Transport for London
London Underground Limited

DTUP OMC Volume 2 Part 3

Deep Tube Programme

Fleet & Depot Maintenance Concept

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Revision	Date	Summary of changes
Draft A	18/12/2015	1st Draft for initial review and discussion
Draft B	02/02/2016	2nd Review for Review and discussion
Version 2	15/04/2016	First Issue – Version 2
Version 3	20/08/2016	Version 3
Version 4	13/06/2017	Version 4

TABLE OF CONTENTS

TERMS OF REFERENCE

The purpose of the Fleet & Depot Maintenance Concept is to describe how new or altered assets will be maintained over their lifespan. This is produced to provide:

- Consistency with corporate investment strategy for this asset group
- Consistency with the Business Plan and investment for related projects outside DTUP
- Early involvement of Operations (Assets) in the design process
- A common and effective understanding between designers and Operations (Assets)
- The asset is designed to fit and function within the proposed/expected maintenance environment
- An aid to the Design Teams to allow understanding of the context of use which enables them to check the users understanding of what is being provided
- This Fleet & Depot Maintenance Concept provides high-level maintenance objectives and assumptions to ensure alignment between the New Tube for London Upgrade Programme (DTUP), Sponsor and London Underground Operational Areas
- This will provide Fleet Management, Project Management and Sponsorship teams with a common point of reference and baseline assumptions
- Alignment between the DTUP upgrade and the maintenance modernisation programme.

CONCEPT FURTHER DEVELOPMENT AND REVISION

This version of the concept has been developed prior to critical input of the detailed Train Maintenance Plans that will be received and analysed from the Rolling Stock supply chain forming part of the submission pack received back in the Invitation to Negotiate (ITN) process.

1 OVERVIEW & INTRODUCTION

1.1 DTUP FLEET MAINTAINABILITY OBJECTIVES

Ensuring that the new Rolling Stock procured under Deep Tube Upgrade Programme (DTUP) delivers world class maintainability and performance is critical to optimising the future whole life costs of the Piccadilly, Waterloo & City, Bakerloo and Central Lines. From the Programme requirements specification, the business objectives of the future maintenance function are stated as:

- Reducing Whole Life Cost
- High asset and service reliability; with the opportunity for continual improvement
- Efficient use of resources
- Consistent, predictable and high levels of asset availability.

The Rolling Stock must, where practicable, be maintained according to its condition with maintenance tasks planned to prevent failure in service. To ensure that the new train (which is equipped with modern technology) can achieve the targeted high level of reliability and overall service performance demanded ,requires alignment of the design, the development of the Depot and the development of skills of the maintenance teams to ensure that the standard of high levels of quality and performance necessary can be achieved.

A supplier developed Train Maintenance Regime, making full use of modern condition monitoring and automated inspection technologies, will drive a predictive and condition based maintenance regime that ensures inspections are undertaken when they are required and where they add value to ensure the drive towards maintenance efficiency.

1.2 The Future Railway Duty Cycle

[redacted] This together with a larger fleet of more technically advanced trains will result in maintenance being scheduled into a smaller window of availability and drives the requirement for a train that that is designed for efficient maintainability minimising maintenance production time.

Productivity of the Depot is paramount for successful delivery of upgrade benefits. An overarching requirement upon the Depot design is to ensure that facilities are designed to be as flexible as possible to eliminate (or minimise) train movements during any planned intervention. Guidance from Operations (assets) shall be sought to identify the optimal location for facilities, for example train wash plants located on reception or exit roads from Depots. The final design will cater for different types of maintenance being carried out on specifically designed maintenance roads as close to a production line methodology as possible.

Up to 90% of the DTUP fleet will be required to support the peak service train declarations, excluding any hot spares. In principle, this means a low number of trains available (between 3 and 10 depending on fleet size) on each line will be available at Depots during the days for longer planned interventions (e.g. wheel turning, door examinations, exams & programme lift) and casualty repairs. [redacted]

[redacted]

1.3 The Commitment to Safety, Quality & Efficiency

With the decision to retain first line maintenance of the new trains in house, the development of maintenance team skills to rise to the challenge of new technology is a fundamental part of the overall strategy for the introduction of these fleets. The introduction of the DTUP fleet must drive exceptional levels of maintainability that put the availability of the DTUP fleet into "World Class" performance. The organisation has a fundamental commitment to the safety and efficiency of our teams undertaking maintenance. The facilities needed for the next generation of Rolling Stock must enable best practice in the development of production facilities, human factors and safety of operation in line with legislation including:

- Electricity & Work
- Working at Heights
- Human factors that take into account the working environment

2 REQUIRED RELIABILITY, AVAILABILITY, MAINTAINABILITY & SAFETY

A declared strategic objective of the DTUP is improved railway reliability while increasing railway capacity, reducing journey times, lowering life cycle costs and improving customer experience. To ensure these objectives are achieved, DTUP are following the general guidelines of EN BS 50126 Railway Applications – The specification of Reliability, Availability, Maintainability and Safety (RAMS) and EN BS 50128 Railway Applications – Communications, Signalling and Processing systems: Software for railway control and protection systems.

[redacted]

- Customer influences (not a DTUP responsibility)
- Staff influences (not a DTUP responsibility)
- Traction and Auxiliary Power
- Platform / Train Interface equipment
- Railway Control System (Signalling & Train Control plus Operational Control)
- Rolling stock
- Track & Civils (minor DTUP input only)
- Station infrastructure (not a DTUP responsibility)
- Operational influences

The System Definition considers all modifications within the DTUP scope of work associated with the future upgrades and how such changes will influence the overall Railway Level RAMS performance. A RAMS Strategy has been published to outline the processes by which the DTUP RAMS requirements are determined, delivered and validated. It defines how RAMS will be managed to meet the DTUP RAMS requirements as defined in the SPR documents, including the

RAMS contribution to life cycle cost reduction. The document describes the organisational arrangements for RAMS management, the approach to be adopted and the activities to be performed to identify, implement and assure compliance with the RAMS requirements.

The DTUP RAMS Strategy also describes the methods by which the RAMS objectives will be controlled, as defined within the RAM Management Plan and how RAMS will be progressed to ensure that all RAMS considerations are taken fully into account during the design and optimisation of whole life asset performance.

The DTUP RAMS Strategy is supported by a Management Plan, which provides a description of the DTUP roles and responsibilities and, for each identified line upgrade, the tasks to be carried out to successfully deliver them. The aim of the detailed activities identified is to assess the design specification against the requirements and targets.

The RAMS work is intended to influence the overall operational reliability of the railway and therefore the associated activities specifically include consideration of all factors that may affect service performance. This includes not only the failure of hardware, but also operational and maintenance issues that may contribute to reliability. Detailed targets are presented within the System Definition for all routes (lines) along with formal classification and acceptance criteria for each phase of the project ([redacted]

3 LEVELS OF MAINTENANCE LEVELS (DEFINITION)

There are various types of maintenance interventions expected to be undertaken on the train. It is recognised that there are different, often interchangeable, terms are used to describe the various levels of maintenance intervention. For this reason, and to promote a common recognition of the terms used throughout this document, these interventions have been categorised into three levels; first-line, second-line and third-line.

In the context of this document first-line has been sub-divided to encompass response and corrective maintenance activities, whilst second-line and third-line Maintenance is used to describe the particular pathways taken in the repair and overhaul of equipment 'returned from the train following a first-line maintenance intervention. The table below indicates where each type of maintenance intervention lies in respect of first-line, second-line and third-line. A set of definitions is also provided for clarification purposes.

Category	Maintenance Activity
1st Line Incident	1st Line Response
	1st Line Corrective
1st Line Preventive	Planned, Periodic Maintenance
	Preventive Corrective
	Component Wear Analysis
2nd Line Maintenance	'In-house' Overhaul & Repair
3rd Line Maintenance	'Out-sourced' Overhaul & Repair

Maintenance Intervention Categorisation

3.1 First-Line Maintenance (Definition)

First-line maintenance has been sub-divided to form two distinct categories of maintenance activity; first-line incident and first-line preventive.

3.2 First-line Incident (Definition)

'Incident' comprises both 'first-line response' and 'first-line corrective' maintenance activities and is primarily associated with the diagnosis and rectification of those faults and failures which are, or have the potential to become, Service Affecting Failures (SAF's) on any train across the fleet during its current or next service cycle.

It is necessary here to make the distinction between 'first-line response' and 'first-line corrective' activities. These have been defined as a function of those activities that are undertaken while a train is in service as "Incident" and those activities that are undertaken on a fault on a train in the depot as "Corrective.

3.3 First-line Preventive (Definition)

Preventive Maintenance relates to the planned, periodic maintenance activities seen as necessary to ensure the continued and effective operation of the system and identified by the Train Maintenance Regime. The extensive use of condition monitoring and automated inspection will enable direct information to more intelligently target the maintenance regime based on asset condition rather than periodic intervals.

3.4 Second-Line Maintenance (Definition)

Second-line maintenance describes the process for repair and overhaul of whereby equipment, returned following a first-line maintenance intervention, is sent to an 'in-house' facility equipped with the capability of undertaking the work. Traditionally, the full repair and overhaul of legacy train equipment has been undertaken utilising London Underground's Railway Engineering Workshop (REW) based at Acton works. Once overhauled, this equipment is subsequently returned to Depot stores on each line ready to be refitted to a train as replacement component/module.

3.5 Third-Line Maintenance (Definition)

Third-line maintenance is considered to be the repair/overhaul of equipment returned from a first-line maintenance intervention which is undertaken by the Supplier or a nominated sub-contractor with Supplier involvement. Under this arrangement there no second-line maintenance involvement other than some (e.g. on board signalling equipment) passing through the Underground's 'in-house' maintenance facility which is being used as a 'staging-point' to facilitate the recording and storage of defective items prior to Supplier collection and following their subsequent return.

As modern Train systems have evolved so the equipment involved has tended more toward the adoption of 'black box' technology (hereafter referred to as Line Replaceable Units or LRU's). This approach facilitates quick fault diagnosis and rectification at a first-line maintenance level, allowing units to be replaced without the need for rectification at component level. However, due to its specialised nature any further examination of returned equipment often requires the use bespoke diagnostic and testing rigs.

In some cases it has been found to be more expedient to return defective Line Replaceable Units (LRU's) directly back to the Supplier for repair and overhaul. This ensures that failed equipment is restored to a serviceable state as quickly and cost-effectively as possible. The 'direct first-line to third-line' approach may also be dictated by the conditions of the supply contract and subsequently prohibits the opening of an LRU through the immediate invalidation of its warranty.

4 DTUP FLEET & DEPOT STRATEGY

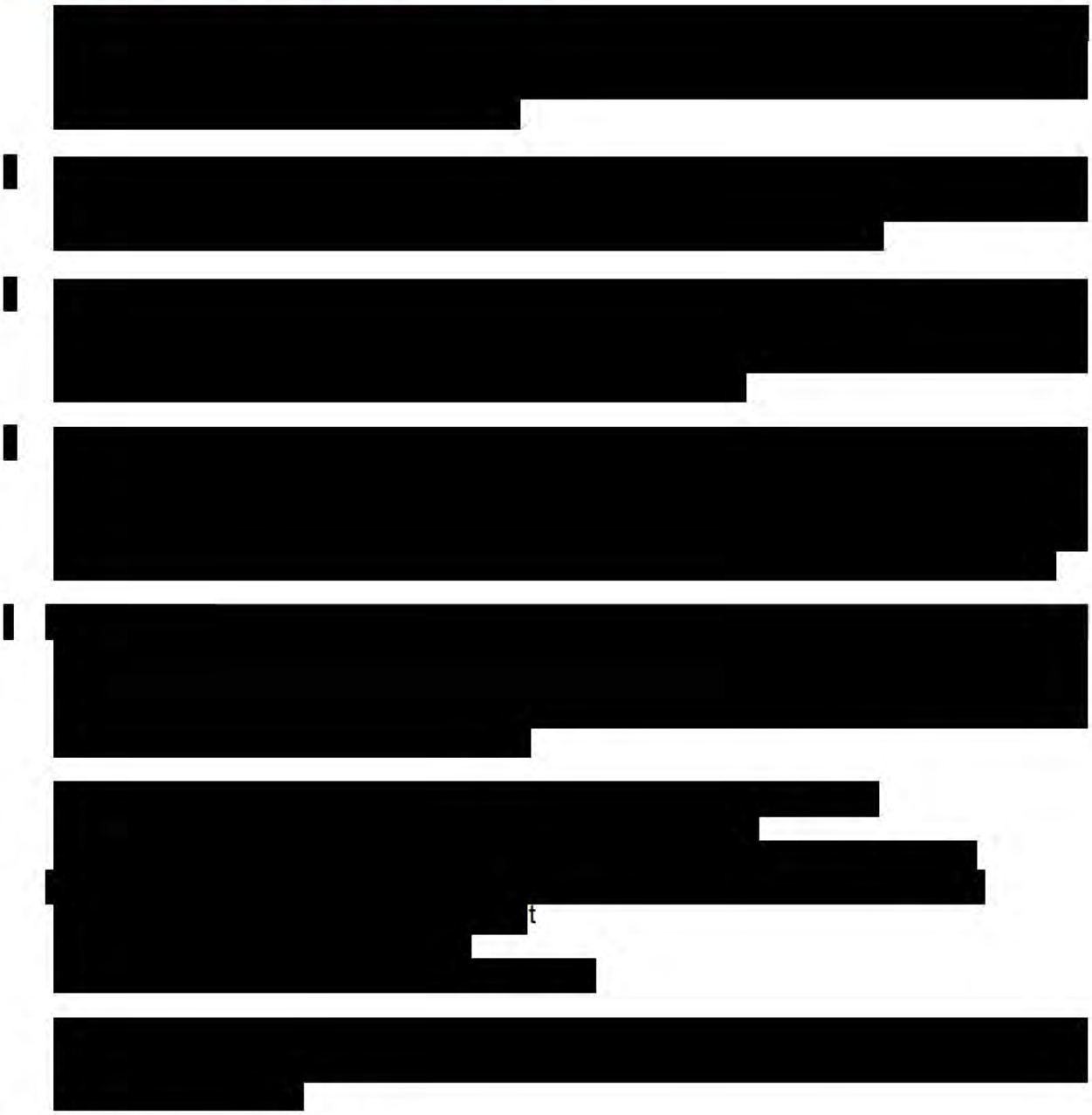
[redacted]

also [redacted]

[redacted]

[redacted]

[redacted]



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4.3 Fleet Maintenance Training Plan

The development and evolution of staff skills is fundamental to the successful implementation of the DTUP maintenance strategy. The principle of the DTUP training philosophy (DTUP-2344.1.1-LUL-RPT-00007) and Rolling Stock Whole Life Technical Support Life Cycle for Deep Tube Upgrade Programme- DTUP-2344.1.1-LUL-RPT-00044 reflects this strategy including the adoption of the strategy for early embedding of maintenance technical staff into the Programme and supply chain.
The Training Philosophy supports the use of a number of options to facilitate the delivery of training and enables greater cooperative working between LU and the Supplier to achieve "Right First Time" delivery of training prior to any assets being brought into use.

4.3.1 Rolling Stock Training

A DTUP training philosophy has been written to provide a structured approach to all aspects of the training of the maintenance workforce up to the post training delivery review encompassing preparation, delivery and management of training material, facilities, documentation and resources. This document has set out the scope of the training that the Suppliers training team will deliver to LU trainers, who will then train the front line Maintenance staff in order to provide a trained and competent workforce.

To support the training strategy, a training-working group has been formed to support the development of requirements with the key stakeholders. A DTUP training plan will follow once more detailed dates for fleet introduction and Depot build sequence is known. A training needs analysis must be undertaken for all staff to ensure that the training can be developed and targeted at the right audience. This analysis will also assist in aligning any recruitment that is being undertaken for future readiness.

It should be assumed that when initial DTUP tube stock training occurs that it will require the permanent daytime use of one DTUP Tube Stock train at the earliest opportunity with the capability to stable new trains at each Depot for parallel training. Training facilities are to be specified to ensure that they will satisfy the requirements.

These arrangements must be integrated with Operational Staff Training to ensure that a comprehensive plan is developed that ensures that the need for new train availability for service and training needs are both satisfied. Training facilities are to be specified to ensure that they will satisfy the requirements. Whilst legacy training activities are often carried out on maintenance trains, recent experience of S-stock has identified that there is a requirement for more ‘power-on’ time for maintenance and fault-finding. For this reason it should not be assumed until fully clarified with the design of DTUP train that a maintenance train can be used for training and a dedicated train must be allocated for the duration of the training plan. DTUP Tube Stock training will include the following courses:

- The vehicle awareness course will consist of an overview of the vehicle, which will be aimed at non maintainers such as Cleaning Supervisors and other Depot Admin staff.

- Planned maintenance training will consist of safety isolations followed by preliminary generic practical skills tuition and then practical training on each system using the VMIs.

- A systems overview course will aid systems understanding with respect to individual components, system function and maintenance requirements. Shunting training will be delivered during initial training for all train maintenance staff who will undertake this task as part of their role.

- Call Point training will be undertaken to ensure that the response to managing faults on trains in service minimises service impact with effective step-by-step instructions to allow Call Point personnel to overcome defects and symptoms of degraded operation of trains in passenger service in the early days of introduction.
- Series train update (refresher) courses to cover any changes to the systems training and planned maintenance training as a result of design changes / modifications made to the series trains.

- Work Arising training on the Vehicle Maintenance Procedures (VMPs) and aspects of inspection, removal and post renewal functional testing.

- Fault finding training will consist of in depth system theory, general fault finding techniques, training in the use of the fault finding guides for each rolling stock system, and practical test exercises in fault finding on the trains themselves.

- 'Specialist Engineer Training' to provide skills to manage technical and incident investigations.

4.3.2 Depot Signalling Training

Training will need to be undertaken for those staff located in the Depot who are controlling the movement of trains in any Depot where the signalling system is installed, upgraded and modified. This training must include both the operation of stabling areas and movement of trains into and out of maintenance facilities.

4.3.3 Depot Facilities Equipment Training

Training is required for all equipment delivered as part of the Depot upgrade including those inside the Rolling stock supplier's scope and all equipment covered in the Depot and Infrastructure scope.

4.3.4 Operational & Information System Training

Various systems will be introduced as part of DTUP such as condition monitoring, automated Inspection and functionality with the Operational control system relevant to fleet operations. Training must be provided on all systems to ensure that staff can fully utilise and realise the benefits. This needs to be delivered as a fully integrated package.

4.4 DTUP Fleet Operations Management

4.4.1 Condition Monitoring Principles

4.4.2 Notification Management – Definitions

Review of the following London Underground Category 1 standards:

Number	Title
G0213	Asset Condition Monitoring, Alarm and Alert Management
S1217	Integration of Human Factors into Systems Development.
S1218	Human Systems Interaction - Dialogues and Notifications.

Provides the following definitions for alarms, alerts and notifications to be used in the following sections defining the management of rolling stock diagnostics to support service operation.

Term	Definition
Alarm	System response that is prioritised according to the severity of impact on safety, or reliability, and time available to the user in which to fully, or partially, mitigate the impact.
Alert	System response with lower priority user action than an Alarm that is prioritised according to time available to the user in which to complete the action.
Notification	A type of system response. There are two types of Notification: Alarm and Alert.

4.4.3 Principles Of Notification Management

From the start of new fleet operation (GOA1) condition monitoring tools are used in key locations across the network defined as Diagnostic Hubs.

Diagnostic hubs will utilise an HMI configured with audible and visual alerts in accordance with their priority and HF best practice. A simple decision hierarchy similar to the following existing Defective in Service instructions (DISI) instructions is recommended such as:

- Remain In service
- Remain in Service to Depot
- Withdraw From Service

The categorisation of priorities using a condition basis enables the probability/severity of the event to be defined with an appropriate maintenance intervention. Access to DTUP asset data will enable the capability (non DUTP upgrade teams) to be developed that enables either by management processes or by automation, the generation and management of work orders (on the LU Enterprise Resource Planning (ERP) system. This enables scheduling priorities to be defined using a condition basis that enables the probability/ severity of the event to be categorised and an appropriate maintenance intervention defined.

The status of adverse weather consumables including de-icing fluid, sanding hopper level and screen wash level will be available as part of the condition monitoring system and prioritised as alarms or alerts raised to the diagnostic tools managed in diagnostic hubs.

4.4.4 Operation of Rolling Stock Diagnostic Hubs

It is currently understood that as part of "maintenance modernisation" the future management of diagnostics will evolve throughout the organisation during the period of Deep Tube Evolution.

As a result multiple locations for data analysis defined as " Hubs" are described to ensure that the future infrastructure can comprehensively support the range of future strategies. Diagnostic Hubs are classified into two groups as shown below :

Primary Diagnostic Hubs	The London Underground Control Centre (LUCC)
	Asset Performance Control Centre (APCC)
	Line Control Centre (as GOA1), Deep Tube OCC (from GOA2)
	Local Performance Centre (Any Deep Tube Line Depot Office)
Support Diagnostic Hubs	Mobile Response (using Mobile Device)
	General User for Data Analysis

Of the locations identified as primary diagnostic hubs one single location will always be selected as the single point of accountability for overall responsibility of data, diagnostics and alarm management to ensure a clear and direct line of accountability and management.

Key principles in selecting the Primary Hub will be based on :

- Ensuring ownership and competence to interpret the data being displayed (Key data will require fleet technical competence to interpret)
- Ensuring effective and efficient co-ordination of response
- Ensuring effective Management of Work Orders without duplication

a) Based the current understanding each diagnostic hub will utilise rolling stock data with the following principles.

- **Network Level – LUCC (including APCC)**

  Access to fleet asset data supports the co-ordination and management of fleet operations including faults/failures, data, diagnostics and fleet technical information to provide an integrated network response. The network level hubs will utilise DTUP fleet asset data using rolling stock diagnostic tools and other existing tools to provide situational awareness to support operation.

- **Local Level - Depot Local Performance Centre (LPC)**

  The Depot Local Performance Centre (depot office not a control room) is a co-location of the main Fleet maintenance functions to ensure effective communication and make best use of skills, resources and proximately to fleet maintenance production, co-locating the key production activities of a depot into a single office. These activities may include:

  - Control Of Depot Operations and Maintenance Facility Area Signalling
  - Planning & Management of Fleet Maintenance
  - Management of Delivery of trains to/from service to service Plan Requirements
  - Analysis and implementation of maintenance variations based on Data Analysis
  - Co-ordination of Materials Management

  The fleet monitoring capability within the LPC requires to access and administration to data, diagnostics and fleet technical information. The role also uses a fixed radio dispatcher and has situational awareness of the location of each train using trackernet or a similar non safety critical tool.

Fleet – Depot Local Performance Centre

- **General User**

Any team member with network access and a log in to the diagnostic system for technical and operational support purposes.

- **Fixed Line /Line Group Control Room Technical support**

  Fleet Technical resource within the DTUP OCC (from GOA2 or existing control centre (at GOA1) supports the operation fleet including fault and failure response operation and ensuring co-ordination of trains required for maintenance to the correct depot.

  This role requires a fixed desk within the Line Control Centre/ DTUP OCC to access data, diagnostics and fleet technical information. The role also uses a fixed radio dispatcher and has situational awareness of the location of each train using trackernet or a similar non safety critical tool.

- **Mobile Response**

  The capability exists/required for Mobile Feet Technical Response to assist with specific rolling stock issues as directed by the Line Control Centre/OCC. The primary activity is to support the incident management process giving on-site technical support with management aligned to the Defective in Service Instructions (DISI) or new equivalent with a decision making tool.

  Currently Mobile Train Technician(s) are strategically located on the line to physically respond to the Fleet faults and failures utilising a mobile device as a data, diagnostic and fleet technical information. The role communicates using a mobile radio.

b) **Data Transmission Capability at each Grade Of Automation**

- At **GOA1**, key event information (only actions the operator can take) will be presented immediately to the Train Operator via the HMI using information from the Train Management & Control System (TCMS) with diagnostics also having the capability to be used to support operations from the identified network hubs and fleet call point location at the next available intermittent transmission point (Located at every Station and Across Depot and Sidings).

- At **GOA2** this is enhanced with critical prioritised real time notifications having the additional capability to be continuously presented via the signalling interface direct to the identified network hubs and fleet call point in addition to the bulk of information being available at the next intermittent transmission point.

- [redacted]

4.5 DTUP Fleet Asset Maintenance Management

4.5.4 Maintenance Planning

The Local Performance Centre includes the planning and control of asset maintenance. The integration of this function to the overall Railway Control Organisation provides continuous visibility of asset status and availability and is a major contributor to the delivery of consistent and resilient services.

Planning of maintenance is undertaken by the LPC utilising the TfL network standard systems (2017 - JNP Maximo, BCV Ellipse). The DTUP programme are not directly delivering upgrades to the maintenance planning systems ,however a modern and capable Enterprise Resource planning System (ERP) must be operation in readiness for the introduction of the new train. This is to enable the functionality delivered by condition monitoring and automated inspection together with the New Train Maintenance Regime to be fully realised.

The ERP system used must be based on Industry best practice systems and must integrate all key functions. Materials management must also be integrated into the capability of the standard network systems used.

A main production activity of the LPC is the planning and delivery of the Asset Maintenance Plan (AMP) to achieve the operational Service Requirements. The AMP contains information on the maintenance requirements of the fleet and the capacity of each maintenance facility of the railway. This information is current, and forecast as far as far as can confidently be predicted. The LPC also holds a record of past maintenance tasks and those planned.

