A Retrofit Solution for Remote Lift Monitoring

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Abstract. A trial has been undertaken on the lifts at Covent Garden station to extract data from the controllers and explore its value for maintenance and asset management. The programmable logic controllers (PLCs) monitor a large amount of information, from discrete signals such as the status of relays, buttons and switches to analogue data for lift car speed and position.

A retrofit monitoring system was designed and installed to facilitate extraction of all available data from the PLCs in real time using a modern lightweight messaging protocol. An original approach to the visual representation of the historical data was developed to enable insights to be gained.

The findings demonstrated that there is value in extracting PLC data for fault diagnosis, improved fault response time and a better understanding of asset operation and condition. This will support a more proactive approach to maintenance and inform whole life asset management.

1 INTRODUCTION

Logging and analysis of data from lifts has occurred since the advent of automatic passenger lifts, originally comprising manual observations in the lobby or lift car including traffic counts and performance parameters such as door operation [1]. In the 1970s after the introduction of the minicomputer, various studies were commissioned by the Building Research Establishment which utilised multi-channel recording equipment to capture data such as intervals and door times for more in-depth analysis of lift systems [2,3,4]. Their use also extended to the provision of call allocation for multi—car systems to minimise total journey time [3] as well as for verification of lift performance. Remote fault identification was also identified as an output of this early work, using telephone lines to alert maintainers in the event of a fault occurring [5].

As technology has continued to advance, the cost and physical size of computers have significantly reduced making onsite data capture more cost effective, and the capabilities have greatly improved. Faster processing speeds, low cost data storage, cloud computing and efficient networking technologies, including wireless, have increased the return on investment in systems for data capture. Data logging has since become available to the average lift operator or maintainer requiring very little investment and is built into many modern controllers [6]. Solid-state storage is significantly more reliable than the early magnetic tape and floppy disks, particularly in harsh environments, making it feasible for equipment to be left in situ with minimal maintenance.

This paper documents a trial to extract data from the lifts at Covent Garden station and explore its value for maintenance and asset management. The controllers are Mitsubishi programmable logic controllers (PLCs) which monitor over 100 discrete signals representing relays, buttons, safety switches, locks, emergency stops and other on/off signals. Lift control mode and analogue lift car speed and position are also available. Remote access to this data is not currently specified for London Underground lift installations or refurbishments.

2 BACKGROUND INFORMATION

As part of the refurbishment of Lifts 1 to 4 at Covent Garden in 2014, a Modbus [7] interface module (Mitsubishi QJ71MB91) was fitted within each of the lift controller cabinets to facilitate data extraction from the PLCs. This would provide flexibility in how the data is processed and stored whilst preventing any unwanted control of the asset by being 'read only'. The reason for selecting Modbus was that the existing monitoring system for temperature and vibration on other lifts and escalators utilises this protocol, so it would provide compatibility if the decision were made to integrate the data into this system.

The trial was limited to four lifts, however, there is potential to expand the solution to other compatible controllers across the London Underground network comprising around 30 lifts and 110 escalators. Similar solutions are also possible for other controller designs.

Having access to the data from the PLCs could provide a number of advantages. For example, maintainers could be alerted to a fault and given relevant information about it instantly, before it is detected by station staff and reported to the maintainers via the London Underground fault reporting process thereby improving response times. Having the event history available remotely would enable fault finding to be carried out by maintenance staff prior to them leaving their premises, informing which spares should be taken to site and avoiding repeat visits.

As well as providing data for fault detection and diagnosis, there is potential to support predictive maintenance by detecting deviations from normal behaviour and identifying precursors to potential fault conditions using analytics techniques. This could complement condition monitoring data such as vibration, temperature and visual inspections.

Other benefits could include performance and availability monitoring as well as asset usage patterns to inform customer strategy, operational and maintenance planning.

3 STAGE 1 – OFFLINE SOLUTION

The first stage of the trial was to fit a Modbus-compatible data logger on Lift 1 at Covent Garden. This would enable the data from the PLC to be stored on a removable USB drive which could then be analysed to assess its value before progressing to a networked solution. Figure 1 shows the hardware in situ in the lift controller cabinet.

Figure 1 Offline data logger on Covent Garden Lift 1

3.1 System design

The data logger was programmed to poll the status of all the registers in the Modbus module once per second and append the data to a CSV file, with a new file created every hour. This data could then be parsed to extract the status of each individual bit for the discrete signals.

