Reliability Improvement Methodology for Signalling Implementations on Brownfield Metros

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SUMMARY

This paper describes the reliability management systems and processes designed to minimise reliability issues experienced with the implementation of a new signalling system onto a brownfield metro line. The use of a standard metric, common targets and a single method of defining reliability ensured that all stakeholders focused on the most relevant areas. The data capture methodology necessary to capture all the reliability related issues is described. As is the reliability process developed to record, analysis and rectify faults.

Importantly a collaborative approach between the signalling supplier and system integrator was adopted. The importance and benefits of this collaborative approach are discussed as well as the working practices developed to ensure a rapid improvement of the system reliability. This paper details the reliability data, lessons learnt, and an overview of the solutions developed which are being used on a current signalling upgrade project of four London Underground lines.

1 INTRODUCTION

London Underground is the oldest underground railway system in the world and has an annual ridership of 1.357 billion [1]. The population of London is forecasted to continue growing over the next decade and in order to support the increasing demand there has been a series of major signalling upgrades since 2010 which continues today. The Jubilee Line was upgraded in 2011 with the Thales Rail Signalling Solutions (TRSS) SELTRAC Communications Based Train Control (CBCT) S40 moving block signalling system. This replaced the existing fixed block trip-cock protected signalling. The CBTC implementation resulted in faults that in some instances evolved into service delays and partial line closures, especially during the early months of operation.

Extensive reliability improvement works were carried out that resulted in a marked improvement in both the reliability and resilience of the signalling system. These improvements were seen in practice with the successful implementation of the same CBCT system onto the Northern Line in 2014. Figure 1 shows the marked improvement in the reduction of 'service delay minutes' over time for the Jubilee Line. Also, the comparison between Jubilee and Northern Lines 'service delay minutes' due to the signalling system shows a considerably reduction. The reliability management systems developed, and the expertise acquired are currently being deployed on the Four Line Modernisation (4LM) signalling upgrade project.

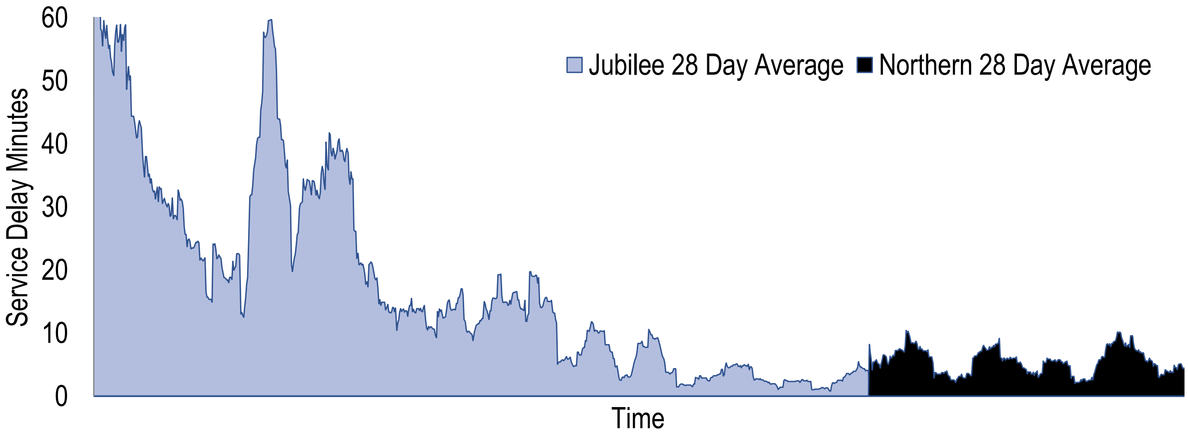

Figure 1 - Service delay minutes due to the signalling system for the Jubilee and Northern Lines

2 REALIBILTY IMPROVEMENTS

2.1 Four Line Modernisation (4LM) Signalling Upgrade Project

2.1.1 Project Overview

The 4LM signalling upgrade is a highly complex, large-scale project with an estimated cost of £760 million [2]. The upgrade comprises of four lines the Metropolitan, District, Hammersmith & City and Circle. Together they make up 40% of the London Underground network and carry approximately 1.3 million passengers per day. The 4LM project has a planned completed date of 2023 and will increase the service frequency by 33 % and the trains per hour in the central section by 14 %. Furthermore, a peak capacity increase will be provided on each line allowing for significant additional passenger capacity, Table 1.