Maintenance tasks can be planned quite a way into the future but it is important that the plan be flexible to maximise its robustness to events. The defining details of a task (such as the exact time and location) are only added to it as the time for its execution nears.

The schedule can be changed at any time as circumstances demand, although this becomes progressively undesirable as it might disrupt the planned usage of trains.

The Plan reflects the loading of both planned and reactive maintenance activity onto maintenance capacity including the consideration of facilities, Plant, Human resources, Spares and Materials. If the new proposed Train Maintenance Plan (TMP) does include a significant condition based analysis to avoid regular planned activities, then a likely key change is the need to be more reactive (for general maintenance as well as ‘faults’) and this is a key step change from current planning arrangements.

The Local Performance Centre (LPC) is updated with the status of maintenance work-in progress and completed such that it continually reflects the availability of maintenance capacity and any change in the planned availability of assets. Local and Mobile Fleet Maintenance staff will make extensive use of handheld electronic devices to manage work orders and to view Work Instructions and other key information.

4.5.5 Flexibility in Maintenance Planning

When the execution of maintenance work diverges from the plan and as a consequence the availability of the maintenance facility capacity changes then the LPC will use the tools available to amend and adjust the works schedule.

[redacted]

With planned levels of enhanced operation and the likely removal of the inter-peak period rolling stock, maintenance will have to be concentrated in the remaining periods of availability. This is likely to mean that the remaining night and weekend periods, where lower frequency services remain in operation, will be the most productive for the execution of maintenance. Step Changes in existing planned maintenance will be required prior to stock introduction.

[redacted]

[redacted]

4.6 DTUP Fleet Information and Data Management

The use of remote monitoring and risk based maintenance regimes have the potential to significantly improve the asset performance and reduce whole life costs. To fully exploit the opportunity afforded by the DTUP Tube Stock on-board condition monitoring system, DTUP shall provide suitable communication and IT infrastructure (fixed and wireless), both in the Depot and across the lines, to efficiently capture all available train data for timely analysis at Asset, Line and Network levels.

At the introduction of the Train in GOA1 the likely use of intermittent data transmission may impact the timely download of data. The collective use of IT and on-board electronic systems will allow operations to move towards predictive failure prevention and, as a result make more efficient use of staff resources. The DTUP upgrade teams shall assume that a high specification network link is required for access by all on-site computers used by both staff and suppliers.

A Modern method of Tagging (using latest technology) is to be adopted by Operations to improve stores and materials processes, to ensure efficient operations and in particular to ensure effective stock management under the MSA/FSA obligations. This solution will be required to track component utilisation, serialised component configuration and component storage across all main Depots.

4.7 DTUP Fleet Reliability and Performance Management

System performance under the Manufacture and Supply Agreement (MSA) and Fleet Support Agreement (FSA) is likely to be managed via a joint LUL / supplier DRACAS/FRACAS process which will start before the train enters service. This will be set up to monitor and analyse each defect and ensure that an agreed responsibility for resolution is agreed. The Majority of the new train equipment can be interrogated via the TCMS or stand-alone specialist equipment (laptops). This approach shall necessitate a step change in staff skills, but should reduce fault-finding time and instances of no defect found 'NDF' compared to legacy stock.

5 DTUP - DEPOT OPERATIONS MANAGEMENT PRINCIPLES

5.1 Key Principles

The movement of trains in depots will change significantly as a result of the planned increases in automation. Key operations principles include:

- There shall be safe operation of train movements within the Depot area.
- [redacted]
- Ensuring that the injection and reception rates (maintenance and stabling areas) of trains to/from service can be managed in a timely manner that safely supports service frequency, or train maintenance schedules.

- The fleet injection and reception process must not adversely impact on the time available for main line engineering hours access as a result of manual operation of depots resulting in extending the time required to complete this process.

- It is recommended that from GOA2 service uplift that the operation of powered operated points is introduced for all depot routes covered by regular train movements. This eliminates the need for staff to manually operate each point on the ground. The Human factors and human error issues around the continued used of ground shunting is a concern, particularly where the operational workload of train movements will increase with enhanced service levels.

- Ensuring that all movements including those required for maintenance are enabled and supported by the upgrade.

- [redacted]

- Train paths starting in sidings shall preferably be scheduled to stable at the end of that service period in a major Depot, with a view to supporting a 3-day frequency of Automatic Train Washing, Automated Underframe Inspection and the Exam maintenance cycle.

- Trains are to be presented for service, having passed any remaining elements of pre-service inspection, within maintenance tolerances, and railed with at least one pair of shoes on a conductor rail. [redacted]

- All DTUP trains, at all locations shall be capable of being stabled with at least one pair of shoes on conductor rails, to enable cleaning, pre service checks, and unassisted entry into service. Traction current feeds to all major depots and sidings are normally continuously "on" 24 hours a day to enable train movements, testing, and supplies for lighting, heating and compressors.

- Traction sectionalisation and alternative feed arrangements are to be agreed with Fleet Operations (Assets) to facilitate planned maintenance and incident management.

- Alternative operating procedures will be put in place from time to time to cope with abnormal conditions, for example:

  - Service disruptions leading to stock imbalance
  - Stabling of excess trains (i.e. emergency stabling)
  - Use of Depots for service reversing
  - Use of overtime and unscheduled shifts (e.g. Late Turn) to address unplanned demand.

- The number of separate stabling locations (outstabling) shall be minimised where reasonably practicable to reduce the number of locations requiring daily attendance of maintenance and or cleaning staff.

5.2 Principle of Operation - Fleet Introduction to Automated Operation

5.2.1 Depot Operations at Fleet Introduction (GOA1)

At fleet introduction the boundary agreements for train movements remain similar to today with the main control centre on each line interfacing with a method of local control within the depot with the exception of the Waterloo & City Line that is integrated as part of signalling system).

Stonebridge Park Depot on the Bakerloo Line is operated by a control tower with power worked points, Waterloo Depot on the Waterloo & City line is managed by the dedicated Line Control System, and the remaining Depots are operated with handwork points utilising ground shunters up to the depot outlet.

Note: It should be noted that the responsibility for train movements in within depots may be subject to change prior to DTUP.

5.2.2 Depot Operations at Signalling Upgrade to ATO (GOA2)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]ible and the additional resource of a local signalling solutions are minimised.

[redacted]

[redacted]

[redacted]

[redacted]

6 DTUP TUBE FUTURE TRAIN MAINTENANCE REGIME

Note: As of April 2017, the full set of maintenance interventions are part of the information expected to be received back for bid evaluation, together with the supplier's assessment of maintenance facilities required for the train and associated equipment. A recent Train Maintenance regime similar to that from 09 Tube Stock and S-stock is shown in Appendix H as a reference point only to show the expectation of what should be significantly improved upon with the new train.

There is a clear expectation that the new train maintenance regime will be more advanced than any current existing fleet and the existing maintenance regimes will not be used as a basis of future.
The DTUP Tube Stock Train Maintenance Regime (TMR) (and Train Maintenance Plan) is to be developed by the supplier who will act as the Technical design authority. The new train maintenance regime must make full use of modern condition monitoring and automated inspection technologies, that will drive a predictive and condition based maintenance regime ensuring that inspections are undertaken when they are required and where they add value to ensure the drive towards maintenance efficiency. The LU DTUP Rolling Stock Project Team, Maintenance Representative and Fleet Maintenance Sponsor shall jointly agree a process to validate the VMI's with respect to safety, tooling, maintainability, content and periodicity.

The TMR and VMS are to be approved by the LU Professional Head of Rolling Stock, supported by the Fleet Maintenance Sponsor who shall assist in determining the TMR suitability compared to industry best practice. The strategic objective for DTUP tube stock maintenance is to establish a preventative and risk-based regime, which reduces the amount of reactive work to a minimum. Planned maintenance will be balanced as far as possible with modular examinations where reasonably practicable.

6.1 Levels of Train Maintenance

There are some key assumptions about the future maintenance regime:

- **Condition Monitoring & Automated Inspection** – This is not a level of physical maintenance, but the use of monitoring and inspection technologies to report, analyse and confirm rolling stock status and condition. This will enable the optimisation of planned maintenance interventions and to "predict & prevent" failures, thereby enabling interventions prior to them causing impact to the service and damage of the asset. The analysis of data undertaken in the LPC will utilise specific technical resources to support data analysis (not a fully 'automated' process). This will lead to the need to adopt a flexible and proactive approach to subsequent on-train activities (to replace before failure rather than investigate after a failure as exists in todays fixed interval maintenance). The Condition Monitoring and Automated inspection Solution must operate as an integrated package to support the efficiency of the maintenance regime.

- [redacted]

- **General Inspection & Repair** – The maintenance strategy supports the use of condition based data driving the timing of general inspection activities with a significantly extended interval that is achieved today.

The approach for routine maintenance activities is to 'balance' all non-overhaul activities into General inspection so that they can be delivered within a maximum of 1 shift without the need to move the train; with fleet resource requirements calculated to support this demand.
With maintenance intervals extending significantly the wear rate of consumables such as shoe wear may be a future factor in prescribing the periodicity of inspections. The bid evaluation stages must consider this carefully in order to optimise the maintenance regime.
The more complex and extensive levels of general inspection and repair (particularly door systems) may necessitate a workload that exceeds a single shift of work; however this is dependent upon the reliability of the systems, DTUP Stock maintainability and the best use of staff. The aspiration is that some activities will take one long shift and a door general inspection will require an estimated duration of two shifts.

Note on Door Maintenance - This has been a key issue on modern recent fleets with many lessons learned. It is critical that the facilities required in each depot are developed closely alongside the Train Maintenance Regime (TMR) to ensure that the most efficient design of train, maintenance facilities and processes of maintenance can be implemented.

- **Heavy Maintenance -** The new train will require heavy maintenance to service, maintain and replace heavy equipment that involves the separation of car body from bogies and the removal of bogie mounted or underframe equipment.

It is anticipated that the intervals requiring this activity will be extended and optimised as far as is practical however there will be an additional activity to routinely subject components samples to condition assessment between overhauls such that overhaul frequencies can be continually altered and extended.

- **Component - Off Train Module Overhaul** - Components and modules removed from the train will require overall, repair and replacement to form the spares stock for the train. Serialised spares shall be managed to ensure that traceability and the history of parent / child components is maintained throughout component life.

- **Mid-life 'heavy' Overhaul** of the DTUP train may be required. Consideration must be given to these major overhauls, internal and external refurbishment if these are undertaken in an internal or external facility. This heavy overhaul should combine obsolescent component replacement throughout the train in accordance with the Obsolescence Plan.

- **Wheel Turning** - On-condition turning of Wheelsets shall be undertaken to optimise the wheel life and maximize the lifting periodicity, this is assumed to start as an 18 monthly-planned activity (based on recent Analysis on optimizing wheel turning frequencies)

- **Cleaning-** Train Cleaning will be conducted in line with current best practice, frequencies and regime. Appendix F gives details of a notional cleaning regime that represents best practice in LU Fleet Operations. Maintaining the current standard of cleaning will result in an increased labour demand owing to the increased number of cars in the new fleet.

- **Underframe Cleaning** - It is envisaged that under frame cleaning will remain due to a potential increase in gearbox oil leaks and sander use, although track borne grease contamination should reduce owing to the application of on-train 'stick lube'. An additional HVAC cleaning activity will be adopted for DTUP Tube Stock, requiring dedicated depot cleaning road facilities.
- **Sanding:** Refilling the sanding system sand boxes will be a new maintenance activity not encountered on current tube stock fleets. Calculations concerning sand dispensation and maintenance intervals required to refill the sand-boxes are given in SSR document SUP-PSGC0007-SSL-RPT-00016, Issue 3 for S-Stock; however, further work is required to map this to DTUP stock. The sanding equipment refill rate could vary from between 60 days in low risk areas to 7 days in the leaf fall vulnerable areas of the Piccadilly and Central Lines in autumn.

6.2 Additional Items

Note: Depot upgrades should not introduce gauge infringements that prevent movement of pre-existing LUL stock, including heritage stock that may need to be repaired.

For seasonal Maintenance, the Sandite Trains are required to continue at Hainault and Ruislip Depots and may also be required at the other upgraded depots. A Future strategy for provision of Rail Adhesion Trains to replace the legacy trains (Central & Piccadilly Line Provision) will need to be agreed to ensure it continues following completion of the upgrade.

Recent experience of doors has highlighted that the capability should be designed into the train (to enable under a controlled technical process using the appropriate safety change procedure) to

enable the re-configuration of the timing parameters of train door (and any associated equipment) opening and closure sequences to facilitate door timing modifications.

7 MAINTENANCE ARRANGEMENTS INITIAL, MIGRATION AND END STATES

7.1 Maintenance Arrangements Summary Table (Balanced Option)

Legacy & Depot	Initial State	Migration State		DTUP Stock
	Legacy Fleet	Legacy Fleet	New Train	New Train
Piccadilly Line (East End) Cockfosters Depot	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment
Piccadilly Line (West End) Northfields Depot	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Wheel Turning	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment

Legacy & Depot	Initial State	Migration State		DTUP Stock
	Legacy Fleet	Legacy Fleet	New Train	New Train
Ruislip Depot (West End)	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Wheel Turning	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Wheel Turning	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment
Hainault Depot (East End)	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment

Legacy & Depot	Initial State	Migration State		DTUP Stock
	Legacy Fleet	Legacy Fleet	New Train	New Train
Bakerloo Line (North End) Stonebridge Park Depot	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Train Preparation Exam Shed Day/Modular Maintenance Programme Lift Minor Overhaul Heavy Overhaul Casualty Maintenance Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment	Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Wheel Turning Interior & Exterior Cleaning Underframe Cleaning De-icing Replenishment Sanding Replenishment
Bakerloo Line South End (London Road)	Train Preparation Casualty Maintenance Interior & Exterior Cleaning	Train Preparation Casualty Maintenance Interior & Exterior Cleaning	Pre-Service Inspection/Walk Through Interior Cleaning General Inspection & Repair De-icing Replenishment	Pre-Service Inspection/Walk Through Interior Cleaning General Inspection & Repair De-icing Replenishment
Waterloo & City Line Waterloo Depot	Train Preparation Casualty Maintenance Interior & Exterior Shed Day/Modular Maintenance Interior & Exterior Cleaning Programme Lift	N/A as planned blockade so no operation migration		Pre-Service Inspection/Walk Through General Inspection & Repair Heavy Maintenance Interior & Exterior Cleaning Underframe Cleaning
ALL LINES TMU ACTON	N/A	N/A		Heavy Overhaul

Key DTUP Depots and Maintenance Roles per line

7.2 Migration of Legacy Stock Maintenance Regimes

It is likely that the current maintenance frequencies of exam and shed day activities on 73TS, 72TS and 92TS will continue to be optimised up to the point of fleet replacement.

Leading up to and during disposal, the 73TS, 72TS and 92TS Fleet Managers shall assist the DTUP CPD Team in the detailed planning of disposal activities such as spares retention and the scrapping sequence for their respective fleets. Furthermore, the Fleet Managers shall pro-actively seek cost saving opportunities during stock disposal with the support of the Sponsor.

Extension of Programme Life (and other maintenance) periodicities should be undertaken where it can be demonstrated that the assets continue to function safely and without risk to operational performance. These activities support the overarching AAMP objective to minimise residual asset value at the point of disposal whilst enabling LU to recoup the maximum sale value. Contingency plans should exist to deal with unforeseen delays to the new stock delivery.

7.3 Migration Maintenance Arrangements

As part of the depot feasibility report, a description of several potential migration maintenance arrangements have been considered. With the exception of the Waterloo & City Line, which will be closed to facilitate the line upgrade, full operational service and maintenance capability must be maintained in the other depots during the migration phase. During 2017 the baselined depot options will be further reviewed as part of the extended depot design feasibility work with an external supplier. The supplier will review current options and develop them further based a design review process that includes stakeholder workshops. The reviewed options will include:

1) Modification of existing depot facilities, whilst the depot remains operational for maintenance of the existing fleet.
2) Modification of the existing depot facilities, whilst removing the capability for maintenance from that depot for existing maintenance.
3) Construction of a new maintenance facility on existing depot footprint whilst existing depot facilities remain operational for the existing fleet
4) Construction of a new maintenance facility on existing depot footprint whilst removing the capability for rolling stock maintenance in that depot.

Once the project progresses to the chosen solution, this report will be updated with those maintenance arrangements.

7.3.1 Piccadilly Line - Cockfosters and Northfields Depots

The Piccadilly Line will be the first location to maintain the new DTUP Rolling Stock, although Ruislip is likely to be the delivery and initial commissioning and testing location for the initial trains. During migration, the Piccadilly Line will be served by both by 73TS and DTUP Rolling Stock. This means there will need to be sufficient facilities to deal with maintaining both sets of trains until the rollout is complete. The CPD team will manage the overall introduction, testing and commissioning of the new trains in parallel with decommissioning and disposal of the legacy Tube stock.

7.3.2 Waterloo & City Line - Waterloo Depot

It is proposed that the Waterloo and City Line is shut for upgrade works and introduction of the new fleet. Therefore the existing fleet will cease operations within the existing facilities and the maintenance of the new train will be undertaken in the new commence in the upgraded facilities once the line has re-opened.

7.3.3 Bakerloo Line - Stonebridge Park Depot

During migration, all levels of 72TS planned and corrective maintenance shall continue to be undertaken at Stonebridge Park Depot, with the new DTUP train introduced alongside the existing fleet. This means there is a need for sufficient facilities to deal with maintaining both sets of trains until the rollout is complete. The CPD team will manage the overall introduction, testing and commissioning of the new trains in parallel with decommissioning and disposal of the legacy Tube stock.

7.3.4 Central Line – Hainault and Ruislip Depot

During migration, all levels of 92TS planned and corrective maintenance shall continue to be undertaken at Hainault and Ruislip Depots with the new DTUP train introduced alongside the existing fleet. This means there will need to be sufficient facilities to deal with maintaining both sets of trains until the rollout is complete. The New Train project team will manage the overall introduction, testing and commissioning of the new trains in parallel with decommissioning, stripping and scrapping of the legacy Tube stock.

8 END STATE MAINTENANCE ARRANGEMENTS

The Depot operating options that were under consideration during 2016 have now clarified and been confirmed as part of NTfL-2344.3.4-LUL-RPT-0057 “Fleet Maintenance strategy For End State Maintenance Arrangements”. The confirmed set of decisions for Locations are shown below for:

- Heavy Planned Maintenance
- All other Levels of Maintenance below Heavy Planned Maintenance for the Piccadilly Line , Central line , Bakerloo Line and Waterloo & City Lines (including intermediate Maintenance requiring removal and replacement of large underframe train equipment in line depots**)**

8.1 Heavy Planned Maintenance At TMU Acton Works

The new DTUP train will require heavy maintenance to service, maintain and replace heavy equipment that involves the separation of car body from bogies and the removal of bogie mounted or underframe equipment on a planned basis following a number of years post introduction of the fleet.

This Maintenance is defined as Planned Heavy Maintenance will be undertaken centrally at the New Trains Modification Unit Facility at Acton Works. Further work will be required to confirm the frequency and scope of activities that will be undertaken at Acton and those undertaken Line Depot Facilities (intermediate Maintenance).

The use of the TMU facility at Acton will be planned and dovetailed into the availability schedule in the late 2020's which facilitates the smooth transition of the existing CLIP workforce who would have completed the Central Line improvement programme and then will be carrying out S stock Overhauls. S-stock planned lifts will continue within the facility when the new Deep Tube fleet begins its cycle. This approach is consistent with the benefits outlined in the business case for the TMU facility.

The impact of using TMU Acton for heavy planned maintenance on DTUP will be a reduction of heavy lifting facilities on the Central and Piccadilly lines (by one road per line) resulting in the requirement for only one Heavy Lifting Maintenance road per Depot.

The requirement for one lifting road per depot is considered to be the most efficient recommendation to support the planned and casualty and intermediate maintenance regime proving the ability to lift a whole train using a lift system (type to be specified) without inefficient train movements or moving defective trains through the high frequency central area with limited engineering hours.

Storage facilities would need to be confirmed as suitable in order to deliver and deal with parts for just in time fitment and removal for overhaul components Materials management of the parts removed for overhaul will gain the benefit of logistics through the proximity of location of the TMU/REW site in Acton relative to a line Depot location.

No alteration of headcount will be required at the Depots when the Heavy Planned Maintenance cycle begins because this would be accounted for in the TMU workforce scheduling. This gives the opportunity to smooth the TMU manpower to support S-stock and DTUP fleets at one location rather than at multiple fleet depots.

The movement of trains to the facility is possible for Piccadilly and Central fleets but is more complex for Bakerloo fleet given the need for them to be run in a possession (ITMP) to the facility which could take multiple nights.

Note: Overhaul frequencies and scope will be determined by the emerging New Train Maintenance Regime. However, there are clear constraints on the capacity of the new shed at Acton Works. The capacity constraints are likely to restrict trains being sent to Acton at less than approximately 10 year intervals and further analysis is required to actually define this by the time the preferred Rolling Stock Supplier is selected (May 2018).In addition a mapping exercise should be carried out to clarify the extent of how the facility will be utilised by the existing and new fleets to ensure throughput.

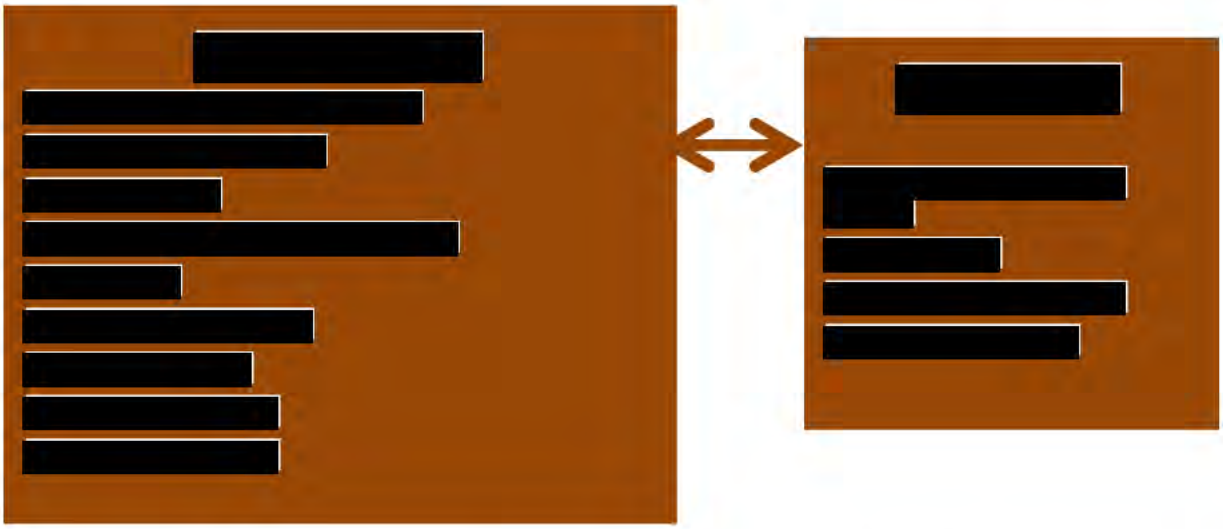
8.2 All Levels of Maintenance Below Heavy Planned Maintenance

8.2 1 Bakerloo Line

The Bakerloo Line remains a self-contained operation for all activities below Heavy Planned Maintenance at end state. It uses the DTUP materials distribution network, with component overall (items removed from train and sent away) undertaken remotely using Acton Works to undertake these activities where appropriate.

- **Stonebridge Park Depot - (Main Depot)** - will continue to operate as the main depot on the line undertaking planned and casualty maintenance in a similar way to today. Of particular note is that a heavy maintenance facility and wheel lathe have been specified as part of the user requirements set to support casualty and intermediate planned maintenance below overhaul.

- **London Road Depot – (Satellite Depot)** - will operate as a light satellite Depot able to undertake light maintenance up to underframe module replacement. The exact number of roads will need to be modelled however it is estimated that 3 pitted roads will be required for this activity. The stabling area outside the maintenance facilities will operate as manually driven signalled sidings. The facilities are required to undertake the following activities at London Road.



Note * Casualty and intermediate maintenance requires removal and replacement of large underframe train equipment

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8.3 Lessons Learned From Recent Fleet Introduction

Experience first identified during S-stock introduction has shown that the low solebar height prevents adequate visibility and access to the bogie mounted and under frame equipment from the existing side pitted roads. Although the DTUP solebar height is similar to existing stocks the problem remains due to existing deficiencies in side pit width and dimension in particular.

For this reason, all Depots roads that will be used for routine maintenance or casualty inspection will be upgraded to Swimming Pool type roads where new roads are constructed. Where existing side pits and centre pits remain, these must take account of human factors for those undertaking maintenance. Changes to working practices and implications for Health and Safety must be considered as part of this fundamental change. Protection against falling from height through an open door is an issue that needs to be mitigated on swimming pool roads.

Maintainability and Human Factors studies have identified that the optimum distance between adjacent Swimming Pool pit roads is 3 metres between car-bodies – this distance allows un-hindered movement of most Mobile Access Platforms (MAPs) and the tooling between adjacent roads during examinations. It should be noted that the Depot facilities should be designed to minimise the use of MAPs where possible, for example provision of permanent access platforms for Door examinations will eliminate inefficient and costly maintenance.