3.2 Findings

To visualise the data effectively, the discrete events were overlaid against the analogue data which gives a clear picture of the behaviour of the asset over time. Figure 2 and Figure 3 show an example of a safe edge fault event which can be seen to have occurred when the lift was at the top landing. The vertical lines represent the change in status of a binary signal, with red being a transition to active state and green being a transition to inactive. In addition to the events from the PLC, faults raised are also listed on the event log, which enables all relevant data to be viewed in chronological order. In this case, the fault was reset locally so no fault was raised to request maintainer attendance.

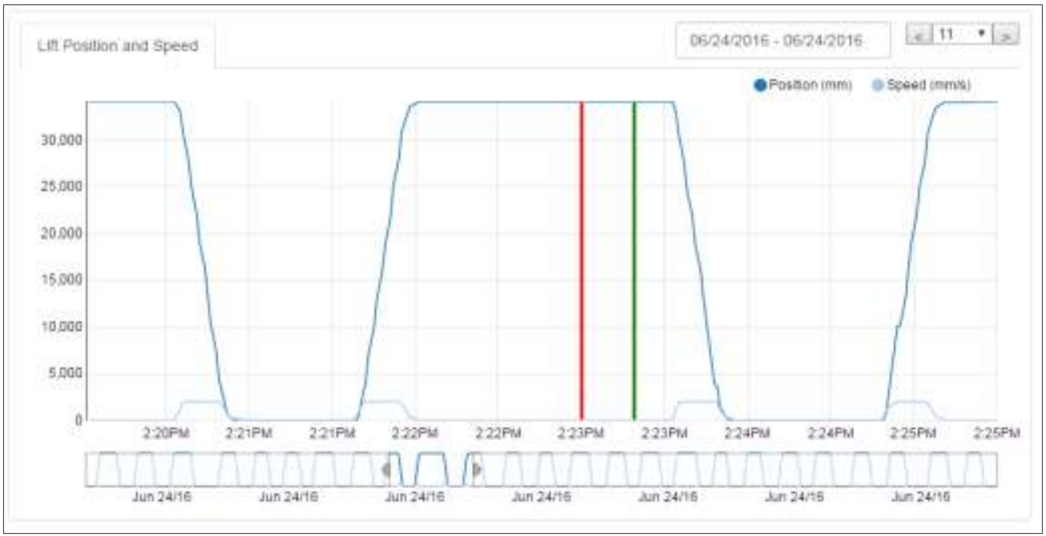
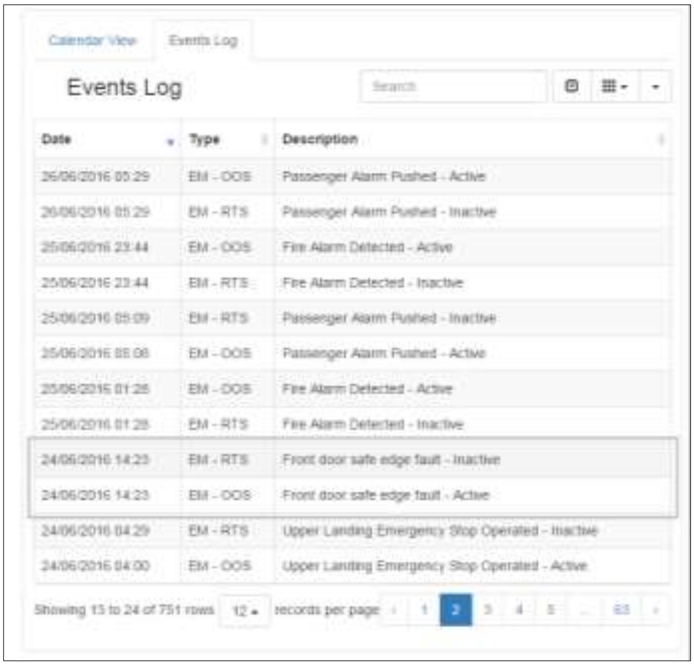