	Peak capacity increase	Additional passenger per hour increase
Hammersmith & City and Circle lines	65 %	17,000
Metropolitan line	27 %	9,500
District line	24 %	10,000

Table 1 – 4LM project Improved capacity by line

2.1.2 Project History

The 4LM project has a complex history with extensive delay and cost increases. An initial contract was awarded in 2011 to another signalling supplier, however this was terminated in 2013. The termination was externally reviewed by the London Assembly, an elected body which is part of the Greater London Authority, and KPMG, a private consultancy. The main conclusion from this review determined that London Underground had expected the signalling supplier to delivery an “end to end design solution” [3]. This was extremely ambitious considering the complexity of integrating a new signalling system onto an existing operational railway. The insulation of a new signalling system cannot be thought of as an isolated project. A railway is a system which is reliant on the interrelationships between subsystems.

Therefore, any upgrade to a subsystem may necessitate alterations of the other related subsystems. A signalling system is complex and requires extensive integration with other systems such as the permanent way, rolling stock and control centre. A new contract with TRSS was awarded in 2015 which was more focused on a collaborative working arrangement between parties. The installation works began in 2017 and the first section was commissioned into service in March 2019. It should be noted that the 4LM project is only a part of larger upgrade programme costing £5.4 billion [2].

2.1.3 Project Environment

In railway terms a brownfield project is one that modifies or upgrades existing infrastructure as opposed to a greenfield project which is the implementation of new infrastructure. There are extensive differences between introducing a new signalling system onto a brownfield site compared to a green filed site. A greenfield site has contemporary infrastructure with which to integrate a signalling system plus less restrictive access to the railway to allow for the installation and testing of equipment. Whereas a brownfield project requires the integration with the existing assets.

The 4LM project includes significant challenges, not least with having to conduct the implementation and commissioning whilst maintaining the existing revenue service. The bespoke and in some cases life expired assets within the existing London Underground environment poses an immense technical challenge. London Underground has the experience of implementing signalling systems onto brownfield metros however, the challenges of the 4LM project are greater. This is due to the larger scale of the project and to the complexity of the lines which have shared tracks with both other London Underground lines and National Rail.

The 4LM project must replace the existing signalling assets which are time-expired with 62% of the assets aged 45 years old or more. One interesting example is the signal cabin at Edgware Road which is still in operation after 92 years of service, Figure 2. Another 17% of the assets are aged between 25-45 years old with the remaining

21% being between 20-25 years old. The signalling upgrade will improve whole life costs by preventing unnecessary expenditure on the piecemeal renewals of already time-expired equipment.

Figure 2 - Edgware Road signal cabin in operation [4]

2.2 Reliability Improvement Methodology

2.2.1 Efficient Preparation

The integration of a new signalling system with such an aging infrastructure presents challenges with bespoke legacy systems requiring both time and effort to fully understand their interfaces. Given the need to keep the railway operational there is only restricted accesses possible for onsite works at night. For London Underground night work is limited to approximately three hours. This requires that both efficiency and productivity are maximised on-site. This is achieved by prefabricating both fixtures and the equipment plus ensuring that all risks are minimised by accurate contingency planning. Additionally, extensive testing by both the integrator and the signalling supplier needs to be carried out to ensure that both systems and software are verified before being installed on-site. The aim of these wide-ranging preparations is to minimise the use of on-site testing and fault rectification.

2.2.2 Unified Reliability Metric

The Jubilee Line signalling upgrade originally operated a system of arbitration to identify the root cause of any fault either being due to the signalling equipment or to the operator. There were financial penalties linked to the outcome of the arbitration process. However, several faults were due to a complex series of events and valuable time and resource was used in determining the root cause. This process was designed to focus on fault rectification. However, in practice it was time consuming and acted as a distraction. Faults were not quickly rectified resulting in hampered reliability growth. To combat the initial poor levels of reliability a Reliability Task Force (RTF) was setup consisting of a group of specialised engineers. The RTF was tasked with implementing systems in order to prioritise the limited resources available while maximising the effectiveness of the reliability improvements.