The DTUP Tube Stock bogies are not likely to be designed to be mechanically retained when the train is lifted. As a consequence of the permanently coupled through-gangway design, potentially with articulation, this could result in the process of lifting a train being is a lengthy procedure – risking lost service if the maintenance activity takes longer than a few hours. DTUP lifting systems must therefore be specified to avoid the practice of manually securing the bogies to the underframe for lifting. Suitable products would include under-wheel lifting systems, bogie jacking systems or bogie drop systems.

The introduction of S-stock as a long fixed formation train has identified significant challenges in visibility while moving a train over facilities such as the fixed wheel lathe. These types of issues must be considered as part of the development of each facility and solutions found where appropriate e.g. use of CCTV to aid positioning operations.
Experience of recent fleet introductions has demonstrated the importance alongside training of ensuring that there is strong leadership , partnership and co-operation with suppler to ensure that internal fleet maintenance staff achieve competence on the train without heavy long reliance of the supplier. Early consideration has been given to a process of co-operation between the supplier and internal fleet staff during introduction and this has been written into the DTUP tender . This will be further refined once the preferred bidder has been selected and aligned as part of the agreed readiness plan.

Recent initiatives have been implemented on LU Depots to introduce Lean practices, in particular the 5S methodology (Sort, Segregate, Standardise, Shine and Sustain). DTUP should ensure that special storage and floor markings are reinstated after intrusive works. Project teams shall work jointly with depot representatives to identify opportunities when specifying racking, tooling and general storage locations.

8.4 DTUP Depot Maintenance Facilities

8.4.1 Summary of New Depot Facilities Required for DTUP Tube Stock

The new train will require a range of modified and new maintenance facilities to facilitate its maintenance. These include:

Facility	Current Equipment	Mechanism For Upgrade / Change	New Facility/ Equipment	Additional Requirements notes
Heavy Maintenance Facility	Piccadilly Line & Bakerloo Line Lifting shop with overhead crane for single car lift on to move car to car stands Central Line & Waterloo & City Line 2 car synchronised lifting Jacks with Overhead crane Hainault/Ruislip	New rolling stock designed as fixed car formations with inter-car gangways semi permanently coupled not designed to be easily split	"PIT STOP" Modular component Replacement Targeted module/component replacement in a specific area of train	Whole train synchronised lifting either by jacks or in floor lifting system (Train Static In Shed) or Component drop (Train moved to defined position) In floor lifting systems or jacks Must lift the train under each wheel and have built in car stands to secure the car and then enable the bogie to be lowered. Space requirements to enable equipment to be removed from side of train with fork lift/plant
			TMU ACTON Overhaul Facility Access to whole train for removal/replacement of components	Whole train synchronised lifting either by jacks or in floor lifting system In floor lifting systems or jacks Must lift the train under each wheel and have built in car stands to secure the car and then enable the bogie to be lowered. Component Drops NOT to be used for this activity Space requirements to enable equipment to be removed from side of the train

Facility	Current Equipment	Mechanism For Upgrade / Change	New Facility/ Equipment	Additional Requirements notes
General Exam and Inspection Facility	Roads with Centre Pits & Roads with centre and side pits	New modules components on the train that require removal	Modified Central Underframe & Side Access Roads	Existing pitted Maintenance Facilities in the depot reused for defined DTUP tube stock Tasks. These roads have between 1.9m and 2.4m space between car bodies
			New Central And Side Access Roads with enhanced space between trains for worksite and materials efficiency and management	New roads typically "Swimming pool pits". Designed for centre and side pit access with a minimum of 3 m between trains. Exact number of Swimming pool pits depends on rolling stock design and safety human factors considerations
Cleaning Facility	Above solebar Platform roads in depot with current rails into the sheds		Facilities to ensure access to both sides of the train to maximise production	Longer train length or alterations to floor height. Many cleaning roads do not enable access to both sides of the train.
	Underframe Cleaning Road	Centre Pitted Road	Centre Pitted Road	Underframe inspection should be automated
	Automated Train Wash	Requirement to fulfil; exterior cleaning targets	Similar facilities to Today. Cleaning of specific items such as fans/ducting etc. may be needed.	Current located in Cockfosters , Hainault Stonebridge Park and Waterloo depots Location carefully considered in new installations to maximise throughput of trains while entering / exiting depot
Door Maintenance Facility	Periodic Inspection Facility	New train	Equipment to facilitate maintenance of DTUP doors	
	Overhaul Facility	Increased door size and mass on New train.	Dedicated facility to remove and manipulate DTUP door	

Facility	Current Equipment	Mechanism For Upgrade / Change	New Facility/ Equipment	Additional Requirements notes
Adverse Weather Facilities	Sandite Facilities Currently only in Neasden , Ruislip and Hainault Depots	Characteristics of future line upgrades result in Sandite treatment being proposed	Equipment to handle IBC for loading to train and or pump's to load in to Sandite hoppers	
	Sanding Facilities Only currently installed in Neasden Depot in Preparation operation of S-stock in ATO	Increase brake rates introduced for ATO may result in on train Sanding on Future Fleets	Sanding silo and multiple distribution points in suitably identified locations in depot	Exact requirement to be developed and then revised following in service experience of S-stock in ATO 2018 approx. Thought very likely on Piccadilly Lines and Central Line less likely on
	De-icing facilities currently in all depots	Modern practice and minimising cycle time into the depot during high risk periods	Multiple filling points should be considered as best practice	
Screen Wash Facilities	Currently used on S-stock	Incorporate lessons learned from S-Stock experience	Learned best practice for filling device	
Underfloor Wheel Lathe	Currently in Some Depots	In situ wheel Turning reduces Maintenance Burden. Bi annual skimming of wheels		
Store Facilities	Traditional Depot stores facility	Need to consider more efficient storage methods and storage of new sensitive electronic components	New modern stores and materials management	Need to ensure adequate storage for both migration between old and new and final states Operations will consider as part of future materials strategy.

Facility	Current Equipment	Mechanism For Upgrade / Change	New Facility/ Equipment	Additional Requirements notes
General Office Facilities	Many offices still traditional and contain separate offices	Need to promote open plan and interaction between all parties on site	Convert or construct new open plan offices to create depot hub	
Staff Amenities	Accommodation, lockers , mess facilities, toilets & showers , canteen , security , cleaners facilities , training facilities, visualisation room	Facilities introduced and upgraded to modern standards	Facilities maintained and upgraded for new depots	Adequate provision for requirements needs to be made for new facilities and new ways
Power Supplies	Existing power supplies	Needs to upgrade power for trains that enhanced power supplies including air conditioning etc.	Upgraded power supplies	
Shore Supplies	Existing shore supplies	New to upgrade supplies for higher power requirement of train	Upgraded shore supplies	Roof structures may need to be strengthened to facilities improved supplies. Consider use of battery back-up to reduce reliance on shore supplies.
Battery Charging Facilities	Legacy Fleets requires dedicated battery charging rooms	Introduction of New Fleet	Objective for new fleet not to require regular battery charging between replacement	Should regular be required a facility will be required and this must also include transportation of batteries to and from trains

Facility	Current Equipment	Mechanism For Upgrade / Change	New Facility/ Equipment	Additional Requirements notes
Pit Bridging Boards	Boards designed to specified structural load requirements	Upgrade to new facilities	New equipment for revised pit design	
Air Supplies	Clean ,dry compressed air supply provided for air bake testing and also for pneumatic tools	Upgrade to new facilities		Depot upgrade to considered redundancy of compressed air supplies where possible
Car parking	Car Parking traditionally restricted in Most Depots	Depot Upgrade	Additional parking	As a result of an Increased number of personnel on site as a during and post upgrade additional parking should be considered
Crane – overhead	Cranes providing facility to lift equipment from roofs , from track level and from floor level	New equipment Lifting requirements for new rolling stock and for modern human factors requirements	New cranes should:- Be a minimum of 10 tonne capacity on a travelling gantry. Have twin gantry cranes provided with movement restrictions to avoid clash and interlocked with traction power	Requirement for cranes even with in floor, on floor lifting systems /jacks remains. Exact capacity depends on maintenance requirements of new train
Depot Protection system (DPS)	A variety of systems in some depots	Depot upgrade and in particular increased levels of depot automation.	Interlocked systems to segregate maintenance areas from operational areas within the depot	Future systems to in particular enforce controlled safe handover between maintenance areas and operational areas of the depot.

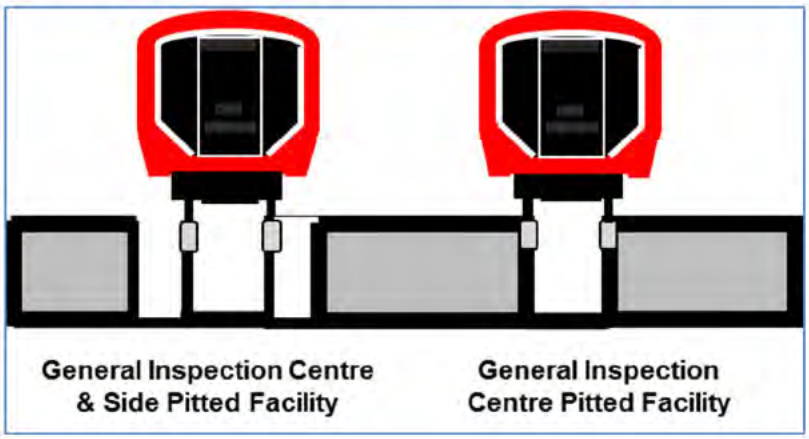
Facility	Current Equipment	Mechanism For Upgrade / Change	New Facility/ Equipment	Additional Requirements notes
Depot Access Road Pedestrians , vehicles & Emergency Access & for emergency appliances	Road access. Where required arrangements for second or alternative emergency access must be maintained	Alternations to depot as part of upgrade	Access Requirements need to be both maintained and improved to modern standards. Methods for controlling vehicle speed in depots must be incorporated	Segregation of people from vehicles where possible. Particular consideration to movement and reverse movements of large goods vehicles in depots must be considered.
Length Of Shed	Shed length acceptable for existing train lengths	New Rolling Stock introduction	Extended train lengths requiring extended shed facilities	
Depot Lighting	Traditional light with varied condition	New standards and technical analysis	Improvements made in lighting levels improve visibility and safety particularly in confined areas.	Efficient lighting is a clear requirement
Track Standards	Many depots to be upgrade have legacy track formations	Upgrade of depot, introduction of new control systems and better whole life cost management of track spares	track formations designed to modern standards	

8.4.2 General Inspection & Maintenance facility

The most versatile maintenance type of facility on both existing and future Depots is the General Inspection & Maintenance Facility (Pitted Maintenance Roads). This enables a range of regular inspection and lighter component and modular replacement maintenance activities to be undertaken. The activity range extends to the use of manipulation equipment to assist in the manipulation of bulky or heavier components and modules. Critical to the facility is the need to create an efficient human factors driven working environment for the maintenance activities that are going to be undertaken.

a) Modification of Existing General Exam & Inspection Facilities

The future suite of depots facilities may include the re-use of the existing Depot pitted facilities that can continue to undertake some tasks with either no or limited modification. The length of these roads, centre pit depth, side pit depth/ width, space between roads, lighting, drainage, materials movement logistics, worksite management and other enabling activities such as shore supplies will affect the practicality of future re-use of these facilities for DTUP tube stock. In particular the space between roads is likely to remain restrictive to optimising maintenance production and limit the scope of activities where these roads can be re-used. 0



Note: It is essential that the method of safety protection e.g. working at height can be implemented in a timely manner.

Example of an existing Centre & Side Pitted Road at Stonebridge Park Depot on the Bakerloo Line. Existing space between trains is 2.4m between car bodies (1.7m between side pits in this example although typically on the Piccadilly Line this is reduced to 1.9m

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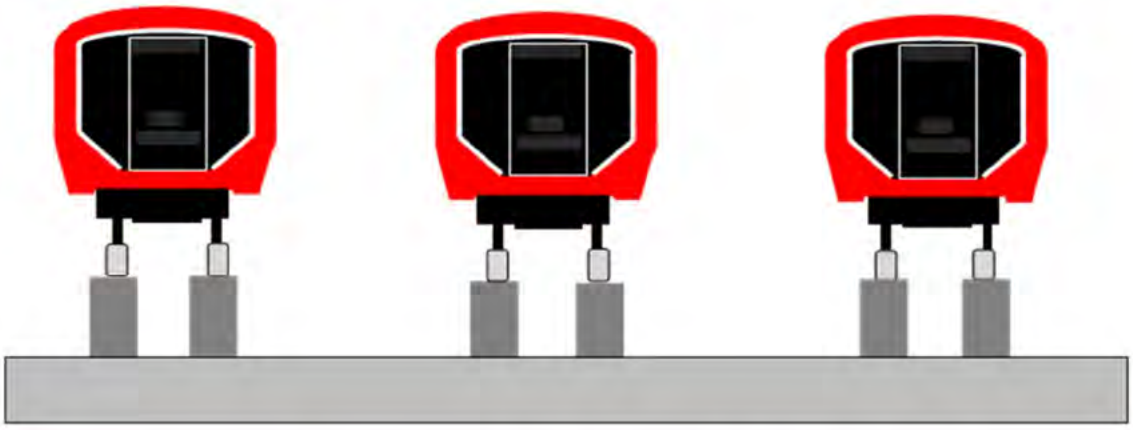


Example Cross Section of a typical modern "Swimming Pool Pit Facility provides improved access to the underframe and side of the train below solebar and increased working space between trains

Example of the newly constructed swimming pool pit roads At Neasden depot for S-stock. Note the increased height from the mobile platform to ground level. The minimum space between trains is 3 metres

8.4.3 Heavy Maintenance Facility

Heavy Maintenance Facilities are required when large components and modules of the train need to be removed or replaced using dedicated equipment. The introduction of the DTUP tube stock results in the need to significantly upgrade these facilities. This is primarily because the new train is of a fixed formation with the potential use of articulation (i.e. it cannot be routinely split easily). In addition the available space means that the underframe is the primary position for the location of heavy modules and equipment including HVAC and train-borne signalling which would need to be removed. For reference, the existing facilities split the train into either single cars where they are then lifted using an overhead crane or lifted as two cars using mobile lifting jacks (Central Line & Waterloo & City Line only). It is recognised that the strategy for heavy maintenance facilities involves two specific areas:

- Rapid Modular Component Replacement
- Overhaul Facility (At Acton TMU)

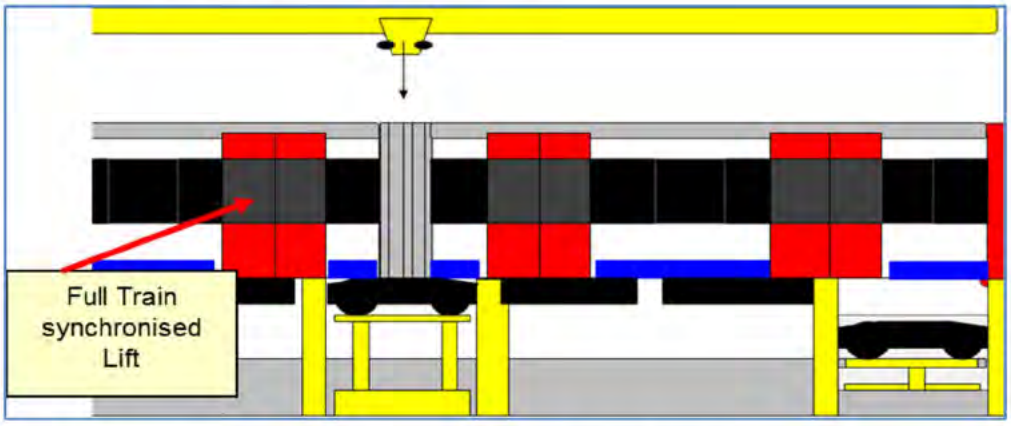
Existing Heavy Maintenance Facility at Cockfosters Depot with a single car lifted on Car Stands and bogie removed

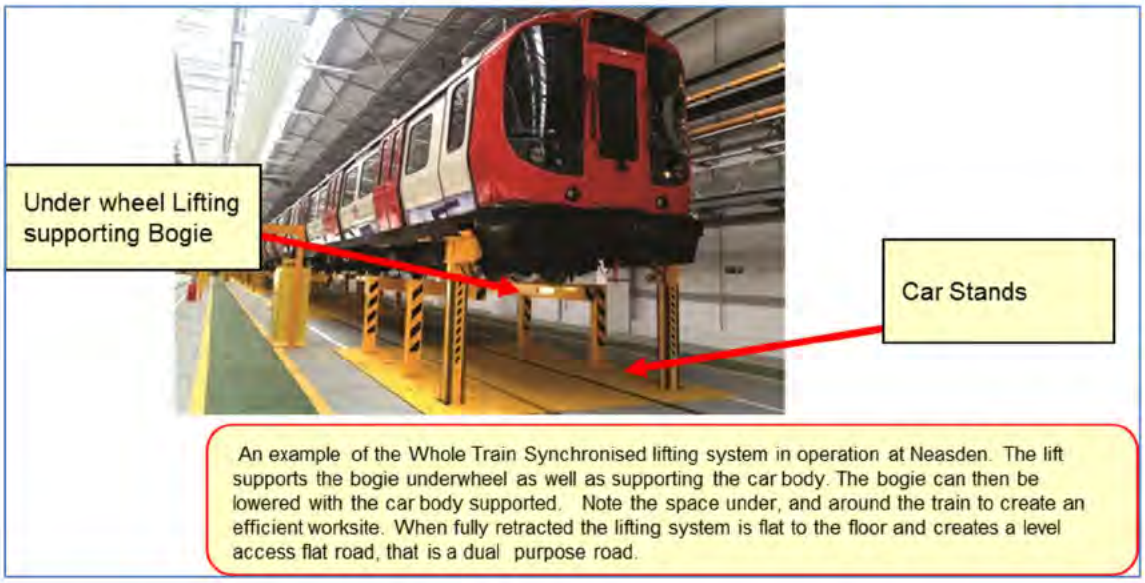
a) Casualty Maintenance Activity Lifting - Rapid Modular Component Replacement

The purpose of this facility is to remove, replace or access large and/or heavy component/modules in a specific targeted area of the train outside the normal heavy maintenance regime. Therefore the requirement is for the train to re-enter service with the principle of minimising the production down-time by ensuring rapid utilisation of the maintenance facility. For the scope of this facility, the train can either be lifted (whole Train Synchronised lift) with the train fixed in position within the maintenance road, or the train moved to the required position and the component removed and replaced by using a drop system. London Underground has recent experience of introducing lifting systems but has not thus far used dedicated component/bogie drops, although these are used extensively in other railway operations both in the UK and across the world.

Experience of lifting systems has identified that there can be a considerable set up time (2 man hours for 4 cars of 09TS) in chaining bogies prior to lifting (DTUP tube stock would require the same process), therefore lifting systems that lift under wheel for example, eliminate this activity and significantly reduce set up time. Where a synchronised train lift is used facilities shall be provided with the capability of using a mobile train manipulator to accurately position trains for maintenance tasks.

For the bogie drop/component drop to be effective, the activity of movement of the train to position the target section of the train, as well as its impact on other shunting moves within the maintenance facility and operational depot area has to be fully considered. In moving part of the train outside the shed, the protection of those inside the shed from the weather and temperature extremes outside it must also be considered.





An example of the Whole Train Synchronised lifting system in operation at Neasden. The lift supports the bogie underwheel as well as supporting the car body. The bogie can then be lowered with the car body supported. Note the space under, and around the train to create an efficient worksite. When fully retracted the lifting system is flat to the floor and creates a level access flat road, that is a dual purpose road.

b) Overhaul Facility

With the conformation NTfL-2344.3.4-LUL-RPT-0057 "Fleet Maintenance strategy for End State Maintenance Arrangements" DTUP fleet heavy overhauls are planned to be undertaken at the new facility built at TMU Acton (Central Line Overhaul Facility).

The facility will need to be configured to lift the train and given the design characteristics (articulation) the whole train may have to lifted via a synchronised whole train lift. Given the need for all trains to be serviced though this facility set up time must remain minimised so as to reduce wasted time in the maintenance operation and as a result the lifting principles as described above remain applicable.

8.4.4 Cleaning Facilities

The new train will require a range of cleaning facilities and the intention to continue undertaking on train litter picking activities both in service and in stabling areas [redacted] should be noted.

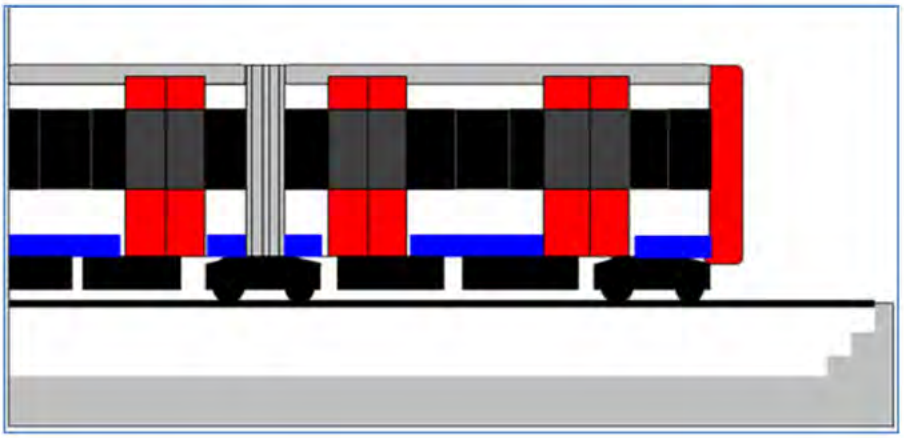
a) Above Sole-bar Cleaning facilities

To facilitate the cleaning of the DTUP Tube Stock, above sole-bar level dedicated cleaning roads are to be used to facilitate the more advanced interior cleaning, exterior hand cleaning and graffiti removal from the train. To maximise efficiency and production all cleaning roads must provide platform level access to both sides of the train, and be designed for the equipment and processes required to undertake this activity. Drainage must be specifically incorporated into the design of this facility. Dedicated Cleaning roads must have the functionality for isolating the traction current supply in the cleaning facility area.

Platform cleaning Road at Northfields Depot

b) Underframe Cleaning Road

The operating environment of London Underground makes the requirement for underframe cleaning a very necessary activity and this will continue thought the life of the DTUP Train. Currently this is typically an activity undertaken on a 56 day cycle (6 weeks) and has remained a very manual activity with efforts to automate it not being successful. Eliminating this manually based activity that puts cleaning teams in a dirty, cramped environment is a clear operational requirement for the new fleet and this should be investigated further. Should new methods of automation not be practicable, a dedicated road with good drainage that is easy to clean must be developed.



c) Ventilation System Cleaning

The build-up of dust in rolling stock Ventilation System equipment fans and ducts has proved very challenging with recent fleets.

For the Central Line Fleet a dedicated single road with ventilation cleaning plant system is in operation. More recent fleets have not got a dedicated plant system and are continuing to refine and develop smaller equipment manipulated to the train in a pitted road. Ensuring that these facilities remove dust in a way that prevents it being ejected in to the working environment of the Depot has proved difficult and therefore solutions are required for DTUP Tube Stock.

A solution must to be found to ensure that DTUP tube stock ventilation ducting is kept clean with dust removal in a safe an efficient way. To address this, there are specific requirements in the Rolling Stock Tender to ensure that there is both access to equipment on the train and to reduce build-up of dust and dirt on critical surfaces; but this is unlikely to fully eliminate the need for cleaning.

d) Automatic Train Wash

Automatic Exterior Train washes exist on each line to facilitate the cleaning of trains in a 3-4 day cycle. Train washes must be located at a position in the Depot that has the highest frequency of trains entering and leaving the depot. With specific cleaning targets to be achieved, the existing train washes will need to be modified, where necessary, to accommodate the new train. The train Washes are currently located at:

- Piccadilly Line - Cockfosters Depot
- Bakerloo Line – Stonebridge Park Depot
- Central Line – Hainault Depot x2 (East & West) & Ruislip
- Waterloo & City Line – Waterloo Depot

Waterloo & City Depot Underground Wash Plant

The existing train washes are largely life expired and should be replaced with new facilities in each depot. It is recommended to install train washes in either end of double ended depots. Where existing train washes are reused careful consideration must be given to ensure they are fit for purpose for long term use. Note: it is anticipated that as the profile of the new train is similar, the

train washes can be used simultaneously with the existing and new fleets, possibly with minor changes to the brush arrangements. New train washes must be considered.

8.5.5 Wheel Turning Facilities

The wheel profile on DTUP tube stock will require a machining operation to restore it to the designed profile.

Dedicated wheel turning facilities are an absolutely essential facility for the operation of DTUP tube stock on all lines. The Piccadilly Line (73TS) and Bakerloo Line (72TS) tube stock do not have effective Wheel Slide Protection (WSP) and as a result suffer significantly from casualty wheel flat issues. It should be noted and the Bakerloo Line in particular does not have on site wheel turning facilities. The introduction of the new train with efficient WSP (on those lines where WSP is not already fitted) is likely to significantly reduce the number of casualty wheel flats (particularly during the autumn leaf fall period); however wheel turning remains a vital maintenance activity. This has been endorsed by recent analysis that strengthened the engineering case behind a cycle of regular wheel turning (bi-annually approx.) to restore the wheel profile to “new” condition. This has positive benefits for not only wheel life but also rail life.