Figure 2 Data visualisation showing safe edge fault event


Calendar View | Events Log

Events Log

Date	Type	Description
26/06/2016 05:29	EM - OOS	Passenger Alarm Pushed - Active
26/06/2016 05:29	EM - RTS	Passenger Alarm Pushed - Inactive
25/06/2016 23:44	EM - OOS	Fire Alarm Detected - Active
25/06/2016 23:44	EM - RTS	Fire Alarm Detected - Inactive
25/06/2016 05:09	EM - RTS	Passenger Alarm Pushed - Inactive
25/06/2016 05:08	EM - OOS	Passenger Alarm Pushed - Active
25/06/2016 01:28	EM - OOS	Fire Alarm Detected - Active
25/06/2016 01:28	EM - RTS	Fire Alarm Detected - Inactive
24/06/2016 14:23	EM - RTS	Front door safe edge fault - Inactive
24/06/2016 14:23	EM - OOS	Front door safe edge fault - Active
24/06/2016 04:29	EM - RTS	Upper Landing Emergency Stop Operated - Inactive
24/06/2016 04:00	EM - OOS	Upper Landing Emergency Stop Operated - Active

Showing 13 to 24 of 751 rows 12 records per page 1 2 3 4 5 ... 63

Figure 3 List of events corresponding to safe edge fault event

The data that was collected using the data logger demonstrated that being able to view historical events alongside reported faults can provide an in-depth view of the asset. This gave confidence that a networked solution on all four lifts was worth pursuing. Some limitations were found with the system, however. The data recorded was subject to latency, compounded at each stage of the path that the data was transmitted. The solution trialled in this case was subject to the rate at which the PLC data was stored to the registers of the Modbus module which was every 100 ms, and this was then sampled at 1 second intervals by the data logger. The analogue data, obtained from an encoder, was subject to a 10ms resolution, which added yet more inaccuracy to the recorded time. These errors are not significant but had to be taken into consideration when analysing the data.

4 STAGE 2 – ONLINE SOLUTION

Once the value of extracting data from the lift controllers had been demonstrated using a data logger on Lift 1, the second stage was to make the data available remotely via a network connection and extend the monitoring to all 4 lifts. This would enable data processing to occur in real-time, providing the ability for alerts to be generated in the event of a fault condition or event of interest if required. A networked solution would also eliminate the manual task of physically visiting site to replace the USB drive and transfer the data which is impractical for a larger scale solution.

4.1 System design

To enable the data acquisition, an NPE X500 M3 industrial computer was installed in the controller of Lift 2 with a connection to the Modbus interface module. The other 3 lift controllers were fitted with a Modbus to Wi-Fi converter, enabling them to transmit data from the Modbus module over a local Wi-Fi network hosted by the X500. This would minimise the amount of hardware and local cabling required and enable the data from all four lifts to be connected to the Wide Area Network via a single 3G connection. The new data acquisition setup allowed the polling of the Modbus module at the maximum frequency available of 10 readings per second. The tenfold increase in time resolution with respect to the offline trial identified more subtle effects such as switch bounce and readings noise. Figure 4 shows the configuration of the networked system.