Failures of the signalling hardware were generally measured in Mean Time Between Failure (MTBF). However, having many hardware components in parallel did not cause a service delay. Non-technical teams may not be familiar with MDBF. In order to avoid the ambiguous or even conflicting reliability reporting, the RTF selected a standard metric which both simplified and standardised the reliability analysis. The metric selected was 'service delay minutes', which was agreed between the project team, operations and TRSS. This metric is focused on the failures or issues which impact the train service.

Strategic performance objectives were agreed between the London Underground and TRSS. This was done by setting common objectives for all the involved parties. Collaboration became an objective for every individual team member based on delay minute targets. The alignment of objectives provided a method of measuring performance, communicating progress and providing motivation. The use of a single set of reliability matrixes ensured that all the reporting issues and progress report were consistent [5]. All the teams and reports were based on the same information which safeguarded against any decision making based on obsolete data. A clear set of reliability targets were used to promote collaboration and to unify different teams towards a set of clear shared goals. A conscious effort was made by all the stakeholders to overcome any blame culture. This approach aided the philosophy of collaboration throughout the project.

It is important to set a target for the final desired level of reliability of the signalling system, this sets an appropriate level of reliability acceptable to all project stakeholders. The estimations for delay minutes for the 4LM project were based on the typical roll out as seen on previous signalling upgrades. Currently the Jubilee and Northern lines are meeting these targets. Each upgrade had a calculated end state target for delay minutes on a 28-day average, Table 2. Currently the Jubilee and Northern lines are meeting these targets.

Line(s)	Delay minutes per day
Jubilee Line	2
Northern Line	4
4LM Project	6

Table 2 - End state service targets for 28-day average delay minutes per day for the new signalling systems

2.2.3 Phased Migration

The size and complexity of an existing railway often necessitates the staged migration from the existing to the new signalling system. Initially, the Jubilee Line upgrade implemented this same strategy, however project delays resulted in the amalgamation of several migration areas. This had several impacts on the initial system's reliability as there were both systematic and site-specific issues. Due to the high volume of issues there were difficulties in identifying both the root cause of the faults and the correct prioritisation of resource allocation. The benefit of a staged migration is the ability to isolate faults and implement corrective measures more rapidly. Additionally, it allows a fleet of trains to operate on the commissioned signalling area which allows the identification of specific train faults.

Each section of the railway commissioned to the new signalling system was called a Signal Migration Area (SMA). Reliability predictions in terms of service minute delay were required for each SMA so that a suitable project commissioning plan could be developed. A reliability prediction was generated by the RTF based on an extensive review of the previous signalling upgrades. These calculations took into account the size and complexity of each SMA including the number of migration boundaries, complex junctions and depots involved. A standardised rate of 0.3 mins per day was used to calculate the recovery period for each SMA. The reliability prediction was generated by the RTF of the Northern Line Signalling Upgrade and is shown in Figure 3, which represents the target delay minutes versus the actual delay minutes as a 28-day average. This shows a reasonable correlation between the actual trend compared to the original predictions which gave the RTF confidence in both the prediction methodology and the use of estimated delay minutes as a reliability metric for the 4LM project.