The DTUP strategy for facilities is therefore to manage a limited number of casualty wheel turning events in addition to regular planned turning cycle of the entire fleet. This in turn makes a strong case for a dedicated facility for this activity since there is going to be a constant cycle of wheel turning production. There are two options for wheel turning facilities:

a) Fixed Wheel Lathe

A fixed wheel lathe is one in which the train is not dismantled and is moved over a dedicated facility to restore the wheel to its new condition.

Considering the frequency of wheel turning a dedicated fixed wheel lathe is recommended operationally for DTUP tube stock maintenance, as it avoids the need to undertake a separate lifting activity prior to the commencement of wheel turning process. To maximise production efficiency the wheel lathe must be double headed and enable all wheelsets of the train to move over it. In addition it aids the collection and removal of swarf during the wheel turning process. Working in an exposed shed environment must be considered as part of this strategy.

The existing single Headed Wheel Lathe at Northfields Depot on the Piccadilly line

b) Mobile Wheel Lathe

A Mobile Wheel Lathe is where the train is lifted on synchronised jacks and then the wheel lathe is moved underneath the train to restore the wheel to the desired profile.

An Example of a Mobile Wheel Lathe in a non- London Underground Depot

Example of a Mobile Wheel Lathe in operation at Ruislip Depot on the Central Line

Mobile wheel lathes have recently been used in a number of London Underground Depots as an alternative to a fixed underfloor wheel lathe and it is recognised that in some locations, space constraints mean that they are the preferred option.

In consideration of their use with DTUP tube stock, the production time for lifting activity to ready the train for wheel turning must be considered together with the feasibility of their use where under wheel lifting is used. Practical use has also highlighted that swarf needs to be carefully managed in their operation. The expected frequency of wheel turning also means they are likely to need a dedicated road, so use of the heavy Maintenance Facility is likely to cause scheduling conflicts.

8.5.6 Door Maintenance Facilities

Doors are critical components that exist in high numbers on the train and traditionally maintenance has been an annual inspection activity (activity 3 times longer on recent new fleets) with a 4-5 year overhaul cycle. The maintainability of recent fleets that have been introduced to London Underground has resulted in an increase in the production time for door maintenance, due to the amount of dismounting and reassembly required which adds no value to the overall maintenance being undertaken. Typically each train will spend a complete week per year undergoing door maintenance.

It still remains the case that dedicated facilities are required to undertake this activity. Within these maintenance roads, some maintenance tasks are completed with the assistance of manipulation equipment and plant to reduce the level of human movement of doors.

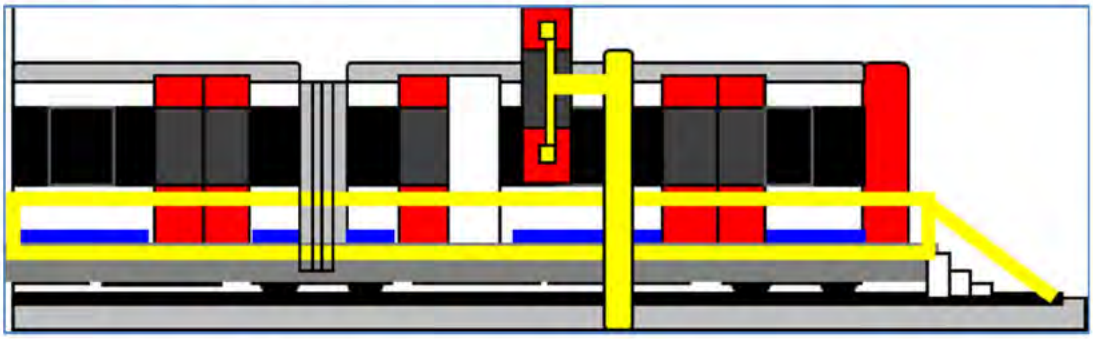
a) Periodic Door Inspection Facilities

For the more frequent periodic door maintenance activities, good access to the upper and lower door areas is essential. Mobile access platforms have often been used for this activity, however they require manipulation to move into the correct position so a fixed and dedicated facility is required for an activity that will be part of a constant production cycle.

b) Overhaul Door Maintenance Facilities

The more intrusive door maintenance activities result in complete removal and manipulation of the door and associated equipment.

With door size and mass possibly increasing, it is anticipated that dedicated equipment is required to manipulate the door; this in addition to the space required around the train to undertake this activity.



8.5.7 Adverse Weather Consumable Re-fill Facilities

DTUP tube stock will have equipment to mitigate the impacts of poor adhesion, winter weather and dirty windscreens. All of these require consumables, which in turn will need management and refilling to ensure safety and service performance is maintained. Refilling is required to be undertaken quickly and efficiently for all trains to ensure rapid refill production rate of all required trains in the fleet (Target 8 mins per train). These consumable levels will be monitored remotely with an appropriate threshold for alarm notifications in addition to physical indications on the train. [redacted]

Winterisation Facility Constructed at Neasden Depot for Sanding and De-icing refill for S-Stock

a) De-icing Refilling Facility (Not W & C)

Approximately 30-40% of the DTUP tube stock fleet will be fitted with the capability to lay an anti–icing fluid on the positive and negative conductor rails to prevent the formation of ice and snow in winter conditions.

The size of tank specified for DTUP is similar to that on S-Stock, which has a fluid laying duration of approximately 9 hours. In high risk periods trains may need to be cycled through the de-icing facilities rapidly to ensure the fluid continues to be dispensed across the line.

[redacted]

To facilitate rapid refilling of de-icing tanks in both the planned and reactive maintenance cycle, a target fill rate of 450/l min has been specified to the rolling stock suppliers.

The facility must consider turning of the train (on appropriate lines) and have the capability to refill the de-icing tank regardless of train orientation. The working environment of the maintenance staff must be considered to ensure it is acceptable. The number of required de-icing facilities for the DTUP lines must be carefully calculated to meet operational requirements.

b) Sanding Refill Facility (Not W & C)

Sanding will be fitted on every DTUP train, with sand hoppers fitted on multiple locations along the train. The rate of sand usage will have a significant impact on the type of facilities required and will vary on each Line. For lines with heavy sand usage, Central Line & Piccadilly Lines, there will be the requirement for dedicated facilities to rapidly replenish hoppers on multiple locations along the train.

For the Bakerloo Line, where sand usage is likely to be much lower, the use of mobile bowsers may be considered. This approach is similar to the approach taken on the Sub-Surface lines (Metropolitan vs. District Line). The maintenance working environment must be considered to ensure it is acceptable.

c) Screen Wash Refill

A Mobile bower used on any general maintenance in the Depot will fill the Screen Wash tanks. It should be noted Screen Wash Refill has presented unexpected problems for S-stock in that there was no automatic cut off system when the tank was full, hence the liquid continued to overflow when being refilled. A Low fill pressure method of operation had to be developed to overcome these issues.

d) Sandite Refill Facility (not Bakerloo or W & C)

On the Central Line and possibly the west end of the Piccadilly Line), Sandite Trains will operate during the autumn leaf fall period. This notes/ assumes that the eastern end open section of the Piccadilly line is short and is treated with Sandite by infrastructure based methods.

These dedicated trains will require Sandite hoppers to be refilled at regular intervals during the leaf fall season and requires a location in the depot where this task can be undertaken. Based on existing operation this consists of a platform where the International Bulk Container (IBC) that contains the Sandite can load the hoppers. It should be noted that Sandite has a limited life and will harden when left within a short number of hours.

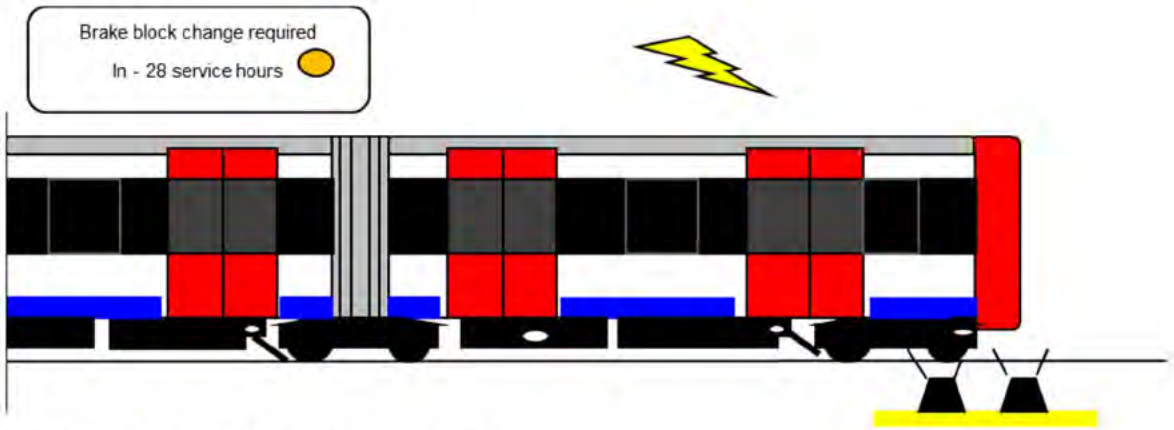
8.5.8 Stores Facility

The full strategy for stores management will be outlined in a subsequent version of this concept. It is currently envisaged that there will be a large central stores location (separate from depot locations and located at Acton) with each Depot holding the key spares for its planned and casualty maintenance operation. Delivery to and from the central store will be undertaken on a “Just in Time” principle. The planned stores and management arrangements will be consistent with the agreements for suppliers operations under the FSA and MSA arrangements.

8.5.9 Automated Inspection Equipment

Automated inspection equipment is likely to be used as part of the future Maintenance Strategy. It is similar to the requirements for facilities such as the train wash, in that the location of the equipment

will be critical to ensure that the required number of trains can pass over it at the required frequency. [redacted]



8.5.10 Workshop & Special Facilities

Further work will be undertaken for the next revisions of the concept to review the requirements for workshop facilities required in new depots in line with the emerging train maintenance regime and arrangements agreed for component overhaul.

8.5.11 Depot Security

Each depot must be equipped and operated as a secure facility. Authorised personnel must present a valid pass and safety induction certificate at a security gate to enter a Depot. All other pedestrian and vehicular access is subject to a security procedure at a manned or monitored entry point.
CCTV must be extended and expanded across internal / external areas of the depot to ensure protection as part of the new operational model.

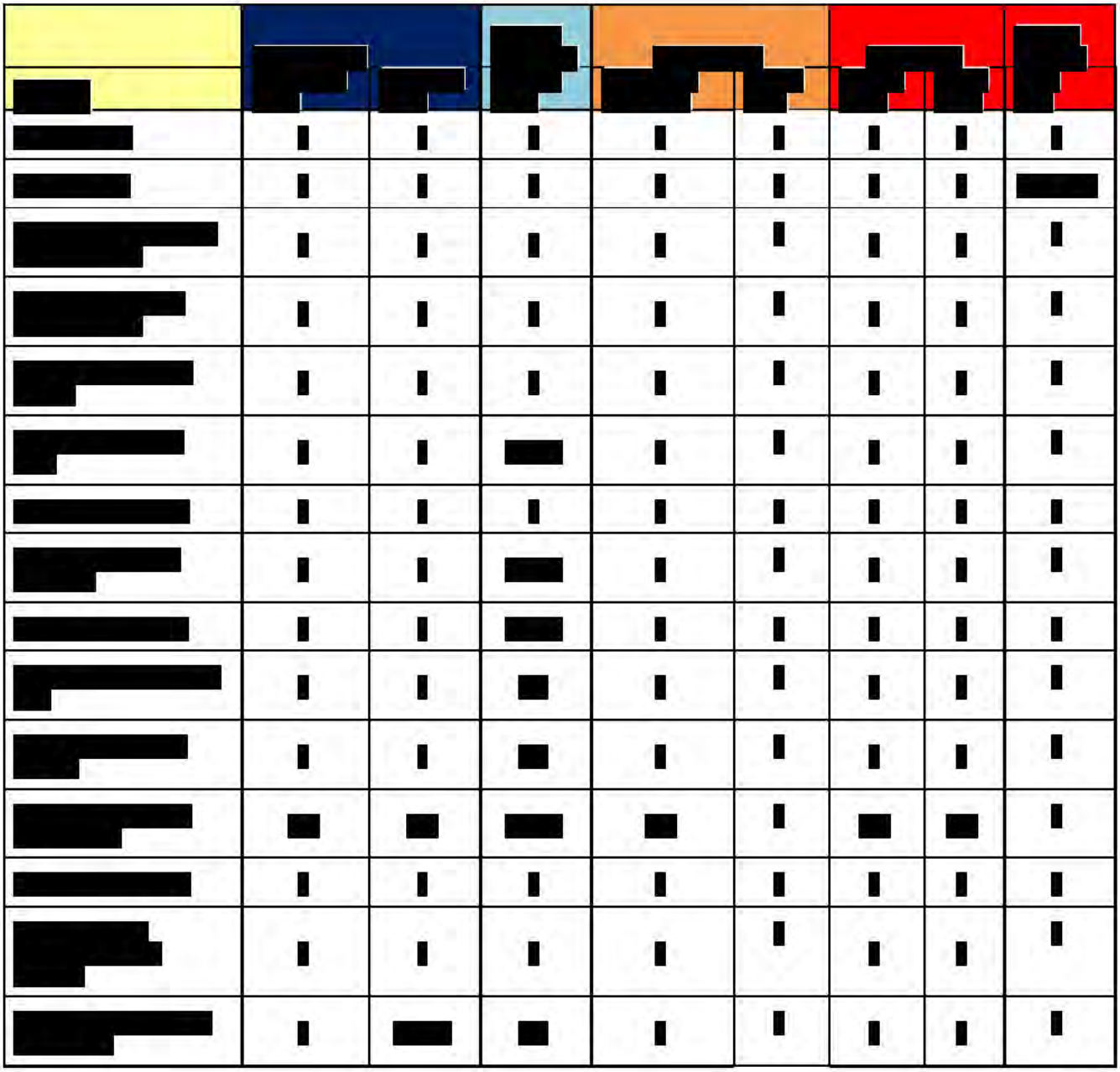
8.5.12 Depot Safety Systems

Protection Systems are installed in modern depots to warn staff of train movements in and out of shed roads. There are currently no Depot Protection Systems installed at any DTUP Depot sites. Therefore, introduction of an audible and visual warning system (plus physical train obstruction or indication) linked to train movement will be required to continue to reduce the risk of injury or death in a Depot to ALARP.

The Depot Contractor is to examine the feasibility for providing audible and visual warning of train movements in and out of maintenance sheds. The warning could be activated from wheel detection switches (treadles) upon the approach of a vehicle towards the particular shed road on which it is to run or via local driver activated switches for exit from particular Depot roads.

The Depot Protection System is to enhance the current depot rule (which requires trains to stop before entering a shed) by installing a local stop/go light linked to the roller shutter door and an audible/visual warning system on that road.

[redacted]



[redacted]

Facility	Piccadilly Line		Waterloo & City Line	Bakerloo Line		Central Line		Network Overhaul
	Cockfosters Depot	Northfields Depot	Waterloo Depot	Stonebridge Park Depot	London Road	Hainault Depot	Ruislip Depot	Acton TMU
Automatic Inspection Equipment	1	1	0	1	1	1	1	0

10 CORRECTIVE MAINTENANCE AND REPAIR STRATEGIES

10.5 Corrective Maintenance Assumptions

Train reliability represents the greatest risk to satisfactory Depot design and train availability. Although contractual targets exist within the DTUP rolling stock specification and contract, the potential for variation that comes with the reality of in service performance will have to be considered.

Where assumptions associated with train reliability are sensitive with respect to decision-making, it is proposed that benchmarking of facilities required for similar modern rolling stock should be undertaken as far as possible. Before the trains enter service, reliability modelling will be based upon sub-system reliability design data supplied by the supplier.

Assumptions may be necessary to develop Depot road capacity models on contingency reliability forecasts, for example; the traditional LU fleet reliability has been very poor at introduction, whilst the reliability contractual targets of 50,000km MBDSAF for delivery and 120,000km for fleet acceptance have been set as high targets.

It is acknowledged that all train fleets are subject to a small number of significant endemic problems/ regular failures requiring inspection or modifications throughout stock life. To this end, special consideration should be given to overprovision of some Depot facilities to balance the risk of significant service disruption. Previous evaluation for 4LM has identified that a business case evaluation supported the case for every depot to be equipped with a synchronised whole-train lifting system (paid back in avoided LCH by just two endemic once-rounds). It is expected that existing centre and side-pitted roads not converted to swimming pool roads will provide adequate provision for non-lifting inspections, modifications or 'once-rounds'.

10.6 Materials and Repair Management

Major traction and auxiliary assemblies (e.g. bogies, compressors and HVAC units) will be swapped out at the depots and sent off site for maintenance (in the same way as Single Minute Exchange manufacturing methodologies). This will ensure shorter train down-time, greater train availability and reduces the amount of required shed space.

Clean rooms are required at Depots to allow first line inspection and testing of on-board electronic modules. The purpose of the clean room is to test, rather than repair; i.e. to confirm a defect by replicating the operational conditions and save costly 'NDF' returns through the repair loop. On this basis, each clean room needs to provide:

- Heating & cooling for ambient temperature control,
- A minimum of two test benches with electrostatic discharge protection
- Space for test racks for electronic modules such as Train Borne signalling
- TCMS, Connect Radio, PIS and OPO modules. Ideally, the clean room should be located within or near the stores area so that components can be carefully controlled and sent to

the repair authority or released back in to the spares stock.

It should be assumed that casualty exchange of bogie mounted equipment will be conducted at each train maintenance Depot, requiring on-site storage of casualty components, to allow 'mix and match' build of any bogie derivative for a repair within a shift.

Other heavy casualty facilities to be supported at each site include HVAC and gangway replacement. In particular, it is considered that the frequency of repairs required for HVAC (underframe mounted) will make it impractical to consider DTUP stock transfers between Depots, for the purpose of HVAC repairs necessitating underframe access and removal of HVAC at each site.

Door and gangway repairs are difficult to predict and the pressure upon fleet availability is likely to mean that at least one casualty platform road for door repairs and facilities for gangway replacement will be required at each Depot.

The DTUP implementation will require significant changes to spares, stores and specialist equipment. A strategic review of spares and storage will be undertaken across all assets, balancing on-site versus off-site holdings that will influence this requirement. The requirements for storage space for spares needs to be carefully considered in each Depot and integrated with the requirements for remote storage of spares.

DTUP will ensure the migration plan and programme will cater for the transition from existing spares and specialist equipment to the new spares and specialist equipment. Efficient use of space and storage will leave minimal unused space and storage. The migration should take into account synergies and efficiencies between upgrades and on-going existing requirements; providing the most efficient possible cost across Operations.

11 MAINTENANCE SUPPORT ARRANGEMENTS

11.5 Manufacturing & Supply Agreement - Warranty Key Points

The Rolling Stock Warranty period has been defined as two years following delivery of last train for each line. This is a key change resulting from lessons learned with recent Fleet introductions where each train has come out of warranty piecemeal two years after its introduction. Longer warranties (of 4 years) were considered, however following consultation with the supply chain it was felt that this would not offer value for money. LU will have all available information for component/LRU Overhaul and so flexibility on how the overall future component strategy is managed (externally procured or managed in house), can be maintained at this point and agreed as appropriate in the future, based on the known design of the train.

12 FLEET SUPPORT AGREEMENT (FSA)

To support the DTUP tube Stock throughout its life, the following arrangements have been agreed for supplier support to London Underground:

12.5 FSA Fixed Fee Services - Service Provider to be available 24/7, 365 days per year for the following services.

Design Authority - This enables the supplier to retain long-term technical knowledge and expertise to perform as Design Authority for the New Trains. For this train, it is likely that Technical Design

Authority will remain within the supplier for at least the first quarter of its life at least if not whole life. This includes managing obsolescence and can be overridden at LU risk.

Technical Information - To support Operation the supplier is required to manage the technical information for the train by maintaining the electronic library (Including documents provided by LU, including assurance submissions and (background information). Documents must be kept up to date (version control). Relevant documents will also be provided to Maximo/Ellipse

Technical Advice – To provide technical expertise during operational service of the fleet, LU has requested the following services:

- On call response for supplier expertise
- Remote and on-site support
- Access to (Original Equipment Manufacturers) OEMS
- Covers trains as they exist and contents of library

12.6 FSA Call off Services – Service Provider (SP) to be 'available' during normal business hours

Technical Investigation (Incidents and Faults) – This service is to enable for provision of the supply chain knowledge and expertise to support LU to resolve Fleet issues and includes the following:

- Undertake supplier led investigations
- Support to investigations led by LU
- Duty to act independently (or report conflicts)
- LU not bound to use the supplier for technical expertise

12.7 FSA Engineering & Maintenance Support

This service is to enable the supply chain to support modifications, performance initiatives and maintenance efficiencies during operation of the fleet and includes:

- Advice in connection with modifications, maintenance efficiency and whole life costs
- Software modifications
- 'Design Authority Assurance'
- Support to LU to transfer Design Authority in-house

12.8 FSA Spares Management Arrangements

The Operations intention is to manage spares supply in house with support from the supply chain where identified for bespoke items. There is also an option for the supplier to provide spares for the first three year period post warranty (can be extended for further periods of time on a rolling basis) to ensure that the internal supply chain is established. The decision point for this service would be circa 2027. The spares service operates on the following principles :

- No obligation on LU to buy
- No minimum quantities
- Detailed priced Bill of Materials ("BoM") provided at contract under MSA
- MSA Whole Life Cost Warranty controls pricing
- 12 month minimum warranty on new items / parts & labour on repairs

- Service Provider manages spares warranty claims arising under MSA or FSA Consumables are excluded.

LU is responsible for stock levels and the supplier is responsible for delivering them within stated lead times.

13 FLEET & DEPOT MAINTENANCE TEAM INVOLVEMENT TO DTUP

13.5 Maintenance Introduction & Readiness

A separate paper (Rolling Stock Whole Life Technical Support Life Cycle for Deep Tube Upgrade Programme DTUP – 2344.1.1-LUL-RPT-00044) has been developed to describe the process of knowledge transfer and how it uses dedicated resource to ensure long term benefit. An overview of the key principles of this approach is shown below.

13.6 Operational Upgrades & Asset Development Team

The Operational Upgrades & Asset Development Team (OU&AD) has a core team embedded into the DTUP programme. From a Fleet & Depots perspective this team will serve as the day to day interface between the Programme and the wider maintenance community. The team should be considered as the 'first point of contact' with Operations (Assets). Where the team has delegated authority from the various asset disciplines then it will provide direct input into the programme. If not, then OU&AD will subsequently ensure that the appropriate representation is provided to the programme.

In order for this approach to be effective it is the responsibility of the programme to ensure that its sub-programmes and projects plan effectively for when maintenance involvement is necessary. It is imperative that sufficient notice is given to allow the designated maintenance representatives to plan for the necessary time.

It is expected that each project will embed into their schedule all activities which involve input from the maintenance organisation. The maintenance organisation will subsequently require that projects needs are 'rolled up' by the programme and are presented to the OU&AD team on a rolling one month 'look-ahead' basis. This look-ahead should provide clear information on what the planned activity is and what asset groups are affected.

13.7 Embedded Maintenance Operations Support to DTUP

Extensive experience and lessons learned of London Underground fleet introduction over the past 25 years has shown opportunities for embedded joint working and clearly defined Operations to CPD responsibilities must be taken early and proactively. This is to ensure both successful fleet introduction and handover in the project delivery phase in addition to ensuring that expert long term internal knowledge is developed to ensure high performing long term maintenance capability.

The embedded team approach is therefore recommended for DTUP, ensuring that internal LU Operations knowledge is integrated within the project team and supply chain throughout the project life cycle, leading to a strong self-sufficient capability at the end of the warranty phase and a long term reduction in reliance of the supply chain. Some areas of this support will also have the benefit of being able to provide the supply chain with London Underground engineering service expertise to

assist in the “right first time” completion of key work stream deliverables as part of the process of sharing information.

The clear clarification of these activities will ensure that the process of proactive involvement and responsibility is understood and committed to and agreed by both the LU CPD and Operations asset organisations (BCV & JNP).

The implementation of embedded Operations teams within the project, supplier and even sub supplier organisations throughout the project life cycle has the objectives of ensuring knowledge and skills are thoroughly transferred from LU operational experience to the project to influence the design phases. The specifically includes:

- Ensuring knowledge and skills are transferred from the Supply chain to the LU Operations Asset teams.

- Ensuring activities that require Operations support, knowledge and approval (including development of manuals and depot processes) are organised to achieve “Right First Time delivery”.

- Ensuring the whole process of maintenance introduction and readiness is integrated.

Ensuring LU Operations has sufficient engineering management of the train through its’ whole life.
Ensuring that the Handover process is achieved thoroughly and promptly, with the main deliverables achieved on a staged basis, with Operations as part of the integrated team.

13.8 Phases/Activities of embedded support

Defining Requirements - The key activity completed for this stage is the completion of the maintenance user requirements. These have been drawn up utilising expertise from around the organisation that are relevant for Rolling Stock Technical Specification, Manufacturing Services agreement (MSA) and the Fleet Support Agreement (FSA). The Operational Upgrades and Asset Development team has co-ordinated this exercise within Operations.

Bid Assessment - At this stage there is wider involvement from Operations asset teams to ensure that the maintenance analysis of the bids is undertaken with input from key subject matter experts within the organisation. This operational input is fundamental at this stage to ensure that the preferred solution is chosen for a strong whole life relationship of forty years.