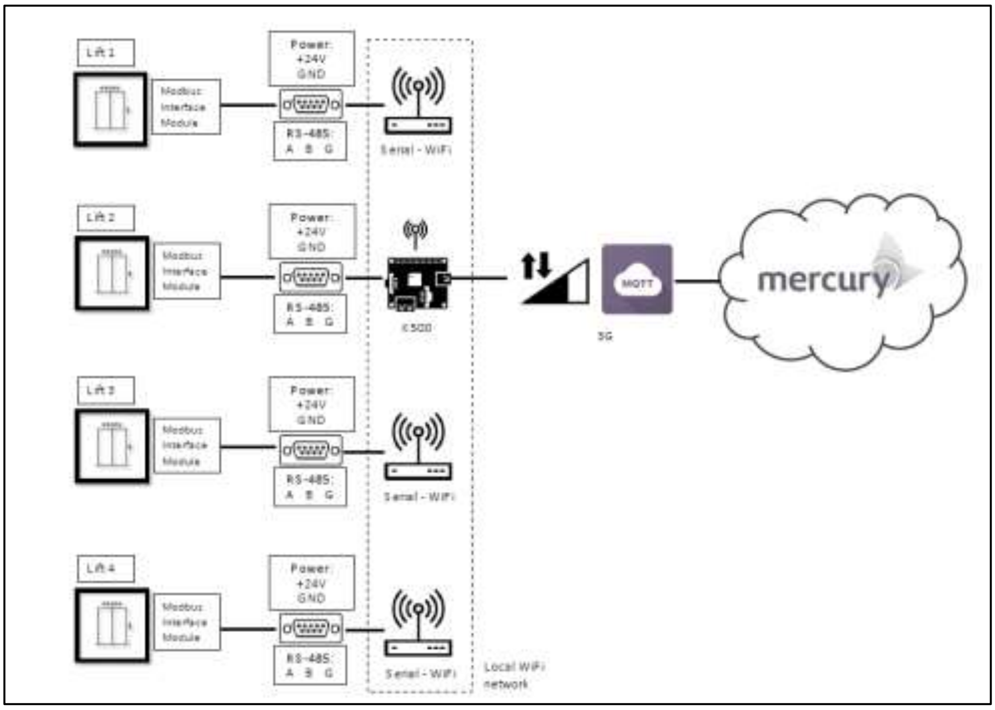


Figure 4 System diagram for online monitoring solution

Using a mobile network with limited availability presented a challenge, especially during peak hours. After appropriate configuration, the X500 would store the messages locally and forward them to the monitoring server when there was available network connection. It was necessary to do some data reduction on site, ensuring that only the changes in the asset state were being sent. This brought the monthly traffic down from 20 GB to 12 GB for all 4 lifts. To ensure data consistency and prevent loss of information, it was decided to use the MQTT protocol. This was encrypted using Transport Layer Security over a Virtual Private Network.

Even after a significant data reduction, a backend was required that could handle the load and allow for the system to scale with ease. The cloud-based asset management platform Mercury [8] developed by Amey Strategic Consulting provided the necessary solution. Utilising RabbitMQ, Apache's Kafka, Storm and Cassandra, the cloud backend can receive and process thousands of messages per second.

The machine information was aligned with the maintenance records and visualised in Mercury's frontend for analysis. The X500 unit in situ on Lift 2 is shown in Figure 5.

Figure 5 NPE X500 installed on Lift 2

Following the data analysis from Stage 1 it was decided to explore what additional data could be extracted relating to the doors, as this was identified as the subsystem with the most reliability problems from maintenance records. Due to the latency of the system, the PLC was configured to calculate the entrance and exit door opening and closing times which were stored in additional registers on the Modbus module. Door events were also added as discrete signals to two additional registers, making up six registers defined as follows:

1. Entrance door closing time (16 bits)
2. Entrance door opening time (16 bits)
3. Exit door closing time (16 bits)
4. Exit door opening time (16 bits)
5. Entrance door lock and signal info
    - Bit 0 – Door close output command
    - Bit 1 – Door closed output command
    - Bit 2 – Door open control input
    - Bit 3 – Door safe edge input
    - Bit 4 – Entrance car lock status

- Bit 5 – Upper landing entrance lock status
- Bit 6 – Lower landing entrance landing lock status

6. Exit door lock and signal info (same signals as Register 5)

5 ANALYSIS

Data from the online system was analysed over a nine-month period alongside fault data and discussions with the lift and control system maintenance contractors and station staff. The outcomes of this analysis shall now be discussed.

5.1 Lift availability and utilisation

The immediate benefit of the monitoring system was the ability to profile the assets' utilisation patterns. A quick overview of a day's worth of data showed how the lifts were not being used between midnight and the morning peak. A closer look revealed more subtle differences between the assets. For example, Lift 1 tends to be idle between 00:30 and 05:30, while Lift 4 is idle between 00:00 and 08:15. This can be explained by the fact that Lifts 1 and 2 are closer to the stations entrance and tend to be used more often than Lift 4 which is at the end of the hall. This simple observation can lead to an adjustment of the maintenance schedule to prioritise the more utilised lifts 1 and 2.

5.2 Failure analysis

The discrete alarms and switches are granular enough to show the state of the lift during a fault and often indicate explicitly what the reason was for the downtime. Having all historical data easily available makes it possible to trace back an incident and review the events that led up to it.

Figure 6 shows a fault occurring on Lift 4 on 3rd May 2018 at 14:49. It is immediately flagged up as 'Failed at Lower Landing' with 'Front door NOT open'. A minute and a half later a member of staff put the lift in landing control and took the lift out of service. Tracing back the asset state over the previous 12 hours shows two intermittent 'Failed at Lower Landing' events with the longer of the two lasting 20 seconds, accompanied by a 'Lower landing front locks open' event. This indicates a developing problem with the lower landing doors mechanism. The maintenance staff attending the fault reported that the lower landing entrance door was out of alignment with the car door skate and was realigned.