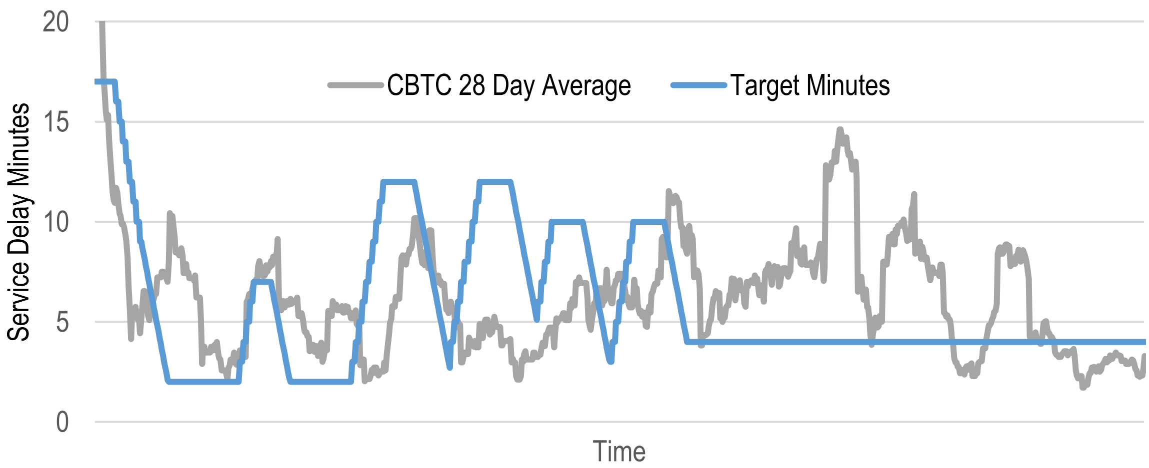

Figure 3 - Northern Line 28-day average delay minutes prediction versus the actual

If the time scale between each SMA was insufficient it could result in an accumulative increase delay minutes, Figure 4. Therefore, adequate time is required between each SMA in order to minimise the risk of having compounded delays.

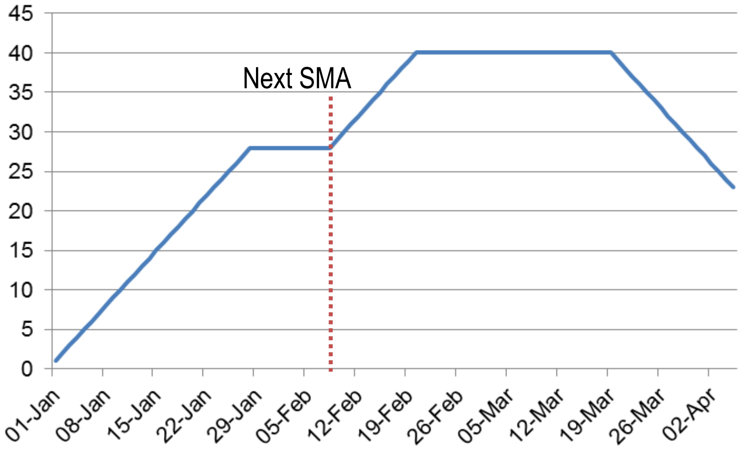

Figure 4 - No recovery time between each SMA

If suitable time was scheduled between each SMA there would be appropriate time available to implement reliability improvements, Figure 5. Therefore, it is essential to plan a commissioning programme around a predicted level of reliability after each SMA.

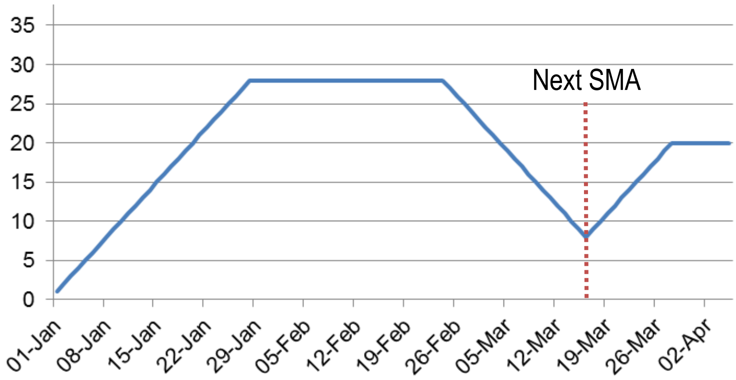

Figure 5 - Suitable recovery time between new section

With the commissioning of each SMA a go/no-go decision was required. This was based on the current level of reliability in terms of 'service delay minutes' of the already SMA(s) and the predicted reliability of the next SMA. If the current SMA(s) were experiencing significant delays, an additional SMA would likely exacerbate the unreliability. Therefore, the decision based on the planned date could alter due to actual reliability results.