Design Phases - Embedded Operations support builds on from requirements definition and bid assessment phases by incorporating critical maintenance engineering technical expertise into the design phases. This is considered to be a fundamental requirement in ensuring that the optimal maintainability solution is achieved, and that operational experience and lessons learned are embedded in to this process.
In particular, the capability of the supplier to demonstrate how design for maintainability is considered and developed in this stage, is an important element to making this stage successful and provides insight relevant to the subsequent maintenance demonstration. This should include consideration of human factors for train maintenance.
This will ensure, with a degree of confidence, that the user requirements have been fully reflected in the detailed design. The Mandatory Asset Information Deliverables (MAID) will be further reviewed

at this stage and a plan will be produced to outline how phasing of critical information throughout the delivery phase can avoid a "Bow Wave" of information at the planned point of handover.

- **Construction & Testing -** Facilitating the embedding of the Operations teams during the construction and testing phases is aimed at developing the core understanding of physical design and operation and maintainability of the train. This phase in particular requires involvement of the Engineering, Maintenance Introduction and Training teams, to ensure they develop the necessary depth of understanding and knowledge. In particular this involves how local information relates to how the system performs in the real world.

- **Maintenance Demonstration -** To ensure that maintainability performance can be physically achieved, the supplier is required to demonstrate the maintenance capability of the train. The involvement of Operations asset teams for this phase ensures a comprehensive assessment can be undertaken, that ensures that the train can be well maintained in the operational environment. It is also an important validation of both the Train Maintenance Regime and Vehicle Maintenance instructions. It should also be noted that this phase is equally important in ensuring that the depot upgrade requirements meet the capability of the train.

- **Fleet Delivery & Introduction -** The full mobilisation and support of both the embedded team within the project and the wider Operations organisation will be implemented for this phase to ensure integrated and effective change to the operational railway.

When the impact of the project becomes live to the operational railway, the level of Integration and Development of a "ONE TEAM" approach will be fundamental in ensuring this introduction is achieved with minimum impact to the operational railway. Learning lessons from earlier projects will ensure that the performance of the introduced fleet achieves its defined targets, with the Operations asset organisation capable of leading and driving the continued asset performance with the contracted support from the supplier.

The comprehensive Asset Performance Readiness Plan together with stakeholder agreement will be critical in ensuring successful delivery throughout the introduction phase. As previously outlined, the activities required to deliver the MAID will be fully supported and actively managed during this phase, to ensure that a successful handover process is implemented.
A range of Operations asset teams will ensure the introduction of the new train through asset introduction and into to immediate high performance. In particular the teams directly involved in training and developing the competence and capability of front line maintenance staff are of key importance and priority.

- **Training Support -** Training will be critical to ensuring all staff are competent to work on the new Train and On Board Signalling. Using in-depth knowledge gained from involvement DTUP Programme will allow the embedded teams to assist in the development of Training Needs Analysis (TNA) and to feed back into the training requirements and maintenance course production. Their use has been seen to be particularly beneficial in assisting in the development of operational rules which are traditionally not provided in the Supplier 'train the trainer' training packages, but are necessary to embed as part of end-user training delivery.

- **Assurance -** Supporting the project with Operations (Assets) staff early in the process will enable maintenance acceptance requirements to be clearly defined ensuring a smooth

handover, also giving assurance and confidence that Operations (Assets) are ready to accept and maintain the new system.

- **Management of Warranty & Handover -** The involvement and embedding of Operations teams throughout the project lifecycle is intended to significantly assist the process of comprehensive and prompt handover through the continuous identification and correction of issues at an early stage including acceptance of all documentation. The role of the Procurement and Commercial teams in ensuring that the key deliverables are achieved prior to delivery are also critical for successful completion of this phase. From project inception, the active, embedded representation from Operations will ensure that that the upgraded railway meets the defined operational needs and performance levels whilst the organisation is migrated to a world class railway.

Successful completion of handover and achieving world class steady state operation will be achieved through ensuring that the long term asset support arrangements are in place, both in terms of those provided by the supply chain and those implemented internally. These are critical factors and it will be by these measures that the success of the embedding process upgrade will be assessed.

13.9 Assets and Facilities Acceptance

Assets shall be designed and managed in such a way as to improve safety and performance and minimise commercial risk in the long term.

13.10 Depot Plant & Equipment

All plant and equipment procured as part of the Upgrade shall be accepted as fit for purpose by the nominated Maintenance Representative for Operations Depot, Plant and Equipment (DP&E). Whole life cost of ownership, repair and maintenance must be a key consideration when specifying equipment. Standardisation of equipment across the DTUP upgrades is preferable in order to rationalise the number of overall contracts that need to be managed by the DP&E team.

Training for DP&E staff will be the responsibility of the DTUP Upgrade Programme (Project Managers) and fit for purpose Operational and Maintenance instructions will be required as part of the handover process. The design life of each asset should be specified on an asset-by-asset basis, based upon an optimum balance between initial and whole life cost. Long life assets (expected to be used for all of the train fleet life) should be nominally designed to last for 40 years.

13.11 Facilities & Premises Assets

All of the Depots on the London Underground (LU) network are equipped with an Energy Management System (EMS) of differing technology types and functions. An upgrade to the building EMS should be evaluated at the time of Depot Upgrade to identify whether synergy of upgrade scope will result in a positive business case for upgrading the whole EMS.
Any new EMS should be set up to allow Depot staff to track faults and optimise energy use by regulating the heating and/or lighting. Any lighting or heating systems not centrally controlled should incorporate a local control, for example motion sensors, lux level sensors and time switches on pit lighting to reduce energy consumption.

It is acknowledged that the DTUP Depot Upgrade scope does not cover renewal of legacy assets unless upgrade is directly required to support the introduction of the new fleets. Where synergies or efficiencies can be identified in replacement of life-expired or failing assets outside the DTUP scope, the Sponsor may request delivery of works by the DTUP project management, subject to access to necessary funding with no adverse impact to DTUP programme delivery. The Depot Upgrade project teams shall consult with the Maintenance Representative and Sponsor representatives to identify acceptable boundaries (tidemarks) for scope enhancements. A balance will be sought to avoid starkly contrasting standards within adjacent Depot facilities whilst avoiding cost escalation.

13.12 Signalling & Control Assets

It shall be assumed that Fleet operations will be responsible for the first line maintenance inspection of on-train signalling equipment (as per the VLU, SSR & JNUP strategy). A Depot based test rig is required in a clean, temperature-controlled environment for the test of modules removed from the train. Additionally, the DTUP signalling requirements will include the provision and fitment of trackside signalling equipment upon a (nominally) 500m maintenance test track within each of the three Depots for the use of the maintainer following on board signalling unit replacement. These facilities are required to diagnose, confirm and record the nature of defective equipment before it is sent to the repair authority. The second line support and supplier management strategy will be covered in the DTUP Signalling Maintenance Concept.

13.13 OPO CCTV & Correct Side Door Enable

OPO, CCTV & CSDE are integrated systems impacting both Rolling Stock Maintenance and Stations Maintenance however they have been allocated for provision by the Rolling Stock supplier. There are significant lessons to learn in terms of defining future maintenance strategy and more development work and stake holder engagement is planned thought 2016 to accurately define maintenance principles to confirm in line with the requirements of this concept.

13.14 Interface Assets

Train Cab Simulators are maintained a C&I asset. Where the simulator needs to be modified, it is the responsibility of the asset that enacts the change to ensure costs are provisioned. Implementation of changes should be coordinated with Signals & C&I Operations (Assets). Operations (Assets) would manage the changes via the CRS (Change to Rolling Stock) process for physical changes to the cab environment (for example cab seats). Where Cab Simulators are maintained away from Depot's or Fleet maintenance sites, the supporting infrastructure will be maintained by Stations Operations (Assets).

13.15 DTUP Maintenance Representative and Stakeholders

Depots are comprised of a large number of assets that are managed by three management groups; these are: Depot, Plant & Equipment, Facilities and Premises. Appendix G is references the relevant User Maintenance Representative for the key assets. Lead Operational Representatives are nominated to represent the Depot production and management teams – these Senior Operations (Assets) Fleet management staff have been embedded in the trains and Depot upgrade project teams to deliver fleet domain knowledge and operational experience. They also ensure that engineering or operational designs and solutions are practical, workable and acceptable to the Fleet organisation.

Whilst the nominated Operational Representatives are responsible for representing Operations (Assets) interests for Operation and Maintenance, it is the DTUP project responsibility to ensure that the relevant Sponsor is involved with any business case evaluations regarding whole life cost. Furthermore, where changes to the Operations (Assets) are materially impacted by DTUP project change (for example, changes to operating efficiency or maintenance contracts), the Depot Sponsor should be engaged to support whole life cost evaluation and budget provision.

APPENDIX A - CURRENT MAINTENANCE LEVELS & DESCRIPTIONS

Type	Description
Check	Visual check of system integrity or performance, to look for damage, defects and loose or contaminated equipment and fittings
Casualty maintenance	A maintenance task undertaken outside of a planned maintenance regime to identify the cause of and rectify a fault, for example replacement of a flatted wheel.
Condition maintenance	A maintenance task undertaken to confirm the continued fitness for use of a piece of equipment, e.g. Non-Destructive Testing.
Intrusive maintenance	An activity which includes interference with the operation of a system or equipment, including adjustment of clearances, cleaning, dismantling and changing of components
Kilometres run	The distance a train travels. When used in a train maintenance context it shall include both running in and out of passenger service.
Maintenance	**Description**
Level 1 Train Preparation	Inspection requiring a functional test of specified (mainly safety) equipment in advance of every continuous period of 24hours that the train is available for passenger service.
Level 2 Examination	Examination and service of specified equipment, including train underside from a pit, at interval determined by TMR
Level 3 Shed Day	Inspection, service and on-train maintenance of specified equipment at intervals determined by TMR
Level 4 Programme Lift	Inspection, service and maintenance of specified equipment including exchange of equipment, normally involving separation of car body from bogies, at intervals determined by the TMR
Level 5 Minor Overhaul	Inspection, service and heavy maintenance of specified equipment including replacement of equipment involving separation of the carboy from the bogies defined by the TMR
level 6 Heavy/Major/half- life Overhaul	Inspection, service and major maintenance of specified equipment involving the separation of carboy from bogies and major renewal of equipment and fittings
Level 7	Replacement of equipment requiring off-train maintenance such as compressors on a time cycle independent of the parent train inspection
Post maintenance testing of trains	The combination of tests and checks to assure that a train has been re-assembled correctly and systems are operating as designed.

APPENDIX B - PICCADILLY LINE FLEET 1973 TUBE STOCK MAINTENANCE ASSUMPTIONS

(Extracted From Approved 2015 Train Maintenance Regime)

Level	QP / PI	Activity	Period	Tolerance	Estimated average duty
1	QP.73.01	Train Preparation	24 hours	n/a	455 Km
2	QP.73.02	Exam	400 service hours	+20 hours	8373 Km
3	PI.73.18.11.01.TF	Air conditioning test	21 calendar days	+ 3 days	9551 Km
3	PI.73.16.00.C	Underframe clean	60 calendar days	+28 days	38203 Km
3	QP.73.21	MAR and battery check	90 calendar days	+28 days	38203 Km
3	PI.73.31.15.OP	Inspection of yolk welds on truck sides	Condition Assessed	+28 days	59649 Km
3	PI.73.11.01.I2	Traction motor brush check	105 calendar days	+28 days	47754 Km
3	QP.73.10	Cab Air conditioning	365 calendar days	+28 days	76406 Km (Assuming 168 service days)
3	QP.73.12	Traction Module	5000 service hours	+300 hours	114610 Km
3	QP.73.16	Ambience module	365 calendar days	+28 days	114610 Km
3	QP.73.17	Auxiliary module	252 service days	+28 days	114610 Km
3	QP.73.14	Functional System Test module	252 calendar days	+28 days	114610 Km
3	QP.73.13	System Service module	252 service days	+28 days	114610 Km
3	PI.73.31.03.C	Grid clean	252 calendar days	+28 days	114610 Km
3	QP.73.11	Door module	365 calendar days	+28 days	155087 Km (Assuming 341 service days)
3	PI.73.19.04.04.RR	Compressor cylinder head-change	491 calendar days	+28 days	223762 Km
3	QP.73.15	Major Service	547 calendar days	+28 days	229219 Km (Assuming 504 service days)
3	QP.73.19	De-Icing module	365 calendar days	+28 days	155087 Km (Assuming 341 service days)
3	QP.73.28	Armature carbon brush tensator spring replacement	1460 calendar days	+105	620348 Km (Assuming 341 service days)
3	QP.73.29	Armature bearing greasing	730 calendar days	+56 days	310174 Km (Assuming 682 service days)
3	QP.73.27	Rocking link replacement	1095 calendar days	+84 days	465261 Km (Assuming 341 service days)
4	QP.73.24	Ground Wheel Lathe	730 calendar days	+56 days	310174 Km (Assuming 682 service days)
4	QP.73.04	Programme Lift	4.5 calendar years	+ 6 months	697891 Km
4	QP.73.04	Wheel-set Overhaul	4.5 calendar years	+ 6 months	697890 Km
5	QP.73.06	Heavy Overhaul	9 calendar years	+ 12 months	1395781 Km

APPENDIX C - BAKERLOO LINE FLEET 1972 TUBE STOCK MAINTENANCE ASSUMPTIONS

(Extracted From Approved 2015 Train Maintenance Regime)

Level	QP/PI or Standard	Activity	Frequency	Tolerance	Facilities
1	RSE-ST-04001	Train Preparation	24 Hours	Nil	
1		Litter Pick /	As required	Nil	
1		Sweep and Dust	24 Hours	Nil	
2	RSE-ST-04002	Cab AHU filter change	14 Days	+ 5 Days	
2		Examination	28 days	Nil	
3	E6823	Battery Maintenance	6 Weeks	7 Days	
3		Traction and Aux Maintenance	18 Weeks	+ 28 Days	
3		Winterisation and Summerisation	26 weeks	+ 18 Days	
3		Shed Day	36 weeks	+ 28 Days	
3		Door Maintenance	52 Weeks	+ 36 Days	
3		Static Converter cleaning	2 years	+ 28 Days	
4		Programme Lift	2.5 Years	+ 6 Months	
4		Safety critical relays	4.5 Years	+ 6 Months	
4		Static converter filter and earth Test	4.5 Years	+ 6 Months	
5		Mini Overhaul	7 Years	+ 9 Months	
5		Heavy Overhaul	9 years	+ 12 months	

7		Compressor overhaul (TBC38Z)	3 Years	+ 6 months	
7		Compressor overhaul (3HC43)	4 Years	+ 6 Months	
7		Traction Motor overhaul	6 Years	+ 12 Months	
7		Motor Alternator overhaul	6 Years	+ 12 Months	
7		Static converter overhaul	10 Years	+ 12 Months	
		Wheelset Ultrasonic Axle Testing	4.5 Years	+ 6 months	
		Routine Brake Test	3 Years	0 Days	
		Standard clean	14 days	3 Days	
		Under-frame clean	9 Weeks	6 Days	
		Under-seat clean	36 weeks	+ 10 Days	
		Train Wash	N/A		

APPENDIX D - CENTRAL & WATERLOO & CITY LINES – 92 TUBE STOCK MAINTENANCE ASSUMPTIONS (NOTE: EXTRACTED FROM APPROVED 2015 TRAIN MAINTENANCE REGIME)

Level	QP/PI or Standard	Activity	Frequency	Tolerance
1	RSE-ST04001 Level 1	Train Preparation	24 Hours	0 hours
2	RSE-ST 04001 Level 2	28 Day Exam QP02	26 Days (Service Days)	+ 2 Days (Service Days)
3	To supplement E6823 Level 3	Batteries QP06	2 Month (61 Days)	+ 18 Days
3	E6823 Level 3	Modular Maintenance Modules [4] QPMM1-QPMM6 [Central] QPMM5 – QPMM6 [W&C]	Yearly (365 days)	+ 90 Days
3	To supplement E6823 Level 3	Door Maintenance QP16	Yearly (365 days)	+ 36 Days
3	To supplement E6823 Level 3	Door Bond Inspection QP35	Yearly (365 days)	+ 36 Days
3	To supplement E6823 Level 3	Door Interlock Inspection QP37	Yearly (365 Days)	+ 36 days
3	To supplement E6823 Level 3	Door Force Gauge & Gapping QP45	Yearly (365 Days)	+ 36 days
3	To supplement E6823 Level 3	Air Conditioning Maintenance QP08 Heat & Ventilation check QP46	Yearly (365 Days)	+ 36 days
3	To supplement E6823 Level 3	ATO/ATP check & Emergency Brake Release Test MY84c	Yearly (365 Days)	+ 36 days
3	To supplement E6823 Level 3	Compressor Service AP04 (Central Line Only)	2.5 Years (913Days)	+ 3 months (91 days)

Level	QP/PI or Standard	Activity	Frequency	Tolerance
4		Programme Lift	6 Years (2190 Days)	+ 6 Months (+183 Days)
5		Minor Heavy Overhaul	12 Years (4380 Days)	+ 1 Year (365 Days)
5		Door Overhaul	14 Years (5110 Days)	0 Days
6		Major Heavy Overhaul	18 years (6570 Days)	+ 2 Years (730 Days)
7		Motor Overhaul	4.5 Years (1643 Days)	+ 6 Months (183 Days)
		Motor Light Overhaul	As Required	
7	E6340	Wheelset Overhaul	6 Years (2190 Days)	+ 6 Months (183 Days)
		Gearbox Overhaul	8 Years (2920 Days)	0 Days
		Compressor Overhaul (Central Line)	5 Years (1825 Days)	+ 6 Months (183 Days)
		Compressor Overhaul (W&C)	1.5 Years (548 Days)	+ 55 Days
	Additional Maintenance	Light Tube Replace	3 Yearly (1095 Days)	+ 4 Months (122 Days)
		Bogie Fixing Check QP52	6 Monthly (183 Days)	+ 18 Days
		NDT Schedule QP53 (No current Activities)	6 Monthly (365 Days)	+ 36 Days
		Gearbox Oil Change QP31	Yearly (365 Days)	+ 36 Days
		Intercar Barrier QP49	Yearly (365 Days)	+ 36 Days
		Windows Security Checks QP19 (Waterloo & City	3 Months (91 Days)	+ 9 Days

Level	QP/PI or Standard	Activity	Frequency	Tolerance
		Only)		
		Gearbox & Motor Security Checks QP55	14 Days (Service Days)	3 Days (Service Days)
	Train Radio	Planned work carried out by Connect LU Fleet Staff Replace LRU	Yearly (365 Days)	+36 Days
		Cleaning – Major Clean (Interior)	21 Days	+ 3 Days
		Cleaning – Underframe Clean	20 Weeks (140 Days) (Service Days)	+ 14 Days (Service Days)
		Cleaning Train Wash	3 Days	+ 0 Days

APPENDIX E - DTUP TUBE STOCK - MAINTENANCE INTERVENTIONS AND SUPPORTING FACILITIES

	NTfL Frequency		Piccadilly Line										Waterloo & City Line				Bakerloo Line						Central Line													
			Cockfosters Depot						Northfields Depot				Waterloo Depot				Stonebridge Park Depot						Hainault Depot						Ruislip Depot							
Activity	S-Stock equivalent frequency	Overhaul?	Initial State for 1973 ts	Existing Facility For 1973 ts Maintenance	Requirement For Migration 1973 ts	Requirement for Migration NTfL ts			Initial State for 1973 ts	Initial State for 1973 ts	Requirement For Migration 1973 ts	Requirement for Migration NTfL ts																								
Pre Service check	24hrs		73	Any	73	ntfl			73	Any	73	ntfl		92	Any			72	Any	72	ntfl	ntfl	ntfl		92	Any	92	ntfl	ntfl		92	Any	ntfl	ntfl	ntfl	ntfl
Balanced Exam A,B and C	25,000 kms		73	Centre Pitted roads with Shallow side Pits	73	ntfl			73	Centre Pitted roads with Shallow side Pits	73	ntfl		92				72	Centre Pitted roads with side Pits	72	ntfl	ntfl	ntfl		92	Centre Pitted roads with Shallow side Pits	92	ntfl	ntfl		92		ntfl	ntfl	ntfl	ntfl
Underframe Clean	50,000 kms		73	Road 46 - (Centre Pitted Road with Shallow Side Pits Centre- Pitted road min)	73	ntfl				N/A	73	ntfl		92				72	Road 32 Road - Centre Pit road with Side Pits Nomiated for underframe clenaing	72	ntfl	ntfl	ntfl		92	Road 46 - (Centre Pitted Road with Shallow Side Pits Centre- Pitted road min)	92	ntfl	ntfl			N/A				
Modular Shed Exam	150,000 kms		73	Centre Pitted roads with Shallow side Pits	73				73	Centre Pitted roads with Shallow side Pits	73			92				72	Centre Pitted roads with side Pits	72		ntfl	ntfl		92	Centre Pitted roads with Shallow side Pits	92		ntfl		92		92		ntfl	ntfl
Annual Door Maintenance	150,000 kms		73	Road 52 - (Centre Pitted road) with Shallow side Pits	73	ntfl			73	Road 17 - (Centre Pitted road) with Shallow side Pits	73	ntfl		92				72	Road 31 - Centre Pitted road side Pits	72	ntfl	ntfl	ntfl		92	Road 52 - (Centre Pitted road with Shallow side Pits	92	ntfl	ntfl		92		92	ntfl	ntfl	ntfl
2 Yearly Exam	300,000 kms			N/A						N/A					N/A						ntfl	ntfl	ntfl			N/A		ntfl	ntfl		No	N/A		ntfl	ntfl	ntfl
Sand filling	Reactive			N/A						N/A					N/A						ntfl					N/A		ntfl	ntfl		No	N/A		ntfl	ntfl	ntfl
De Icer filling	Reactive		73		73	ntfl			73	De-icing refilling undertaken on XX Road	73	ntfl			N/A			72	De-icing refilling undertaken on 45 Road	72	ntfl	ntfl	ntfl		92	De-icing refilling undertaken on 55 Road	92	ntfl	ntfl		ntfl	De-icing refilling undertaken on 36 & 37 Road	ntfl	ntfl	ntfl	ntfl
De Icer Removal	Annual					ntfl					ntfl				N/A						ntfl	ntfl	ntfl					ntfl	ntfl					ntfl	ntfl	ntfl
Screen Wash refill	8 days			N/A		ntfl				N/A	ntfl				N/A				N/A		ntfl	ntfl	ntfl			N/A		ntfl	ntfl			N/A		ntfl	ntfl	ntfl
HVAC Clean	300,000 kms		73 Cab Only	N/A	73 Cab Only	ntfl			73 Cab Only	N/A	73 Cab Only	ntfl		92 Cab Only	N/A			72 cab only	N/A	72 cab only	ntfl	ntfl	ntfl		92 Cab Only	N/A	92 Cab Only	ntfl	ntfl		92 Cab Only	N/A	92 Cab Only	ntfl	ntfl	ntfl
Wheel Turning	18 monthly			N/A					73	Wheel lathe 20 Road	73	ntfl			N/A				N/A		ntfl	ntfl	ntfl			N/A		ntfl	ntfl		92	N/A	92	ntfl	ntfl	ntfl
Planned lifting Light	762,000 kms	Y	73	Lifting Road (53 & 54 Road)	73	ntfl			73	Lifting Road (20 & 21 Road)	73	ntfl	Y	92	Lifting Road		Y	72	Lifting Road (37 & 38 Road)	72	ntfl	ntfl	ntfl	Y	92	Lifting Road (63 & 64 Road)	92	ntfl	ntfl		92	Lifting Road (51 ,52 & 53 Road East)	92	ntfl	ntfl	ntfl
Planned Lift Heavy	1524,000 kms	Y	73	Lifting Road (53 & 54 Road)	73	ntfl			73	Lifting Road (20 & 21 Road)	73	ntfl	Y	92	Lifting Road		Y	72	Lifting Road (37 & 38 Road)	72	ntfl	ntfl	ntfl	Y	92	Lifting Road (63 & 64 Road)	92	ntfl	ntfl		92	Lifting Road (51 ,52 & 53 Road East)	92	ntfl	ntfl	ntfl
Traction Brake Controller Overhaul	762,000 kms	Y	73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl			73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl	Y	92			Y	72	Centre Pitted roads with side Pits	72	ntfl	ntfl	ntfl	Y	92		92	ntfl	ntfl		92	Centre Pitted/ Centre Pitted Roads with Shallow side P ts	92	ntfl	ntfl	ntfl
Planned HVAC Removal	1905,000 kms	Y		N/A		ntfl				N/A	ntfl		Y		N/A		Y		N/A		ntfl	ntfl	ntfl	Y		N/A		ntfl	ntfl			N/A		ntfl	ntfl	ntfl
Gangway Overhaul / Intercar Jumper	1270,000 kms	Y		N/A	73	ntfl				N/A	ntfl		Y		N/A		Y		N/A	72	ntfl	ntfl	ntfl	Y		N/A		ntfl	ntfl			N/A		ntfl	ntfl	ntfl
Coupler / Semi Perm Coupler Overhaul	1270,000 kms	Y	73	Centre Pitted/ Centre Pitted roads with Shallow side Pits		ntfl			73	Centre Pitted/ Centre Pitted roads with Shallow side Pits		ntfl	Y	92			Y	72	Centre Pitted roads with side Pits		ntfl	ntfl	ntfl	Y	92			ntfl	ntfl		92	Centre Pitted/ Centre Pitted roads with Shallow side P ts	92	ntfl	ntfl	ntfl
Planned Door Overhaul	1524,000 kms	Y		Road 52 - (Centre Pitted road) with Shallow side Pits	73	ntfl				Road 17 - (Centre Pitted road) with Shallow side Pits		ntfl	Y		N/A		Y		N/A	72	ntfl	ntfl	ntfl	Y			92	ntfl	ntfl		92	N/A		ntfl	ntfl	ntfl
Casualty repair above floor	Reactive		73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl			73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl		92				72		72	ntfl	ntfl	ntfl		92		92	ntfl	ntfl		92		ntfl	ntfl	ntfl	ntfl
Casualty repair below floor	Reactive		73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl			73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl		92				72		72	ntfl	ntfl	ntfl		92		92	ntfl	ntfl		Yes		ntfl	ntfl	ntfl	ntfl
Casualty Door removal	Reactive		73	Road 52 - (Centre Pitted road) with Shallow side Pits	73	ntfl			73	Road 17 - (Centre Pitted road) with Shallow side Pits	73	ntfl		92				72			ntfl	ntfl	ntfl		92			ntfl	ntfl		Yes		ntfl	ntfl	ntfl	ntfl
Small and Large Raft removal	Reactive			N/A		ntfl				N/A	ntfl				N/A				N/A		ntfl	ntfl	ntfl			N/A		ntfl	ntfl		92	N/A	92	ntfl	ntfl	ntfl
Propulsion software updates	2286,000 kms	Y		N/A	73	ntfl				N/A	73	ntfl	Y	92	N/A		Y		N/A		ntfl	ntfl	ntfl	Y	92		92	ntfl	ntfl		92	N/A	92	ntfl	ntfl	ntfl
Seating Overhaul (Saloon, T/Op)	1524,000 kms	Y	73	Cleaning Shed Road A Flat Road	73	ntfl			73		73	ntfl	Y	92			Y	72		72	ntfl	ntfl	ntfl	Y	92	Cleaning Shed Road A Flat Road	92	ntfl	ntfl		92		92	ntfl	ntfl	ntfl
Exterior Lighting (OSDIL / De Icer)	1524,000 kms	Y	73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl			73	Centre Pitted/ Centre Pitted roads with Shallow side Pits	73	ntfl	Y	92			Y	72	Centre Pitted/ Centre Pitted roads w th Shallow side Pits	72	ntfl	ntfl	ntfl	Y	92	Centre Pitted/ Centre Pitted roads with Shallow side Pits	92	ntfl	ntfl		Yes		92	ntfl	ntfl	ntfl
De Icing tank overhaul	1524,000 kms	Y				ntfl					ntfl		Y		N/A		Y	72		72	ntfl	ntfl	ntfl	Y	92				ntfl						ntfl	ntfl
Casualty repair HV AC	Reactive					ntfl				N/A	ntfl								N/A		ntfl	ntfl	ntfl					ntfl	ntfl			N/A		ntfl	ntfl	ntfl
Train Wash	4 days		73	Train Wash on Depot Entry/Exit coackfosters End of Depot	73	ntfl				N/A				92	N/A			72	Train Wash on Road 21 Depot Exit Road	72	ntfl	ntfl	ntfl		92		92	ntfl	ntfl		No		No	TBC	TBC	TBC
Train Hand bash	TBC		73	Cleaning Shed Roads B & C	73	ntfl			73	Roads 18 &19	73	ntfl		92				72	Roads 39,40,41 42,43 &	72	ntfl	ntfl	ntfl		92	Cleaning Shed Roads A, B & C	92	ntfl	ntfl		TBC	N/A	TBC	TBC	TBC	TBC
Floor Polish	TBC		73	Cleaning Shed Roads B & C	73	ntfl			73	Roads 18 &19	73	ntfl		92				72	Roads 39,40,41 42,43 &	72	ntfl	ntfl	ntfl		92	Cleaning Shed Roads A, B & C	92	ntfl	ntfl		TBC	N/A	TBC	TBC	TBC	TBC
Glazing Descale	75,000 kms		73	Cleaning Shed Roads B & C	73	ntfl			73	Roads 18 &19	73	ntfl		92				72	Roads 39,40,41 42,43 &	72	ntfl	ntfl	ntfl		92	Cleaning Shed Roads A, B & C	92	ntfl	ntfl		TBC	N/A	TBC	TBC	TBC	TBC
Litter pick	24hrs		73	Any	73	ntfl			73	Any	73	ntfl		92				72	Any	72	ntfl	ntfl	ntfl		92	Any	92	ntfl	ntfl		TBC	N/A	TBC	TBC	TBC	TBC