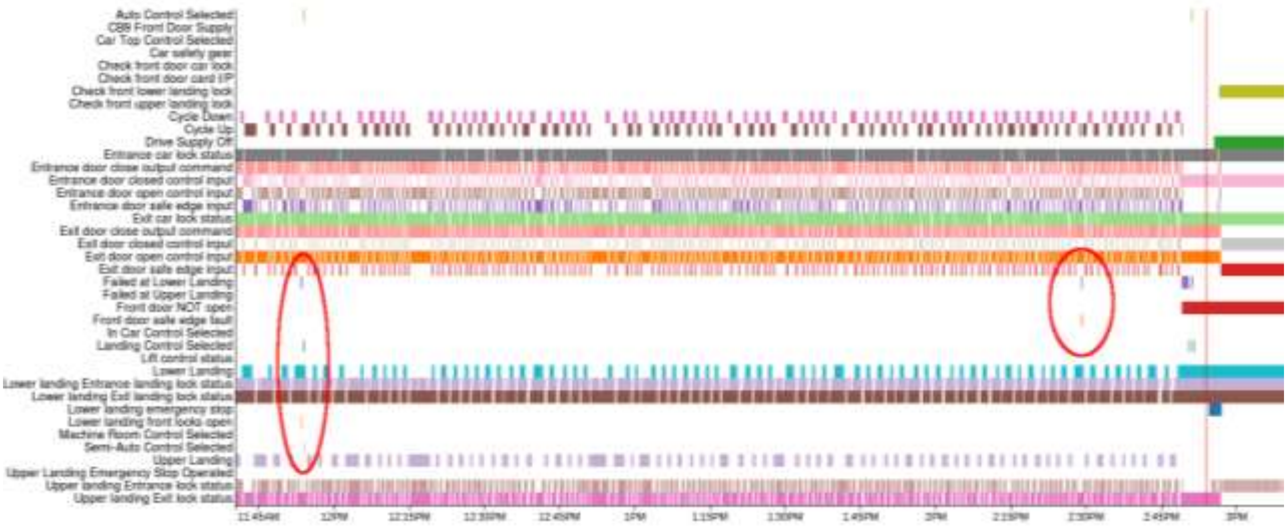


Figure 6 Example of a door fault, 3rd May 2018, Lift 4

5.3 Response times

The occurrence of events that corresponded to actual failures was compared to faults raised by the station staff. It was found that if alerts had been set up, there would have been early warnings for many of the faults which in some cases could have informed maintainers of an issue hours earlier and avoided any loss of passenger service.

The average time saved was around 40 minutes with some faults occurring in the evening and not being picked up until the start of traffic the following morning resulting in disruption during the busy morning peak which could have been avoided. An example of this is shown in Figure 7. The vertical red line indicates a fault being raised to request maintainer attendance, the yellow one is the arrival on site and the green one is the recorded resolution time. The fault was reported four hours after it occurred.