The staged rollout of a signalling system can be designed to give the passengers early benefits. For example, the 4LM project is divided into 14 SMAs, however the initial SMAs covered the section which carries the most passengers. This allowed for interim upgrades to the service by improving the service frequency for customers several years before the project is completed. Of course, there are risks with introducing the new system onto a heavily used section as any fault will have an impact on a higher number of passengers. However, the 4LM project was confident that the predicted reliability figures were supported by the on-site test results.

2.2.4 Onsite support during migration

One of the consistent causes of reliability issues was the migration boundary between the original signalling system and the SMA(s). To tackle this issue support staff were made available on-site at each migration boundary during service hours at the initial stages of each SMA. They were able to quickly assist with any technical issues to minimise or even prevent service delays. Additional support staff were also available at the signalling control centre to assist with failure management and rectification. This aided greatly with both minimising any service disruption and developing the knowledge of operation staff [6].

2.2.5 Data Collection Improvements

Before any issue can be rectified adequate data is required to investigate the problem particularly with a complex signalling system. London Underground has extensive experience as an operator in recording Service Affecting Failure(s) (SAF). These are defined as issues that cause a service delay of more than two minutes to normal service. This was determined by how long the service train was delayed, rounded to the nearest minute. Every SAF is recorded and documented by the service control centre. The RTF classified the reported SAFs into three types:

1. Delays directly caused an issue with the to the service signalling system. These statistics were used to represent the reliability of the signalling system.
2. Delays which were related to the signalling system that were issues that were caused by non-signalling components that directly interact with the signalling system. For example, incorrect maintenance of signalling assets could result in a SAF. However, this is not an issue with the signalling system rather the auxiliary systems. These events were recorded and monitored to justify alterations or improvements to these auxiliary systems. From past projects, delays can be exacerbated by mishandling the failure mode which can be due to inadequate training, incorrect documentation or familiarisation.
3. Incidents not related to the signalling system. Due to the complexity of the systems involved some delays could present as being caused or related to the signalling systems. These required investigation and reallocation to the correct subsystem once the true cause of the fault was known. These issues were recorded so to aid the identification of similar future misallocations.

However, these methodologies had to be enhancement to capture the specific information required to investigate all the issues with a signalling system. With only SAFs being reported in detail smaller failures which were quickly rectified or non-service affecting faults were not being captured for review. Therefore, an extensive engagement programme with operational staff involved with the new signalling system was carried out. Staff were trained to report any abnormalities they identified which resulted in a delay under the two-minute SAF threshold or no service delay. The purpose was the early reporting of issues and their correction would prevent delays from occurring in future. Data collection forms were developed to ensure that all relevant information was recorded up to the necessary level of detail and in the correct format. These measures ensured that the extent and quality of data gathered was comprehensive.

A review of the minor delay issues highlighted that many issues were being managed by operational staff which minimised their impact. Although this is the desired behaviour is not corrected the long-term work load of the operators would be increased. Analysis of the Northern Line signalling system issues from 2014-15 shows that delays under two-minute accounted for approximately 60% of all delays identified, Figure 6. The data collected was analysed to highlight persistent issues which could be rectified. The data was also reviewed to identify issues which could result in a SAF in future. Limitations on resources restricted the extend of detailed analysis possible, however reliability improvements were implemented based on the information obtained.

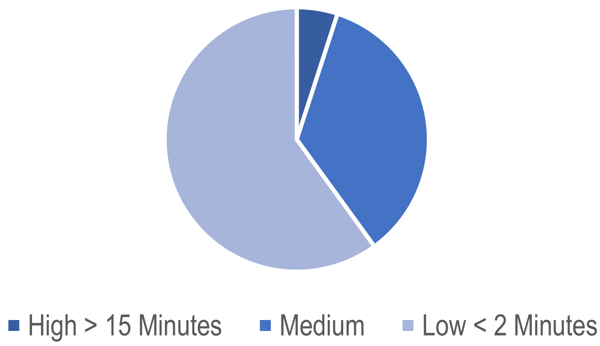

Figure 6 - The Northern Line signalling system delay minutes categorised by length

2.2.6 Data Analysis Methodology

A daily teleconference was operated by the RTF, this was used to review the incidents from the previous service day and to identify those related to the new signalling system. The teleconference was attended by engineers from all stakeholders involved and it was used as a method of triage for the issues. This methodology is depicted in Figure 7.