APPENDIX F - NOTIONAL TRAIN CLEANING REGIME (GOOD PRACTICE)

Types of Clean	No of Units per Week	Frequency	Shift
Pre-Service	All service trains	24 Hourly	Days/Nights
Deep Cab Cleans	40	2 Weekly	Days
Seat Well Cleans	10	15 weeks	Days
Standard Clean	60	14 Days	Nights
MSS Clean	70	Weekly	Nights
Modular (+ "I" Clean)	60	14 Days	Days
Under frame	10	15 Weekly	Nights
Exterior Wash Manual	30	2.5 Weekly	Days/Nights
Exterior Wash Auto		3 Days	Days
In Service Litter Pick	All service trains	Daily	Days/Lates
Paper Re-cycling	All service trains	Daily	Days/Lates/Nights
Siding Accommodation	7 nights	Nightly	Nights

APPENDIX G - BASELINE OF EXISTING FLEET & DEPOTS OPERATION

1. The Current Fleet & Depots Operation - Initial Migration State

1.1 Current Fleet Organisation

The current Fleet organisations for the DTUP lines to be upgraded are run as separate operations. The Bakerloo, Central and Waterloo & City Lines are organised under the BCV grouping, with the Piccadilly Line under the JNP grouping.

The history of the organisation over the last fifteen years resulted in BCV and JNP being operated as separate commercial asset management companies while the Public– Private Partnership (PPP) was in operation. This period of operation has resulted in differences in asset management approach, structure of support services and asset management support systems before those organisations re-migrated to closer relationships back within the TfL group of companies.

1.2 Current Train Maintenance Regimes

The existing Train Maintenance Regimes (TMR) give details of the preventative, supplementary, cleaning and testing activities planned for each stock. For the purpose of capacity modelling, a summary of the current key levels of maintenance is shown in Appendix A. Activities, frequencies and facility requirements for 73TS (Piccadilly Line), 72TS (Bakerloo Line) and 92TS (Central & Waterloo and City Lines) Stock are given in Appendix B, Appendix C & Appendix D.

1.3 Current Depot Operations

1.3.1 Current Train Movement Summary

The current headway injection to service rate from DTUP Depots based on the current peak (as of December 2015) is as follows:

Line	Location	East End of Depot	No	West End OF Depot	No
Piccadilly Line	(East) Cockfosters Depot	East to Cockfosters AM -	22	West to Oakwood AM	12
		West From Cockfosters PM	22	East From Oakwood PM	12
	(West) Northfields Depot	East to Northfields AM	24	West To Boston Manor AM	10
		West From Northfields PM	24	East From Boston Manor PM	10
Central Line	(East) Hainault Depot	To Grange Hill	7	To Hainault -	27
		From Grange Hill	7	From Hainault	27
	(West) Ruislip Depot	East to Ruislip Gardens AM	8	West To West Ruislip AM	9
		West From Ruislip Gardens PM	8	East From West Ruislip PM	9
Bakerloo Line	Stonebridge Park Depot	To Stonebridge AM	12		
		From Stonebridge PM			
Waterloo Depot	Waterloo Depot	To Waterloo AM - 5 From Waterloo PM - 5			

1.4 Piccadilly Line Fleet Maintenance Operation

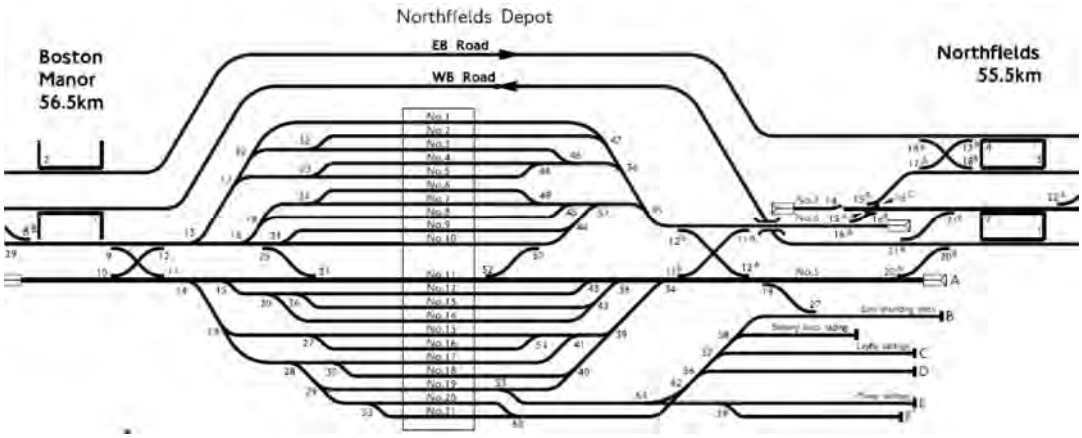
Northfields Depot – Existing Maintenance Facilities & Function				
Road Number	**Location**	**Current Road Type & Length (m)**		**Current Function / Notes**
1	Maintenance Shed	Centre Pit	129	General Maintenance Used for Track Recording Train
2	Maintenance Shed	Centre Pit	129	General Maintenance
3	Maintenance Shed	Centre Pit	129	General Maintenance
4	Maintenance Shed	Centre and Shallow Side Pits	129	General Maintenance
5	Maintenance Shed	Centre and Shallow Side Pits	129	General Maintenance
6	Maintenance Shed	Centre and Side Pitted Calibrated Road	129	General Maintenance
7	Maintenance Shed	Centre and Side Pitted Calibrated Road	129	General Maintenance
8	Maintenance Shed	Centre and Shallow Side Pits	129	General Maintenance
9	Maintenance Shed	Centre Pit	129	General Maintenance
10	Maintenance Shed	Centre and Shallow Side Pits	129	General Maintenance
11	Maintenance Shed	Centre and Shallow Side Pits	129	General Maintenance
12	Maintenance Shed	Centre Pit	129	General Maintenance
13	Maintenance Shed	Centre Pit	129	General Maintenance
14	Maintenance Shed	Centre Pit	129	General Maintenance

15	Maintenance Shed	Centre Pit	129	General Maintenance
16	Maintenance Shed	Centre Pit	129	General Maintenance
17	Maintenance Shed	Centre Pit	129	Door Road Brakes Overhaul
18	Cleaning Road	Above solebar Cleaning Road	129	Door Road , General interior clean , Deep interior clean Platform currently only on one side of train so only interior cleaning is possible
19	Cleaning Road	Above solebar Cleaning Road	129	Door Road General interior clean Deep interior clean, Exterior clean - Hand bashing
20	Lifting Shed & Wheel Lathe	Overhead Crane Lifting Road	113	Heavy Overhaul Brakes Overhaul, NDT Testing
21	Lifting Shed	Overhead Crane Lifting Road	113	Heavy Overhaul Brakes Overhaul, NDT Testing

The 1973 Tube Stock (86.5 trains) is maintained between the two Depots located at the eastern end (Cockfosters) and the central western side (Northfields), with the fleet maintained under the management of the JNP team. Both Depots are equipped to undertake all levels of maintenance. There are some modular maintenance activities that are focused at either Northfields & or Cockfosters to balance efficiency. Equipment overhauls are undertaken at a centralised overhaul workshop run by London Underground at Acton, called the Railway Engineering Workshop (REW) and also by other external suppliers. There is currently a life extension project in progress for the fleet that has included a bogie project and floor covering replacement and extended bogie overhaul. There may be further life extension projects leading up to fleet replacement.

1.4.1 Northfields Depot

Northfields Depot is located on the western side of the Line on the Heathrow Branch. It is a double-ended Depot with a central complex of facilities that is unique, in that the Depot facilities extend across the entire width of the Depot. Its general layout is shown in the diagram below:

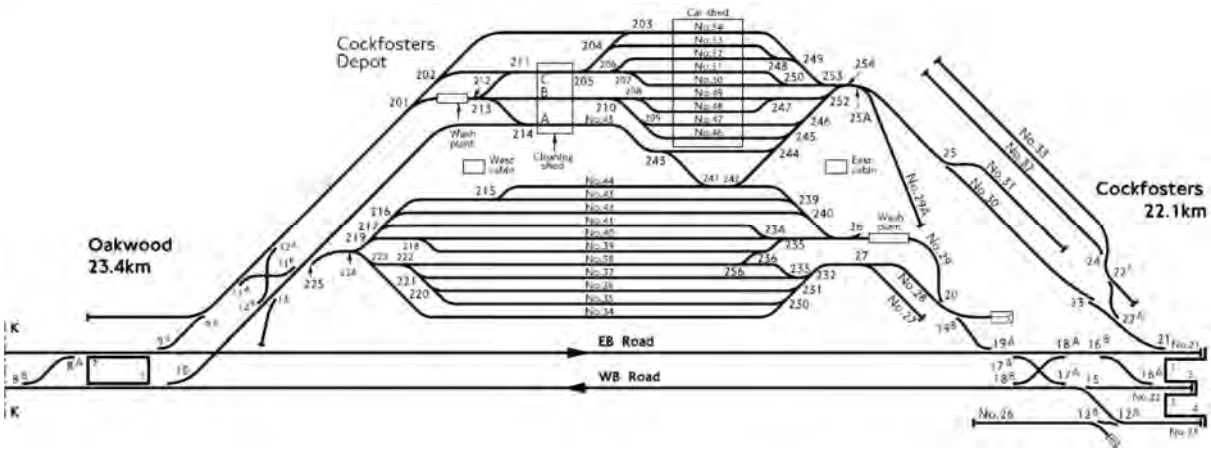


Train movements are currently controlled by hand worked points using a ground shunter past the inlet/outlet roads, which are trailing when exiting the Depot. The heavy maintenance facilities (currently 20 & 21 roads) include a two road lifting facility with an overhead crane to facilitate a single car lift on to car stands. Road 20 also has a single headed underfloor wheel lathe to undertake planned condition turning in addition to casualty wheel turning. There are two dedicated above solebar cleaning roads (18 Road – single sided & 19 Road - double sided).

The remaining seventeen roads are a mixture of centre-pitted roads with no side pits and centre pitted roads with shallow and narrow side pits from which general exam and inspection activities are undertaken. Road 17 has a dedicated crane to facilitate door maintenance and overhaul. Space between pitted roads is typically 1.9m between carbodies. Number 1 road is currently used for the maintenance and stabling of the Track Recording train, new Asset Inspection Train and is also used to stable trains from other parts of the network that have been transferred for testing on the South Ealing test track. The full summary of facilities is shown in the following table:

1.4.2 Cockfosters Depot

Cockfosters Depot is located at the eastern end of the Line and is a double ended Depot with a defined separate triple train length stabling area (30 berths) and an area containing the maintenance facilities consisting of a central shed and separate cleaning shed. Its general layout is shown in the diagram below.



Train movements are currently controlled by hand worked points using a ground shunter past the inlet/outlet roads, which are trailing when exiting the depot.

The Heavy maintenance facilities (53 & 54 road) include a two road lifting facility with overhead crane to facilitate a single car lift onto car stands. Within this facility there is currently a configuration to undertake a bogie overhaul project on 73TS, which includes a bogie jig and a welding plant.

The remaining seven roads in the main shed are a mixture of centre-pitted roads and centre pitted roads with shallow and narrow side pits from which general exam and inspection activities are undertaken. Road 46 is generally dedicated as an underframe-cleaning road. . Typical space between pitted roads is 1.9 m.

There is a separate dedicated cleaning shed (Roads A, B & C). Road A is configured as a flat road and has been recently used as the facility for flooring replacement on 73TS. Of the remaining two above solebar cleaning roads only one is used for cleaning. The full summary of facilities is shown in the following table.

There is an automatic train wash with water harvesting system located at the east end of the Depot (Cockfosters end) to support the requirements for exterior train cleaning. De-icing refill is undertaken on a multiple number of outside roads including 45 road.

Cockfosters Depot – Existing Maintenance Facilities & Function				
Road Number	Position	Current Road Type & Length (m)		Function / Notes
46	Maintenance Shed	Underframe Cleaning Road	129	Underframe clean
47	Maintenance Shed	Centre and Deep Side Pits	129	General Maintenance Door faults, Brake faults, Traction faults, Auxiliary faults and any other faults that do require access using side pits as agreed with an ATM and the DDM
48	Maintenance Shed	Centre Pit	129	General Maintenance
49	Maintenance Shed	Centre Pit	129	General Maintenance
50	Maintenance Shed	Centre and Side Pitted Calibrated Road	129	Compressor replacement Door faults, Brake faults, Traction faults, Auxiliary faults and any other faults that do require access using side pits as agreed with an ATM and the DDM. Manipulator within the centre pit to remove items such as compressor
51	Maintenance Shed	Centre and Side Pitted Calibrated Road	129	Compressor replacement Door faults, Brake faults, Traction faults, Auxiliary faults and any other faults that do require access using side pits as agreed with an ATM and the DDM. Manipulator within the centre pit to remove items such as compressor.
52	Maintenance Shed	Centre and Shallow Side Pits	126	Door Exam , Door Overhaul , Door faults, Brake faults, Traction faults, Auxiliary faults and any other faults that do require access using side pits as agreed with an ATM and the DDM.
53	Lifting Shed	Overhead Crane Lifting Road	118	Heavy Overhaul , NDT Testing , Brakes Overhaul
54	Lifting Shed	Overhead Crane Lifting Road	118	Heavy Overhaul , NDT Testing, Brakes Overhaul

Cockfosters Depot – Existing Maintenance Facilities & Function				
Road Number	Position	Current Road Type & Length (m)		Function / Notes
A	Cleaning Shed	Flat Road	n/a	Currently used for overhaul of components, e.g. seat exchange.
B	Cleaning Shed	Above solebar Cleaning Road	n/a	General interior clean , Deep interior clean Exterior clean - hand bashing
C	Cleaning Shed	Above solebar Cleaning Road	n/a	General interior clean, Deep interior clean , Exterior clean - hand bashing

1.5 Waterloo & City Line Fleet Maintenance Operation

The Waterloo and City line fleet maintenance operation is managed under the Central Line BCV fleet management team.

The asset wear cycle is not high, however, it has a significantly higher number of direction changes compared to other lines and this for example, means that cab equipment suffers greater wear than is experienced on other lines.

1.5.1 Waterloo Depot

The five 1992 Tube Stocks that are captive to the Waterloo and City line are maintained in the tightly constrained Waterloo Depot. It has equipment to undertake all levels of maintenance but does not currently have a wheel lathe. Wheelsets that require turning are removed and transported to REW.

Waterloo Depot consists of two maintenance roads (roads 2 & 3) which are located closest to the Depot staff facilities and pedestrian entrance to the Depot.

Both maintenance roads have centre pits which give staff access to the underside of the train for light maintenance tasks and inspections. The pit on road 3 is of sufficient length to gain access beneath a full train (i.e. a 4-car unit) but the pit on road 2 is only long enough for a 2-car unit.

Road 3 has side pits to both sides of the train of sufficient length for access to a single car only. Road 2 has an in floor lift installed that has the capability to undertake a 2-car synchronised lift of a unit to enable bogies to be removed. The trains can be split into individual cars if necessary to access the couplers and other inter-car equipment.

There are 2 overhead cranes to manipulate bogies or heavy equipment over the area of roads 2 and 3 (coverage is broadly from the end wall up to 2-cars along the Depot, i.e. under the higher, pitched roof section). These cranes enable components to be moved to the area closest to the Depot staff facilities (road 1) where there are further cranes / a bogie turn-table to allow components to be moved up and out of the Depot on the back of a lorry.

The Depot has Mobile Access Platforms (MAPs) available which can be positioned to enable access for door maintenance or to gain access to the side of the train. There is a vacuum system located on the area of road 1 to allow interior cleaning. An automatic train wash is located on road

5, with other routine activities such as litter picking and interior train cleaning are undertaken on stabling roads 5 and 6.

Over-head power leads (jumpers) are provided to power the trains when stabled on roads 2 and 3. The switchgear and supply equipment is located at the northern end of road 1.

Waterloo Depot – Existing Maintenance Facilities & Function				
Road Number	**Position**	**Road Type & Length (m) Current**		**Current Facility Capability Function / Notes**
1	Maintenance Shed	Flat Road with Bogie Turntable	n/a	
2	Maintenance Shed	2 - Car synchronised Lifting Road	50	Heavy Planned & Casualty Maintenance.
3	Maintenance Shed	Centre and Deep Side Pits	63	General Maintenance & Inspection.
5	Automatic Train Wash Road	Automatic train Wash		

1.6 Bakerloo Line

The Bakerloo Line fleet is managed under the BCV Fleet management team

1.6.1 Stonebridge Park Depot

The 36 1972 Mark II tube stocks that operate the Bakerloo Line are maintained from Stonebridge Park Depot a single ended Depot. It is located at the central northern end of the line which is LU owned and operated but connected to the Network Rail controlled main line infrastructure section known as the “Watford DC” Lines outside the Depot limits. The infrastructure reverts to London Underground ownership North of Queens Park.

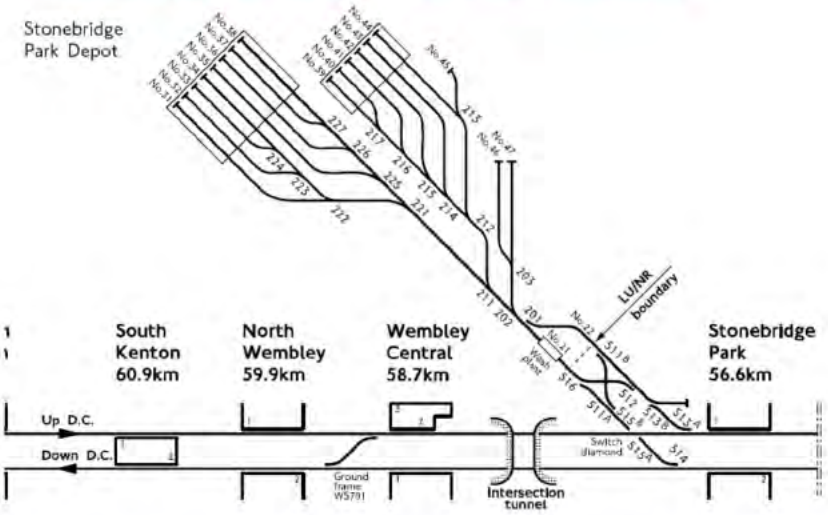
All levels of planned and casualty maintenance including programme lift and overhaul are undertaken within the Depot. Component overhauls are undertaken centrally at REW with support from other external suppliers. The Depot operation today is not able to undertake wheel-turning activities on site and therefore trains have to be lifted and wheel sets sent to the REW for this task to be completed.

There is additionally the first phase (2015) of a life extension overhaul programme to undertake weld and corrosion repairs to the fleet. This overhaul is being undertaken at REW Acton with the trains being moved by rail or by road using a newly constructed transfer ramp in the Depot. There may be a second overhaul phase that includes RVAR modifications before the DTUP programme, but the scope and extent of this overhaul is still under discussion and development.

The Bakerloo Line is physically connected to the Jubilee Line at Baker Street, however obtaining paths for moves between other maintenance locations around the network entails a long transfer time and is difficult to plan. Train movements are currently controlled by a tower within the Depot which operates powered points. These interface with the Network Rail Signalling Centre. Depot maintenance facilities comprise of two main sheds consisting of an eight-road maintenance shed and a six road cleaning shed. The heavy maintenance facilities (37 & 38 road) include a two road lifting facility with overhead crane to facilitate single car lift on to car stands.

The remaining six roads in the main shed are all centre-pitted roads with deeper and wider side pits that undertake general exam and inspection activities with a typical space between the roads of 2.4m. Road 32 is generally dedicated for underframe-cleaning road and 31 road is dedicated to door maintenance and overhaul.

There is a separate dedicated above solebar cleaning shed consisting of six roads (Roads 39-44) and an automatic train wash to support the requirements for exterior train cleaning on 31 road. Note: The Bakerloo Line does not currently have the capability for wheel turning facilities on site and this has caused severe challenges to maintenance delivery.