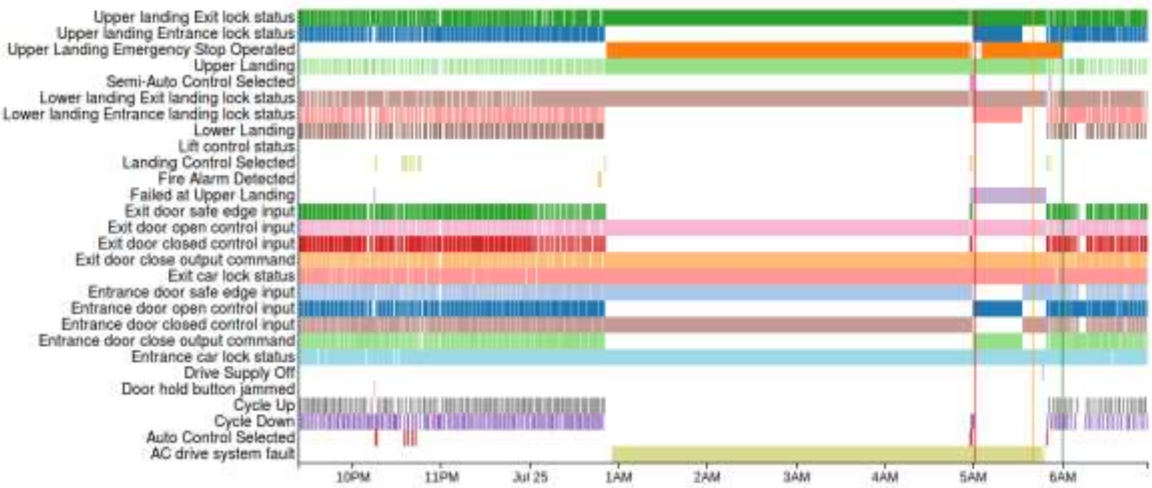


Figure 7 AC drive fault on 25th June 2017, Lift 1

5.4 Unreported faults

It was found from the analysis that there were a few events whereby the lift entered a failed state but was reset locally and no fault was raised by the station staff. In these instances, the maintainers were unlikely to be aware that an issue has occurred and there may be a skewed perception of the reliability of the assets.

It should be noted that if there were alerts to be configured, this would increase the workload of the maintenance contractor and could present a risk of 'information overload'. The design of alert notifications and any business logic behind them requires careful consideration to ensure that they are of value.

5.5 Operational issues

On several occasions, it could be seen that the control was switched between landing and auto control repeatedly prior to a fault occurring. An example of this is shown in Figure 8.

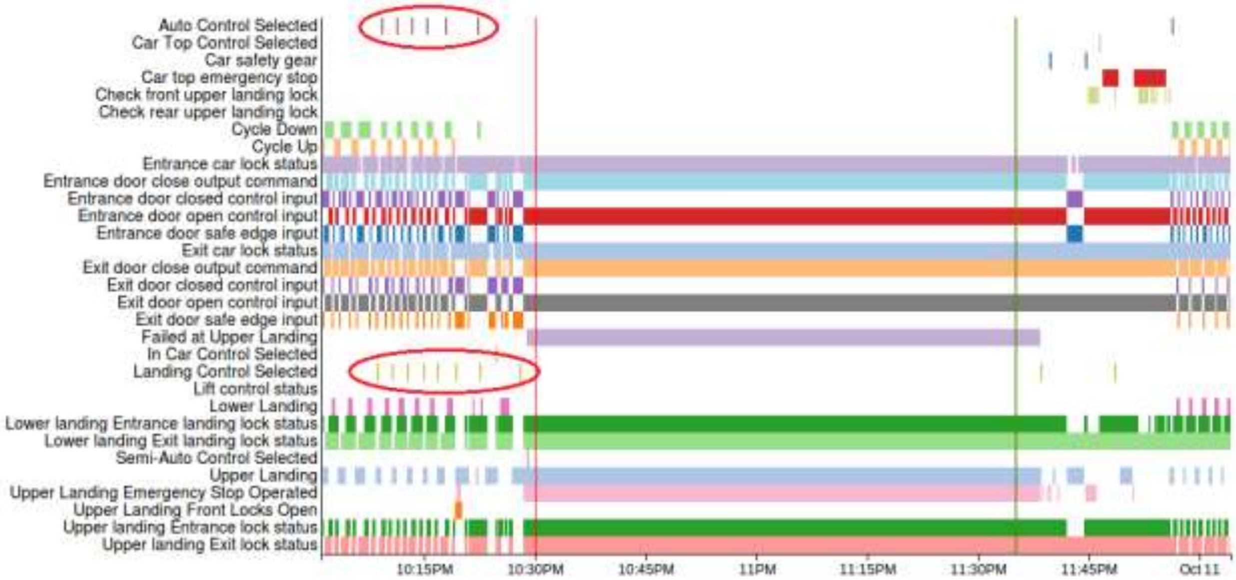


Figure 8 Manual control override prior to fault occurring, 11th October 2017, Lift 4

Enquiries were made with the station staff who reported that they do sometimes manually change over the control mode when footfall is high to keep the lifts moving as quickly as possible. It appears that in some cases this is causing the lift to overshoot the landing and a request has been made to avoid this practice. The historical data can be used to identify when such events are happening to feed back to the station staff, and a more effective solution of modifying the controller program is now being explored.

5.6 Precursors to failures and predictive analytics

The data was analysed to determine if it was possible to spot any developing faults or precursors to failures. After profiling the normal asset behaviour during periods with no known issues, this was compared with the activity during service disruption. Anomalies could be clearly seen where the normal duty cycle of the lift was interrupted, accompanied by the activation of alarms or fault sensors.