Figure 7 - Data analysis methodology

Each issue identified was recorded into a database, categorised, and prioritised. Appropriate resources were allocated to their investigation based on their severity. This process was used to determine which incidents were related to the signalling system. When the incidents were fully investigated, the 'service delay minutes' were assigned appropriately to the correct subsystem. The database of issues was analysed so that trends could be identified in terms of location, time, type, asset and frequency. Over time this proved to be a valuable source of data in order to identify repeated failures. Also fault patterns were identified which prompted additional investigations.

2.2.7 4LM Project Implementation

The first 4LM project SMA was commissioned into service in March 2019 and has been a significant success in terms of minimal faults recorded and high levels of reliability. The average service delay minutes per day for SMA 1 are shown in Figure 8, which are well within the predicted levels. The focus for the reliability issues has been the systems which have been upgraded in comparison to the Northern Line, for example the upgrade to Wi-Fi communications between the wayside and the train.

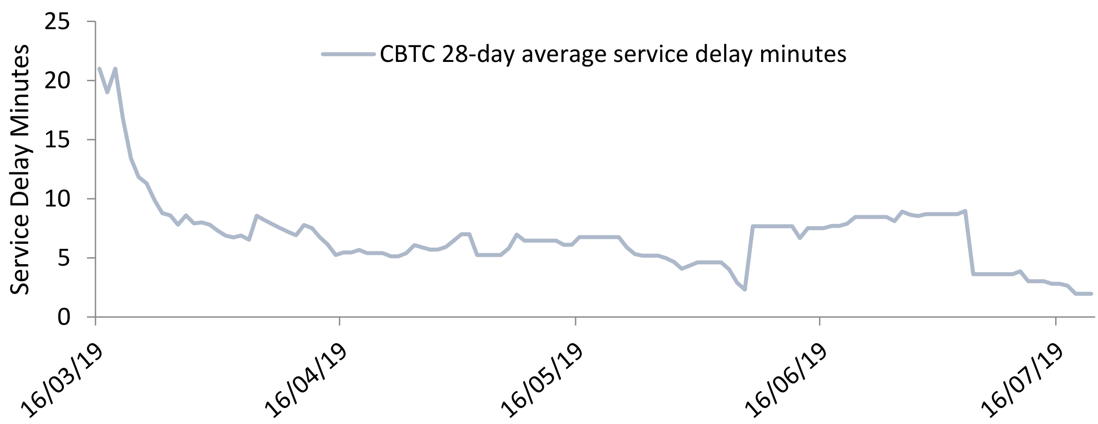

Figure 8 - 4LM SMA 1 28-day average service delay minutes

3 CONCLUSION

A single reliability metric was used for signalling system which was 'service delay minutes'. This was selected because it simplified the reliability reporting and dissemination of the reliability information. It was used to develop common goals which promoted a collaborative approach to the project between the signalling supplier and the systems integrator. The single reliability metric approach provided a single source of information for all project stakeholders. This allowed for consistent reporting which in turn aided the confidence in project progress.

It is not always clear what the cause of an issue is however, accurate attribution of failures to the correct area means that resources can be better focused on preventing subsequent issues. It is important that every issue related to the signalling system is recorded, particularly those with minimal impact to the service or those originally not deemed related to it. These issues can give insight to potential sources of future unreliability issues.

It should be noted that the experience gained from previous upgrades by both the signal supplier and the integrator will be a key factor in the successful implementation of the 4LM project. However, the improved methodology of reliability management and a more collaborative working relationship between the systems integrator and the signalling supplier are also key factors.

4 ACKNOWLEDGEMENTS

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