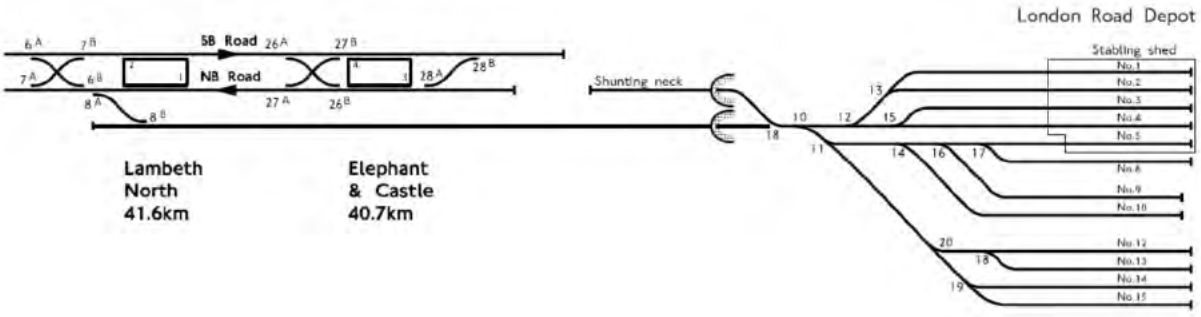


Stonebridge Park Depot – Existing Maintenance Facilities & Function				
Road Number	**Road**	**Current Road Type & Length (m)**		**Function / Notes**
31	Maintenance Shed	Centre and Deep Side Pits	116	Door Exam , Door Overhaul Door Rd Mobile Access Platforms are used.
32	Maintenance Shed	Underframe Cleaning Road	116	Underframe clean Access to the under frame to remove dirt.
33	Maintenance Shed	Centre and Deep Side Pits	116	General Maintenance
34	Maintenance Shed	Centre and Deep Side Pits	116	General Maintenance
35	Maintenance Shed	Centre and Deep Side Pits	116	General Maintenance
36	Maintenance Shed	Centre and Deep Side Pits	116	General Maintenance
37	Lifting Shed	Overhead Crane Lifting Road	116	Heavy Overhaul , NDT Testing , Lifting roads are also used for weld repairs etc.

Stonebridge Park Depot – Existing Maintenance Facilities & Function				
Road Number	**Road**	**Current Road Type & Length (m)**		**Function / Notes**
38	Lifting Shed	Overhead Crane Lifting Road	116	Heavy Overhaul , NDT Testing ,Lifting roads are also used for weld repairs etc.
39	Cleaning Shed	Above solebar Cleaning Road	n/a	Gentle interior clean Deep interior clean Exterior clean - hand bashing Inside Carriage Cleaning
40	Cleaning Shed	Above solebar Cleaning Road	n/a	
41	Cleaning Shed	Above solebar Cleaning Road	n/a	
42	Cleaning Shed	Above solebar Cleaning Road	n/a	
43	Cleaning Shed	Above solebar Cleaning Road	n/a	
44	Cleaning Shed	Above solebar Cleaning Road	n/a	Graffiti cleaned on Road 44 as it has drainage

1.6.2 London Road Depot

London Road Depot has limited older maintenance facilities generally not up to modern standards and is only used as a location for level 1 maintenance - train preparation, daily interior cleaning and emergency casualty investigation. Points within London Road Depot are hand-worked and manually operated by a ground shunter past the shunt neck.



1.7 Central Line

The 1992 Tube Stock (87 trains) are maintained between the two Depots located at the eastern end (Hainault) and the western End (Ruislip). Both Depots are equipped to undertake all levels of maintenance however some activities are focused at either Ruislip or Hainault. REW and other external suppliers undertake equipment overhauls. There is currently (2015) a significant life extension project planned to improve reliability and extend the life of the fleet until replacement with the DTUP fleet.

1.7.1 Hainault Depot

Hainault Depot is located at the Eastern End of the Line on a circular section of the Central Line known as the Hainault Loop. It is a double-ended Depot with a defined separate double length stabling area (30 x berths) and area containing the maintenance facilities consisting of a central shed and separate cleaning shed. Its general layout is shown in the diagram below.

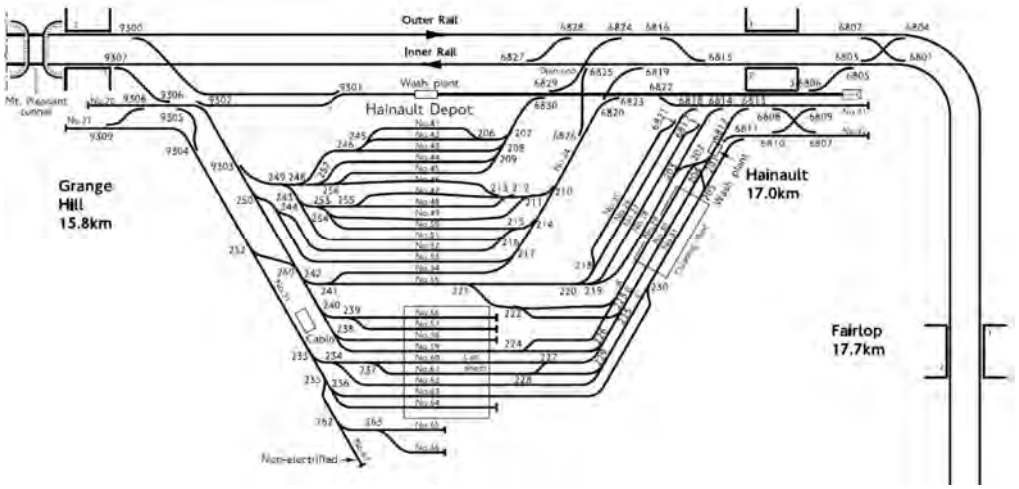
Train movements are currently controlled by hand worked points using a ground shunter past the inlet/outlet roads, which are trailing when exiting the Depot.

Within the main shed the heavy maintenance facilities (60 road & 44 road) include a two road lifting facility with overhead crane and on floor synchronised jacks to facilitate double car lifting under body with bogies strapped

The six roads 57 – 62 are a mixture of centre-pitted roads and centre pitted roads with wider and deeper side pits that undertake general exam and inspection activities. Roads 60 & 61 are currently calibrated roads. Typical space between pitted roads is 1.9 m

Road 56 is a dedicated vacuum plant facility built to resolve the design issues of dust build up in the ventilation ducting of 92 TS, which have also been experienced on subsequent fleets. There is a separate dedicated cleaning shed (Roads A, B & C) that are all configured as above solebar cleaning roads within all activities of this type currently undertaken at Hainault for the whole fleet.

There are two exterior automatic train washes located at both the East and West ends of the Depot to support the requirements for exterior train cleaning. De-icing refill is undertaken on 55 road. The full summary of facilities is shown in the following table. The east end 1962TS Sandite train is operated, refilled and maintained from Hainault during the leaf fall season from September – December.



Hainault Depot – Existing Maintenance Facilities & Function				
Road Number	**Position**	**Road Type & Length (m) Current**		**Function / Notes**
56	Maintenance Shed	Enclosed Vacuum Road	133	Deep interior clean and cleaning of ventilation system
57	Maintenance Shed	Centre and Deep Side Pits	133	General Maintenance including Car Heights, auto coupler height setting, Traction faults, Auxiliary faults and other faults
58	Maintenance Shed	Centre and Deep Side Pits	136	General Maintenance including Car Heights, auto coupler height setting, Traction faults, Auxiliary faults and other faults
59	Maintenance Shed	Centre Pit	133	General Maintenance including Gearbox oil changes, battery set changes, compressor changes, Sandite train refilling, and motor checks , Door faults, brake faults, and any faults that do not require side pits
60	Maintenance Shed	Centre and Side Pitted Calibrated Road	133	General Maintenance including , Exam, battery maintenance, compressor maintenance , Traction faults & Auxiliary faults
61	Maintenance Shed	Centre and Side Pitted Calibrated Road	133	General Maintenance including , Exam, battery maintenance, compressor maintenance , Traction faults & Auxiliary faults
62	Maintenance Shed	Centre Pit	133	General Maintenance including Gearbox oil changes, battery set changes, compressor changes, Sandite train refilling, and motor checks , Door faults, brake faults, and any faults that do not require side pits
63	Lifting Shed	Overhead Crane , Synchronised Jacking Road	133	Maintenance requiring heavy lifting including Wheel set changes, Bogie pressing, Planned motor changes, in brief all heavy lifting. Flashed over motors, all heavy lifting or items that require a bogie to be dropped.

Hainault Depot – Existing Maintenance Facilities & Function				
Road Number	**Position**	**Road Type & Length (m) Current**		**Function / Notes**
64	Lifting Shed	Overhead Crane , Synchronised Jacking Road	133	Maintenance requiring heavy lifting including Wheel set changes, Bogie pressing, Planned motor changes, in brief all heavy lifting. Flashed over motors, all heavy lifting or items that require a bogie to be dropped.
A	Cleaning Shed	Above solebar Cleaning Road	n/a	Gentle interior clean , Deep interior clean Exterior clean hand bashing
B	Cleaning Shed	Above solebar Cleaning Road	n/a	Gentle interior clean , Deep interior clean Exterior clean - hand bashing
C	Cleaning Shed	Above solebar Cleaning Road	n/a	Gentle interior clean Deep interior clean Exterior clean - hand bashing

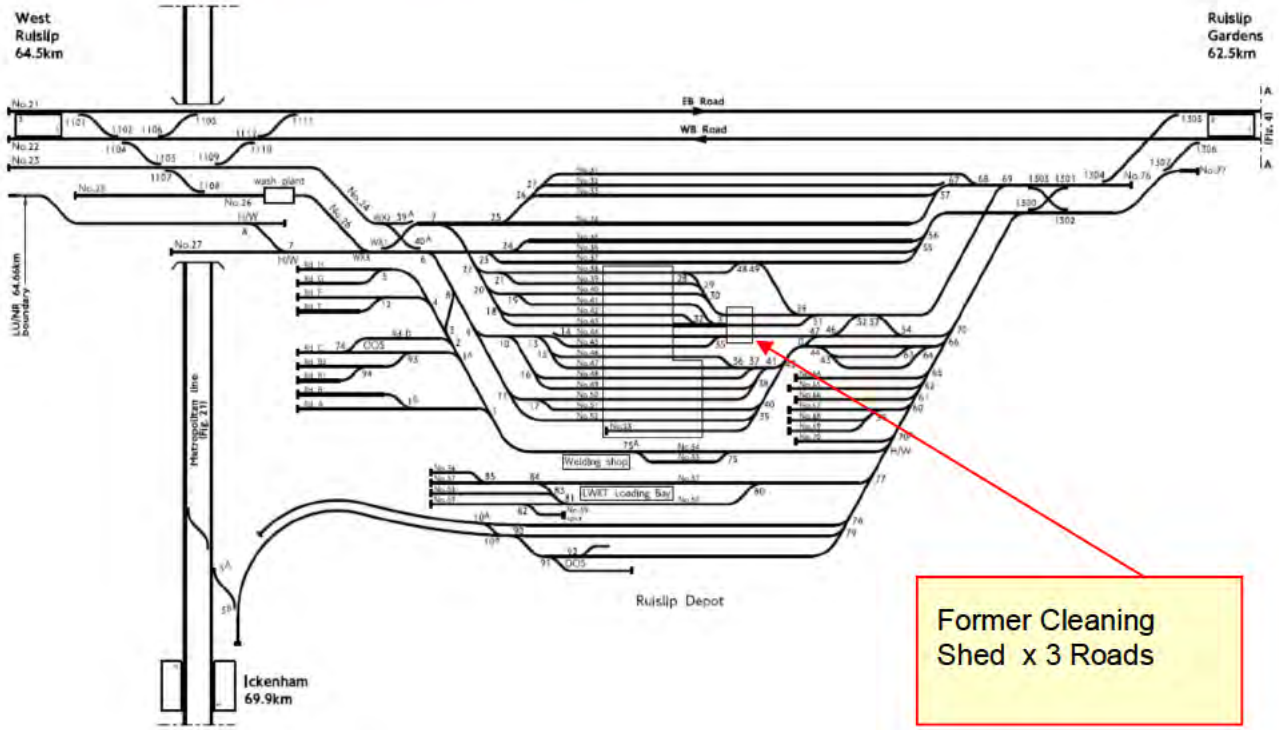
1.7.2 Ruislip Depot

Ruislip Depot is located at the Western End of the Line and is a double-ended Depot with a defined separate 24 berth stabling area (up to 4x trains per road) and an area containing the maintenance facilities consisting of a central shed a separate cleaning shed.

The Depot is also the major hub on the network for engineering trains and the use of facilities and operation of the Depot is split between the Central Line and that of Transplant (LU Engineering Trains Unit).

To facilitate engineering train movements outside of the Central Line the depot is connected to the Metropolitan & Piccadilly Lines via a link to the West of the Depot. It also has a link to Network Rail infrastructure on the “Chiltern Main Line” at West Ruislip.

The general layout is shown in the diagram below:



Train movements are currently controlled by hand-worked points using a ground shunter past the inlet/outlet roads, which are trailing when exiting the Depot.

The eastern end heavy maintenance facilities (51,52 road & 53 road) are used for 92TS maintenance and include a three road lifting facility with an overhead road lifting facility with overhead crane and on floor synchronised jacks to facilitate double car lifting under body with bogies strapped. Wheel turning is undertaken in this facility with the use of a mobile wheel lathe Mobiturn located in (51 Road) and is operated under a lifted train.

The western end heavy maintenance facilities (51, 52 & 53 roads) are utilised for the heavy maintenance of the transplant engineering fleet and are not available for use by 92TS operations.

The remaining seventeen roads in the main shed are a mixture of centre-pitted roads and centre pitted roads with deeper and wider side pits that undertake general exam and inspection activities. Four roads 39, 44, 45 & 46 are dedicated to transplant and not available for 92TS maintenance use. Typical space between pitted roads is 1.9 m.

The former cleaning shed cleaning shed consists of three roads that have recently been modified in preparation of utilisation for ATC modification to S-Stock and as a result they are not used for 92TS maintenance.

The transplant area next to the Depot is the main distribution site used by Track Partnership for preparing, loading and unloading materials transported to worksites by the Engineers Train fleet.

There is an automatic train wash with water harvesting system located at the east end of the Depot at the West Ruislip end to support the requirements for exterior train cleaning.

The west end 1962TS Sandite train is operated, refilled and maintained from 37 road during the duration of the leaf fall season September – December ,with de-icing refill undertaken on 37 road.

Currently some of the London Underground Heritage fleet is also stabled at Ruislip Depot. There is an ATC test track across the length of Road 31 (nearest stabling road to the main line).

Ruislip Depot – Existing Maintenance Facilities & Function (1)				
Road Number	**Position**	**Road Type & Length (m) Current**		**Function / Notes**
38	Maintenance Shed West	Centre Pit	133	Project Road / Body End Repair Road
39	Maintenance Shed West	Centre Pit	133	Not Available for use. Used by Transplant and not available for Central Line Fleet.
40	Maintenance Shed West	Centre Pit	133	General Maintenance and Casualty activities where side pit not required including : On Days – Gearbox Maintenance, oil change & Battery Maintenance On Nights – Under frame Clean
41	Maintenance Shed West	Centre Pit	133	General Maintenance and Casualty activities where side pit not required including. On Days – Gearbox Maintenance, oil change & Battery Maintenance On Nights – Motor Skim
42	Maintenance Shed West	Centre Pit	133	General Maintenance and Casualty activities where side pit not required including , oil change & Battery Maintenance
43	Maintenance Shed West	Centre Pit	133	General Maintenance and Casualty activities where side pit not required including Gearbox Maintenance, oil change & Battery Maintenance. Compressor changes

Ruislip Depot – Existing Maintenance Facilities & Function (2)				
Road Number	**Position**	**Road Type & Length(m) Current**		**Function / Notes**
44	Maintenance Shed West	Centre Pit	133	Not Available for use. Used by Transplant and not available for Central Line Fleet.
45	Maintenance Shed West	Centre Pit	133	Not Available for use. Used by Transplant and not available for Central Line Fleet.
46	Maintenance Shed West	Centre and Shallow Side Pits	133	Not Available for use. Used by Transplant and not available for Central Line Fleet.
47	Maintenance Shed West	Centre and Deep Side Pits	133	General Maintenance. Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.
48	Maintenance Shed West	Centre and Deep Side Pits	133	General Maintenance. Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.
49	Maintenance Shed West	Centre and Deep Side Pits	133	General Maintenance where a side pit is required including Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.
50	Maintenance Shed West	Centre and Deep Side Pits	133	General Maintenance where a side pit is required including Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to

				side covers on trains etc.
51	Lifting Shed West	Centre Pit	119	Not Available for use Used by Transplant and not available for Central Line Fleet.
52	Lifting Shed West	Centre Pit	119	Not Available for use Used by Transplant and not available for Central Line Fleet.
53	Lifting Shed West	Flat Road	n/a	Not Available for use Used by Transplant and not available for Central Line Fleet.
47	Maintenance Shed East	Centre and Deep Side Pits	131	General Maintenance where a side pit is required including Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.
48	Maintenance Shed East	Centre and Deep Side Pits	131	General Maintenance. Only calibrated road so primarily used for PLSW – coupler heights etc. Exam, battery maintenance, Door maintenance, QP maintenance Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.

Ruislip Depot – Existing Maintenance Facilities & Function (3)				
Road Number	Position	Road Type & Length (m) Current		Function / Notes
49	Maintenance Shed East	Centre and Deep Side Pits	131	General Maintenance where a side pit is required including Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.
50	Maintenance Shed East	Centre and Deep Side Pits	131	General Maintenance where a side pit is required including Exam, battery maintenance, Door maintenance, QP maintenance. Traction Faults, Auxiliary Faults and other faults that require side pit access to get to side covers on trains etc.
51	Lifting Shed East	Mobile Wheel Lathe Overhead Crane ,Synchronised Jacking Road	116	Mobiturn Road Only This road uses Synchronised and Standalone Jacks
52	Lifting Shed East	Overhead Crane , Synchronised Jacking Road	115	Heavy Overhaul and Gearbox Project Road
53	Lifting Shed East	Overhead Crane , Synchronised Jacking Road Centre Pit	109	Casualty Wheels and F/O Motor, casualty tasks that require lifting etc.
A	Former Cleaning Shed			Not Available For Use
B	Former Cleaning Shed			Not Available For Use
C	Former Cleaning Shed			Not Available For Use

Appendix H -Train Maintenance Regimes for Recent New Fleets (09TS & S-Stock)

Level	Activity	Period	Back Stop Frequency	Notes / Facilities
0	Condition Monitoring & Automated Inspection	Continuous		
1	Pre- Service Check		24 Hours	
2	'A/B/C Exams	25,000 km	80 days	
	A' Examination Train systems	75,000 km	240 days	
	'B' Examination Train systems	75,000 km	240 days	
	'C' Examination Train Systems	75,000 km	240 days	
3	X/ Y Exams	150,000 km	480 days	
	X' Examination Train systems	300,000	960 days	
	'Y' Examination Train systems	300,000km	960 days	
	SCD testing		5 years	
	Doors Maintenance	150,000 km	480 days	
	Lubrication (e.g. gearbox oil change)	150,000 km	480 days	
4	Bogie light overhaul			
	Z6 Overhaul Bogie overhaul light	762,00km		
5	Minor overhauls			
	Z4 Overhaul Propulsion clean	508,000km		
	Z9 Overhaul Brake valves	1,143,000km		
	Z18 Overhaul Propulsion software reload	2,286,000km		
	Z24 Overhaul – Reservoir replace	3,048,000km		
	Z25 Overhaul DC link Capacitor	3,175,000km		

Level	Activity	Period	Back Stop Frequency	Notes / Facilities
	replace			
6	Heavy overhauls			
	Z10 Overhaul Intercar equipment	1,270,000km		
	Z12 Overhaul - Heavy overhaul, bogie overhaul heavy	1,524,000km		
7	Serialised module equipment overhauls OFF train			
	Z6 Overhaul - Motors and compressors	762,000km		Rotating Machines needs lifting Roads
	Z15 Overhaul - HVAC and CCTV	1,905,000km		HVAC & CCTV replacement
	Z5 Overhaul - Battery replacement	5 years		
N/A	Cleaning			
	Daily clean	24 hours		
	Train wash 7 days	7 days		
	Standard clean	14 days		
	Modular clean	56 days		
	Underframe clean	50,000km		

Note: A, B and C Exams are balanced examinations. Each contains all of the 25,000Km tasks and a third of the 75,000Km tasks. Every 25,000Km either an A, B or C exam is carried out in the order of A, then B and then C.

X and Y Exam are balanced examinations. Each contains all of the 150,000Km tasks and a half of the 300,000Km tasks. Every 150,000Km either an X or a Y exam is carried out in the order for X and then Y.

Z6 Overhaul – Rotating machines (needs lifting roads)

Z15 Overhaul – HVAC and CCTV replacement (needs roof access)

Z5 Overhaul – Battery replacement

APPENDIX I - MATRIX OF DEPOT ASSETS AND MAINTENANCE REPRESENTATIVE RESPONSIBILITIES

Depot Asset area	Nominated Maintenance Representative
Access platforms	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Grit blast cabinet type Euro 7 PF	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
De-icing	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Caustic dosing system	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Energy management	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Running cables and man safe systems	OPERATIONS (ASSETS), Premises (Stations)
Shutter doors	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Wheel lathes, swarfe conveyor, crusher & shunter	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Welding equipment BCV	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
High vacuum & explosion suppression plant	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Grease system	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Battery chargers	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)

Treadview	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Talgo wheel monitoring equipment	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Local exhaust ventilation systems	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Ladders and pit boards (Portable)	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Chimneys	OPERATIONS (ASSETS), Premises (Stations)
Drains, foul and surface water (including Pit)	OPERATIONS (ASSETS), Premises (Stations)
Sumps and interceptors	OPERATIONS (ASSETS), Premises (Stations)
Track (within buildings)	OPERATIONS (ASSETS) Track & Signals Line Manager
Passenger and Material Lifts within Depots	OPERATIONS (ASSETS), Premises (Stations)
Lead Maintenance Representatives	
Piccadilly Line	OPERATIONS (ASSETS), Asset Development
Central Line	OPERATIONS (ASSETS), Asset Development
Bakerloo Line	OPERATIONS (ASSETS), Asset Development
Waterloo & City Line	OPERATIONS (ASSETS), Asset Development

Depot Plant, Equipment, Facilities & Premises	OPERATIONS (ASSETS), Asset Development

Depot Asset area	Nominated Maintenance Representative
Structures and fabric	OPERATIONS (ASSETS), Premises (Stations)
Heating	OPERATIONS (ASSETS), Premises (Stations)
Lighting	OPERATIONS (ASSETS), Site Services (Fleet & Trains Division)
Ventilation	OPERATIONS (ASSETS), Premises (Stations)
Electrical control panels (All) ventilation systems	OPERATIONS (ASSETS), Premises (Stations)
Fireman's switch	OPERATIONS (ASSETS), Premises (Stations)
Air conditioning & ventilation	OPERATIONS (ASSETS), Premises (Stations)
Gas services	OPERATIONS (ASSETS), Premises (Stations)
Water services	OPERATIONS (ASSETS), Premises (Stations)
Ground maintenance – vegetation control	OPERATIONS (ASSETS) Track & Signals Line Manager
Graffiti removal	OPERATIONS (ASSETS), Site Services (Fleet & Trains Division)

Secure perimeter	OPERATIONS (ASSETS) Track & Signals Line Manager
Depot security	OPERATIONS (ASSETS), Site Services (Fleet & Trains Division)
Public address system	OPERATIONS (ASSETS), Site Services (Fleet & Trains Division)
Electrical services	OPERATIONS (ASSETS), Premises (Stations)
Lightning conductors	OPERATIONS (ASSETS), Premises (Stations)
Statutory Inspection	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
In-service testing of in-service electrical equipment	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Compressed air	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Lifting and moving equipment	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Train washing system	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Foam arch system	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
All cleaning equipment	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)
Effluent control	OPERATIONS (ASSETS), Depot, Plant & Equipment (Fleet)

Transport for London
London Underground Limited

DTUP OMC Volume 2, Part 4 Signalling & Train Control System Maintenance Concept

		Signature	Date
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Version 3 (OMC)	22/07/2016	Incorporated into DTUP OMC Version 3
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TABLE OF CONTENTS

1 SUMMARY

The Deep Tube Upgrade Programme (DTUP) programme will provide extra capacity through the renewal of ageing assets by delivering a coordinated series of line modernisations on the Bakerloo, Central, Piccadilly and Waterloo and City lines.

DTUP will deliver new rolling stock and signalling assets. The new trains, operating in conjunction with the new signalling system, being capable of automatic train control (ATC) operation facilitating a more frequent and reliable service.

With the addition of modernised train depots, up-rated power supplies, and optimised track layouts, the DTUP railway will provide London with a transport facility capable of keeping pace with an ever-growing capital city over the next 50 years.

Effective asset management of the Railway Control System (RCS) will be a critical element in ensuring that each DTUP line continues to function at its optimum performance levels. The introduction of emerging technologies built into the core of the various RCS sub-systems provides a unique opportunity for the maintenance organisation to monitor the health, diagnose faults and predict the maintenance needs of the systems in a far more pro-active way than that afforded by the systems of the past.

This capability will significantly enhance the efficiency and effectiveness of the maintenance organisation by continuing to build upon its trademark of extensive knowledge of asset performance and experience in maintenance management.

The purpose of this Maintenance Concept is to describe the maintenance vision for the Signalling & Train Control System (S&TCS) elements of the RCS and how they will be maintained over their lifespan.

The expected key benefits in respect to maintenance of the new S&TCS assets will be a significant improvement in the reliability and maintainability of the railway as a system and therefore a reduction of the future operating costs associated with maintenance, renewals, upgrades and failure/fault rectification.

The reliability of the S&TC system will improve maintenance efficiency and reduce whole life costs because:

- The new system will be designed to minimise service affecting failures with systems designed to eliminate single points of failure.
- Equipment will be designed to be maintenance free to the greatest practicable extent. Condition monitoring will be used extensively to enable preventive maintenance without service interruption. Maintenance “down times” and repairs are expected to be very short.
- Where possible, routine maintenance will change from interval based toward effectively planned interventions based on usage / condition monitoring or predictive (likelihood of imminent failure).
- Training, diagnostics, incident response, flexibility and spares etc. will all be improved through standardised best practice across the lines in scope. Key spares will be held at critical equipment locations that present the greatest potential points of failure.
- Diagnostics and fault rectification will be simplified through the use of centralised fault reporting systems.
- The design will offer high availability via simplicity of design, the use of highly reliable components/sub-systems, redundancy and fault tolerance.