Further analysis was undertaken from times of known faults to look for the identified anomalous sensors. It was found that some lifts experienced intermittent faults hours and sometimes days in advance of a service disrupting fault. Disseminating between intermittent faults and actual precursors to a failure proved to be a challenge.

Alternative methods for anomaly detection were then considered. A common way to identify anomalies in machine behaviour is to use control charts in continuous readings. In this case, measurements of entry and exit doors closing times were used. The time series appeared to be stable and did not show any significant change prior to a fault.

Investigation into automatic extraction of event sequences was considered, made possible due to the cyclic behaviour of the lift system. If a standard sequence could be extracted, this could be profiled to make it easier to track for anomalies in the asset state. By taking the differences in time between all binary sensor changes and sorting them, a typical sequence was identified which defined a fingerprint of the asset that could be monitored continuously. This work is essential in preparing the data for further analysis using advanced anomaly detection methods based on machine learning. To do this effectively would require a larger dataset and this is an area requiring further work.

6 DISCUSSION

The examples presented show some of the insights gained from the use of in-depth remote lift monitoring. The new information can be leveraged to improve lift operation and maintenance, which could lead to increased reliability and reduction of downtime. The challenge in practice is to turn the information into actionable intelligence.

Remote monitoring is a powerful tool. To deliver real benefits it must be used regularly, for example as part of regular technical review meetings, and may require some training. Having immediate access to historical data enables retrospective analysis to be done objectively. The knowledge, not only of the occurrence of an incident, but also the events that led up to it and the outputs of internal diagnostics, aids the failure analysis process. Reviewing the monitoring information manually, at least in the early stages, is helpful in identifying anomalous behaviour and addressing any recurring issues as well as providing a record of maintenance performance levels. Additionally, the preventative maintenance activities should be reviewed and adjusted based on asset utilisation and dominating failure modes.

The integration of remote asset monitoring in existing organisational processes is necessary to achieve the reduction in downtime and cost savings they can offer. The early detection of faults cannot shorten the response time on its own, and must generate an appropriate notification to be sent to the asset maintainer. Additionally, the maintenance process and contract must accommodate for the use of this information. Often, the validity of automated alerts is challenged, and in these cases, there must be steps to efficiently verify the alerts and raise a manually confirmed fault as well as feeding back improvements to the business logic. Providing access to the monitoring system for station staff is an effective way to increase their awareness. Even when done informally, this promotes transparency within the organisation and spreads knowledge.

The benefits of this system can also extend to the customer, for example, providing status information from the asset could improve the communication of lift availability to the public, allowing them to plan their journey based on up to the minute data. This would raise the organisational profile and improve the customer experience, particularly for mobility-impaired customers, and is this is now being explored.

7 CONCLUSIONS

The findings from this trial have demonstrated that there are benefits in capturing in-depth data from lift programmable logic controllers for improved fault response, diagnostics and a better understanding of asset operation and condition. This can add value not only to the maintainer but also to asset managers, operational staff and lift users and has been achieved with minimal investment and in a way that provides flexibility in how the data is used. The system presented can be adapted for use on other types of controller including microprocessor-based controllers, although in future, it would be advantageous for access to data from controllers to be considered when scoping new installations and refurbishments.

Improving reliability and asset performance on infrastructure networks is an ongoing process, during which understanding and capability are built over months and years relying on effective documentation of findings from investigations for continuous improvement. Having a detailed view of asset behaviour is clearly advantageous, and if used alongside other sources of data this can be a valuable tool to support a data-driven maintenance regime. However, effective configuration of the business logic to translate data into actionable insights, a suitable user interface and having the necessary people and processes in place are all essential to achieving the benefits.

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BIOGRAPHICAL DETAILS

Ben Langham is an Asset Condition Engineer at London Underground, where he has held various roles in lift and escalator maintenance over the last ten years since completing the Metronet Rail engineering graduate scheme. Ben has led a number of initiatives using technology and data to enable proactive, data-driven maintenance and inform strategic planning. He has a BEng in Mechanical Engineering from the University of Reading, an MSc in Advanced Engineering Design from Brunel University and is a Chartered Engineer with the Institution of Mechanical Engineers.

Vergil Yotov is a system engineer and data analyst with Amey Consulting since 2016. He spent two years working for London Underground designing and implementing innovative ways for remote condition monitoring and performance optimisation. He has a BSc in Astrophysics from the University of Edinburgh and an MSc in Computer Science from the University of Birmingham.