked in parallel as a joint team on different sections of the project.

Summary We completed the project on schedule with one year of development time, including all design, assurance, procurement and installation. We also delivered under the allocated budget. The system provided a solid architecture utilising an array of FPGA and real-time features to provide a versatile platform for deployment on the London Underground network. We delivered a reliable remote condition monitoring system that empowers maintainers to proactively respond to failures before they occur and provides management with a better insight into the asset lifecycle.

We have a greater knowledge of the real world behaviour of JTCs after the introduction of this condition monitoring system. This helped us to better understand a critical asset, learn the behaviour of a faulty track circuit, identify those that could potentially fail and alert maintenance prior to this event occurring.

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