- The design will minimise the use of trackside equipment - any equipment installed on or near the track will be designed to minimise the risk of damage and will be accessible during traffic hours wherever practicable.

1 Introduction

The purpose of this Signalling & Train Control Systems Maintenance Concept is to provide a vision as to how London Underground Operations (Assets) intend to optimise the opportunities afforded by the delivery of the new DTUP Signalling & Train Control System on the Piccadilly, Central, Bakerloo and the Waterloo & City Lines.

This document provides a high level maintenance concept which describes how LU Operations (Assets) intend to optimise the opportunities afforded by the delivery of the new DTUP Signalling & Train Control System.

The concept establishes a set of high level principles which if consistently applied in the design and implementation of the S&TC system will be instrumental in achieving LU Operations (Assets) objectives of enhancing asset performance and improving maintenance efficiency.

The document is also intended to support a common understanding which promotes the necessary alignment between the DTUP Programme and the maintenance organisation and facilitates toward achieving the common goal of meeting the Programme objectives.

From the DTUP Programme, the key business objectives are stated as:

- Asset/System Renewal
- Increase Capacity
- Introduce/Enhance Automation
- Provide Air Cooling
- Enable Business Transformation
- Improve Customer Experience
- Reduce Whole Life Costs.
- Improve Railway Reliability
- Manage Rising Platform Temperatures
- Manage Safety and Security
- Minimise Access Demand

2 DOCUMENT BOUNDARIES AND EXCLUSIONS

2.1 Document Scope

This Signalling & Train Control Maintenance Concept applies to the Signalling & Train Control system (S&TCS) element of the Railway Control System (RCS) to be introduced on the operational railways of the Piccadilly, Central, Bakerloo and the Waterloo & City lines by the Capital Programmes Directorate's Deep Tube Upgrade Programme (DTUP) Programme. The document should be considered applicable for all Grades of Automation (GOA).

2.2 Document Exclusions

The S&TCS Maintenance Concept does not provide specific information on the maintainability of the Operational Control System nor does it deal specifically with the supporting 'enabling' infrastructure (buildings, power supplies, CRMS etc.) expected to be installed in support of the signalling system.

In respect of supporting 'enabling' assets; as the current approach toward the maintenance of them is not likely to change in future, it is envisaged that further maintenance concept documentation will not be required or provided. However, it should be recognised that any new or novel infrastructure intended to support the S&TCS will ultimately have its own associated set of requirements.

In the intervening period, and in lieu of 'expected' infrastructure, a set of generic requirements will be provided alongside the S&TCS requirements. These are intended to serve as guidance to the DTUP programme on such items such as SER's, CRMS etc.

These generic requirements will be based upon the core principles of safety, reliability, accessibility and maintainability and should be captured by the DTUP programme prior to the tendering stage. Once an S&TCS Supplier has been selected, and the extent of the supporting infrastructure clarified, then further specific technical requirements can be provided. If it is found that the future system does not utilise such infrastructure, then these requirements can simply be removed.

The S&TCS Concept does not take into consideration any Depot re-signalling works which may be required to support the expected service injection rates between the main line and the Depots. The concept for the implementation of depot signalling, alongside its rationale, has been outlined in the Fleet & Depot Maintenance Concept.

The Signalling & Train Control Maintenance Concept is not intended to specify the architecture or design of the system, but does seek to influence and provide a vision of system functionality which may then be exploited to enhance the capability and efficiency of the future maintenance organisation.

The Signalling & Train Control Maintenance Concept also provides a set of fundamental maintenance principles which give essential information for use in supporting the feasibility, design & delivery stages of the RCS Sub-Programme and its associated projects. Careful application of the principles outlined in this document, throughout these lifecycle stages, should not only yield a reliable and efficient railway in the future, but also one which is safe, simple to operate and economical to maintain.

2.3 Planned revisions and how the document will be updated

The Signalling and Train Control Maintenance Concept forms the Volume 2, Part 4 component of the DTUP Operations and Maintenance Concept (OMC).

The OMC is a configuration managed document that will evolve as the DTUP programme progresses. Elements of the existing volumes, including this S&TCS Maintenance Concept, will require greater development and future volumes are dependent upon a greater level of system knowledge. As such, the OMC will be updated, and re-released as required, to incorporate new developments as the programme evolves.

All releases will be executed in line with the Change process outlined in Volume 1, Part 1, Section 9 of the DTUP Operations and Maintenance Concept (OMC).

3 DESCRIPTION OF EXISTING SIGNALLING SYSTEMS

3.1 Description of pertinent aspects of the current systems

The four lines due to be re-signalled as part of the DTUP scope currently utilise diverse signalling systems. These systems are reflective of the era in which each line was last re-signalled and range from conventional systems through to railways which operate Automatic Train Control (ATC). A brief description of each line is provided below:

3.1.1 Central Line

The Central line was re-signalled in the 1990s and utilises coded track circuits which are used to control the fleet of automatic trains. To allow for a variety of train speeds 14 different frequencies are overlaid onto track circuits. These frequencies are read by the train and from which it then determines the optimum ATO (Automatic Train Operation) driving profiles (acceleration and braking) as well as governing when emergency braking needs to be applied (Automatic Train Protection).

The majority of signal Interlocking's on the Central Line are based upon Westinghouse's Westrace platform. Interlocking area's which do not utilise Westrace employ a Relay Interlocking system. These sites are predominantly located to the west end of the line.

The Central Line Control Room, which is responsible for the entire operational line, is located at Wood Lane in White City.

There is the facility to transfer rolling stock to the Metropolitan line via Ruislip depot and in Hainault there is a control tower which allows routes to be set within the Depot area.

3.1.2 Bakerloo Line

The existing signalling infrastructure on the Bakerloo Line utilises an older generation electro-mechanical type of signalling system. As a consequence the railway does not currently facilitate Automatic Train Operation (ATO). Automatic Train Protection is afforded through the trainstop / tripcock arrangement which automatically stops a train if it passes a signal displaying a stop aspect.

The Bakerloo line Control Room is located at Baker Street and is responsible for the running of the entire line from Elephant and Castle to Queens Park. The Control Room interfaces with site computers located at each Controlled area, which in turn operate 'V' style mechanical interlocking frames to control the signalling at ground level.

Control to the north of Queens Park, where Bakerloo trains run over Network Rail tracks, is provided through Network Rail signalling infrastructure. However, a LUL operated control tower exists at Stonebridge Park which serves to signal Bakerloo line trains locally within the Depot area.

The main Bakerloo Line Rolling Stock Depot is based at London Road, located between Lambeth North and Elephant & Castle, and is controlled by the frame at Waterloo.

3.1.3 Waterloo & City Line

The Waterloo and City line operates a twin track between Waterloo and Bank Stations. The line utilises Bombardier's EbiScreen computer based signalling control system which interfaces with the Interlocking's in the SER's. In 2007, the EbiScreen system replaced the old 'NX' (eNtry / eXit) style push button panel as the primary operating system. The Service Control System is operated from a new control room within Waterloo Depot. There is an additional mode of control provided by the Maintainer's panel within Waterloo SER which utilises 'route' push buttons. This panel serves as an emergency back-up system as well as providing the Maintainer with the capability of testing the system in Engineering Hours.

3.1.4 Piccadilly Line

As with the Bakerloo Line, the existing signalling infrastructure on the Piccadilly Line utilises an older generation electro-mechanical type signalling system. As a consequence, the railway does not currently operate Automatic Train Control (ATC).

Most of the Piccadilly Line is currently controlled from the Piccadilly and District line Control Room based at Earl's Court. The interoperable area between Rayners Lane and Uxbridge, which serves both the Metropolitan and Piccadilly Lines, is not controlled centrally from Earl's Court but is instead controlled by the Rayners Lane cabin.

Piccadilly line control (except the interoperable area) is expected to be transferred under the Piccadilly Upgrade (PICCU) programme to the Griffin Rooms at South Kensington. This is expected to be completed by 2018 and will serve as an interim arrangement in lieu of the DTUP Operational Control Centre being developed.

The Piccadilly Line fleet is served by two main Depots based at Cockfosters and Northfields. These Depots are currently un-signalled and rely upon local shunting arrangements for their operation.

3.2 Current Organisational Structures

3.2.1 Bakerloo, Central and Waterloo and City Lines - Background

Under the Public Private Partnership (PPP) contract, the Metronet consortium was responsible for the maintenance of the Bakerloo, Central, Victoria, District, Circle Metropolitan and Hammersmith & City Lines. These lines were subsequently split according to whether they were 'cut-and-cover' or 'tube' type constructions. This meant the Bakerloo, Central and Victoria lines were grouped with the Waterloo & City line and became collectively known as BCV. The other lines are collectively formed what became known as the Sub Surface Railway (SSR).

Following the collapse of Metronet both BCV and SSR were taken back in house and became part of Transport for London (TFL). However, the basic Metronet structure has been retained meaning that the Bakerloo, Central and Waterloo & City Lines remain as part of a BCV group.

3.2.2 Bakerloo, Central and Waterloo & City lines – Signalling Incident Response

Response to signalling incidents on the Bakerloo, Central & Waterloo & City lines is the responsibility of the Incident Response & Command Manager. In support of this function there is a Lead Incident Manager (LIM) who is responsible for a team of Duty Signalling Incident Managers (DSIM's). This team is based in Southwark and are directly responsible for the co-ordination and management of the line-based signalling incident response teams.

These line-based signalling teams are located at various strategically positioned depots: These response (or 'call') Depots operate a 3 shift system giving 24 hour incident coverage. Each Depot usually comprise of Technical Officers, who in turn are supported by Point Fitters and Support Technicians.

The main line-based response Depots for the Bakerloo Line are located at Waterloo and Queens Park. Signalling incident response to the north of Queen's Park is the responsibility of Network Rail.

Due to the length of the line, the Central Line operates more response Depots. These Depots are located at Loughton, Leyton, Liverpool Street, Marble Arch, West Ruislip and White City.

The Waterloo & City Line does not have a specific line-based team. Incidents on the W&C are usually covered by the Bakerloo Line response team from Waterloo and/or the Central Line response team from Liverpool St, dependent upon the location of the fault.

In addition to the line-based depots, Signalling Technicians are based in various line Control Rooms. This important resource facilitates effective incident management between the Control Room and the line Technicians. The Central Line also employs a Control System Engineering Team comprised of eight Field Services Engineers (FSE's). This team is based in the Control Room at White City and report through to the Network Command & Response Manager via the middle manager in charge of the team.

Similarly, the Bakerloo Line retains a small technical signalling presence in the Bakerloo Control Room located in Baker Street.

The W&C line has no Technical Officer presence in its Control Room at Waterloo, however the response TO is located adjacent to the control room.

It should be noted that line-based maintenance teams often come under the control of the DSIMs during Engineering hours to supplement the response teams investigations capability.

3.2.3 Bakerloo, Central and Waterloo & City lines – Signalling Maintenance

Planned, periodic Signal Maintenance on the Bakerloo, Central, Victoria & Waterloo & City lines is the responsibility of the Area Infrastructure Manager (BCV).

Supporting the Area Infrastructure Manager (BCV) are two Signalling Infrastructure Managers (SIM's). There are two SIM's, one in charge of signalling maintenance on the Bakerloo and Victoria lines, whilst the other is in charge of maintenance of the Central and Waterloo & City Lines.

Each SIM manages a group of Signalling Maintenance Managers (SMM's) who, in turn, manage maintenance teams of specialist staff across a variety of signalling grades.

Signal Maintenance teams operate out of centralised Depots, with Leyton being used by the Central Line and Lambeth North being used by the Bakerloo Line. As the infrastructure to the north of Queen's Park is the responsibility of Network Rail, Signalling Maintenance in this area is not undertaken by BCV.

W&C Line signalling maintenance, being the responsibility of the Central Line, is also covered by Leyton Depot.

It should be noted that line-based signalling response teams often come under the control of the SMM's during Engineering hours to supplement the planned maintenance capability.

3.2.4 Piccadilly Line – Background

Under the PPP, the Jubilee, Northern and Piccadilly lines (JNP) became the responsibility of Tubelines Limited. When the company experienced operating difficulties TfL became a major shareholder in the company and took overall control. Amey Ltd retains an association with London Underground and are contracted to manage the signalling incident and maintenance of the three lines.

As a consequence, the organisational model associated with signalling maintenance on JNP differs slightly from that employed by BCV.

Response for signalling incidents and maintenance on the Piccadilly Line is the responsibility of the Head of Signals (JNP). Supporting the Head of Signals are four main teams; Signal Engineering, Signal Response, Signal Maintenance and Signal Works.

Signal Engineering and Signal Works perform particular functions within the JNP organisation and are not discussed as part of this document.

3.2.5 Piccadilly Line - Signalling Incident Response

Overall Signalling Incident Response for the Jubilee, Piccadilly and Northern Line is managed by a Signal Response Manager. Supporting this function are three Zonal Incident Managers (ZIM's). Each ZIM 'champions' a particular line but can work across all three providing flexibility in coverage.

Supporting the ZIM's are a series of incident response Depots which are essentially line based. As with the BCV structure, these response Depots are strategically located and operate a similar 3 shift system giving 24 hour incident coverage. Each response Depot is managed by a Signal Incident Manager who has responsibility for the Depot staff.

The incident response Depots on the Piccadilly Line are located at Arnos Grove, Caledonian Road and Acton Town. Control Room signalling incident response and line based failure support is provided by a small team of Technicians located at Earls Court.

3.2.6 Piccadilly Line - Signalling Maintenance

Signalling Maintenance on JNP is managed through three Zonal Maintenance Managers (ZMM's). These ZMM's manage centralised maintenance Depots at Stratford (Jubilee), Finchley Central (Northern) and Acton (Piccadilly).

Each Depot comprises maintenance teams encompassing specialist staff across a variety of signalling grades. Although essentially line based, each Depot does have the capability of operating across 2 or more lines.

Supplementing the Maintenance Depots is a 'Point Care' team which ensure that points which are deemed to be 'Golden Assets', insofar as they are crucial to service, are '100%ed' every six months.

3.2.7 Sub-Surface Rail - Signalling Incident Response

The Sub-Surface Railway (SSR) operate the same structure for both incident response and planned maintenance as previously described for BCV, although the DSIM role has a dedicated SSR team and the locations of the response Depot naturally differ.

It should be noted that the interoperable area (Piccadilly & Metropolitan) between Rayners Lane and Uxbridge and the section between Barons Court tunnel mouth and North Ealing is the responsibility of the Sub Surface Railway.

3.2.8 Sub-Surface Rail - Signalling Maintenance

Signalling Maintenance on the Sub-Surface Railway (SSR) is the responsibility of the Head of Signals (Sub Surface Lines). In support of this role are a Signal Infrastructure Manager (North), Signal Infrastructure Manager (South) and a Cable Manager.

The Signal Infrastructure Manager (North) manages the Maintenance Depot located at Baker Street. This Depot maintains the signalling assets on the whole of the Metropolitan Line, the Hammersmith & City Line (between Hammersmith and Aldgate East) and the Circle Line (between Aldgate and Notting Hill Gate). The Baker Street Depot comprises maintenance teams of specialist staff across a variety of signalling grades. In addition, a Point Care Team (North) also operates out of Baker Street which is dedicated to improving the performance of critical points assets.

The Signal Infrastructure Manager (South) manages the maintenance depot located at Earls Court. This Depot maintains the signalling assets on the whole of the District Line, the Hammersmith & City Line (between Aldgate East and Barking) and the Circle Line (between High Street Kensington and Tower Hill). Similar to Baker Street, the Earl's Court Depot comprises maintenance teams of specialist staff across a variety of signalling grades and includes a Point Care Team (South) who work on critical points assets.

The Cable Manager role is responsible for Cable test and repair Team which, as the name implies, undertakes the periodic testing, conducts fault investigations and effects repairs on worn and damaged signal cable assets. Although primarily an SSR team, it provides a specialist function that is used by both SSL and BCV lines. This team currently operate out of Baker Street Depot.

Also under the management of the Cable Manager are two teams based at Acton Town; of these, the 'Track Support Team' are used to support the various track works and track circuit testing regimes across SSR, whilst the 'Locking Team' provides the capability for maintaining the various mechanical interlocking's left in use across LUL.

3.2.9 BCV & SSR Engineering and Signal Works

- Engineering Support

Engineering Support for BCV & SSL is provided through the office of the Head of Engineering. This is essentially a 'matrixed' function which provides specialist engineering team resource which spans across various assets and disciplines. The organisation arrangement for engineering support on BCV and SSL differs slightly from that of JNP where the Engineering Manager is a direct report of the Head of Signals (JNP).

- Signal Works

The majority of Signal Installation works on BCV and SSL are provided through the Signal Works team based at Acton. Most of this team form part of the Capital Programmes Directorate (CPD) rather than the Operations Directorate and therefore do not report directly to the Head of Signals (SSL), the Area Infrastructure Manager (BCV) or the Network Command & Response Manager).

This organisation arrangement again differs from that of JNP where Signal Works is seen as a direct report to the Head of Signals (JNP).

However, there are various Signal Works functions such as track support and Point care, which are managed directly through the Signalling Infrastructure Manager (Central & Waterloo & City) and the SSL Cable Manager.

4 THE MAINTENANCE VISION FOR DTUP'S S&TC SYSTEM

4.1 Core Maintenance Principles

The four core maintenance principles on which this S&TCS Maintenance Concept is based are those of Reliability, Availability, Maintainability and Safety. The DTUP programme should consistently apply each of these principles during the procurement, design and installation stages of the future system. This approach will be vital in ensuring an S&TC system that is fit for purpose, safe to maintain and will fully realise the benefits expected from such a large upgrade programme.

4.1.1 Reliability

It is a fundamental requirement that the S&TC system functions safely whilst remaining dependable and performing consistently to its specification. The design should be developed to achieve high reliability rates from the overall system via simplicity of design, the use of highly reliable components/sub-systems and fault tolerance. Safety signalling and service affecting components will need to be designed to eliminate single points of failure wherever practicable. RAMS analysis will be undertaken to ensure that the requirements of the Railway Performance Strategy is met.

A description of the desired RAM's targets for the DTUP S&TC system(s) is provided in the section entitled '**Required Reliability, Availability and Maintainability Performance'** which is contained in this document.

4.1.2 Availability

In order to mitigate against the impact of such occurrences, prime consideration will need to be given to ensuring that failures are unlikely to become service affecting and that the design of the system is sufficiently resilient so that in the event of failure the railway is able to sustain the timetabled level of service until the failing condition can be resolved.

In this respect, asset availability is a fundamental design consideration. Single points of failure should be eliminated where practicable and there should be a significant level of redundancy designed into the system which affords time for Maintenance to both respond to and subsequently rectify the failing condition without affecting the ongoing operation of the railway service.

4.1.3 Maintainability (Fault Response)

Although a key principle of this maintenance concept is to reduce, as far as possible, the number of service affecting failures through inherent system reliability and availability, it is recognised that there will inevitably be service affecting failures that will occur over the lifecycle of the assets.

Therefore it is essential that faults can be identified easily and faulty equipment changed quickly and efficiently. Current key objectives for maintenance are biased toward achieving the 'Time to Site' (TTS) and 'Time to Fix' (TTF) requirements for first-line incidents where a fault or failure is service affecting. These terms relate to the maximum expected time for a Maintainer to arrive on site following the initial report of a fault (TTS) and the maximum time expected to resolve the service affecting issue (TTF).

Although the times allocated in both categories differ according to a variety of factors, the Current TTS and TTF times are 10 minutes and 8 minutes respectively for sites located in the centre of London. Times for the outer zones differ and have a TTS and TTF of 20 minutes in each case. It should be noted that these times are a contractual measure and do not take into account service requirements.

A fundamental principle of this concept is the emphasis on ensuring that the requisite TTS and TTF times can still be achieved during migration, with the aim to reduce these times further at end state.

The achievement of improved 'Time to Site, Time to Fix' times at end state will depend heavily upon the application of core maintenance principles being incorporated into the design of the new system. It is critical, therefore, that the following principles are recognised as part of this concept document.

- Equipment should be kept to a minimum with as much of the 'intelligent' aspects of the system (such as site interlocking's) being co-located as far as practicable.
- Wayside assets should be kept to a minimum, where required they should be readily accessible during traffic hours and positioned in a place of safety.
- Adequate access shall be provided for all new or modified equipment to allow for its maintenance, testing and replacement.
- Where local Signalling equipment rooms (SER's) are required, they should be minimum in number, allowing for the effective strategic placement of maintenance staff capable of supporting the requisite first-line 'Time to Site' response times.
- Where not already available, facilities should be provided at strategic sites nominated by the maintenance organisation which support the requisite 'Time to Site' response times. These facilities should be considered as being operable 24 hours a day and therefore should include the necessary messing and welfare arrangements.
- The Signalling & Train Control System sub-assemblies and equipment should be modular in design and construction such that defective items can be replaced by a single technician in a timely, safe and efficient manner.
- The wayside assets should be lightweight in design to ease the maintenance activity and improve removal, handling and replacement in maintenance process.
- Sufficient 'in-car' access should be provided to trainborne signalling equipment such that it allows first-line response maintenance interventions i.e. equipment resets, to be undertaken whilst a train is still in service.
- The Signalling & Train Control System should be designed to avoid the need for working at height by maintainers as far as practicable.

- Hot-swappable equipment is preferred to enable replacements to be effected without the need to power down the system. Any replaceable item should not need to be configured once in place.
- Where practical, quick release/access points within trim panels should be used to enable swift visual inspection of the operational mechanism.
- The Signalling & Train Control System should be designed such that access panels can be removed without the use of special tools.
- Sub-systems should be modular in design to ensure that they can be physically handled within human factors standards.
- Where system resets are required, the process should not be dependent upon the area being ‘wheels free’.
- Access to components should not be restricted by other components such that they do not need to be removed or adjusted to allow the actual maintenance activity to commence.
- A storage capability should be provided at strategic sites (nominated by the maintenance organisation) such that it is capable of holding a small amount of critical spares that support the requisite 'Time to Fix' times.
- The Signalling & Train Control System should minimise the need for specialist tools and test equipment, including software.
- Test points and/or diagnostic ports placed trackside should be positioned in such a way that they allow for the safe testing and/or monitoring of equipment operation by a maintainer.

4.1.4 Maintainability (Planned, Preventive)

The existing signalling infrastructure on both the Piccadilly and Bakerloo lines utilises the older generation electro-mechanical type signalling systems. Electro-mechanical infrastructure, by design, requires regular preventative maintenance because the mechanical components are prone to wear and have a greater probability of failure than comparable electronic systems.

Emphasis, therefore, is to be placed upon ensuring that the design of the new DTUP Signalling & Train Control system(s) seeks to eliminate entirely, or reduce significantly, the number of periodic preventive maintenance interventions required.

Where periodic maintenance is a necessity then there should be a focus on ensuring that the times between planned maintenance activities are extended as far as possible without increasing the risk of failure to the signalling system.

System design should consider equipment location to be as centralised as possible which will reduce the ‘dead-time’ associated with travelling to and from various locations to undertake planned maintenance activities.

Where planned maintenance activities are required for the new system(s) then the design should consider the following:

- New and novel equipment introduced to the railway shall be designed for reduced maintenance interventions.
- Any equipment that is required to be near the 4 foot shall be designed such that it requires minimum maintenance.
- Equipment requiring periodic maintenance should be positioned such that it is easily accessible and maintainable.

- The wayside assets should be lightweight in design to ease the maintenance activity and improve removal, handling and replacement in maintenance process.
- Components should be designed in a way such that spares are not likely to be damaged when handling/stored, and are therefore of robust construction.
- Adequate access shall be provided to all new or modified equipment to allow for its maintenance, testing and replacement.
- Adequate task lighting to facilitate maintenance activities is provided at new or relocated P&C locations within tunnel areas.
- Maintenance activities that involve the loading or updating of software should be capable of being undertaken from a central location and not rely upon the local use of CD's, memory sticks etc.

Whilst it is understandable that development of a new S&TC system tends to become focussed on signalling maintenance tasks, the S&TCS design must also consider the impact upon other asset areas within the maintenance organisation.

Previous signalling designs have often not fully considered these impacts and have experienced difficulty in gaining assurance or attaining handover of the asset into maintenance. The Programme should ensure that all works are properly assessed such that all the affected asset groups are fully identified and that the relevant Stakeholders are engaged as early as possible.

In particular, signalling designs must consider the impacts the system may have on future Permanent Way maintenance tasks and track renewal works where fixed trackside equipment, particularly those mounted on rails and on bearers, make it difficult to perform tasks such as re-railing and tamping which can lead to unnecessary increases in the time and costs required to undertake track-works. As a result the assets negate some of the benefits expected from S&TCS implementation. Design of the signalling system should therefore consider the principles outlined below in respect of trackside equipment and Permanent Way works:

- Where attachment of signalling equipment and materials to the rail is necessary, the method should prevent any subsequent deterioration in the performance or condition of the rail which could result in a subsequent failure of it.
- The Signalling & Train Control System architecture and design should avoid, as far as practicable, the use of 'on-track' cabling.
- The Signalling & Train Control System architecture and design should avoid, as far as practicable, the use of track circuits.
- Where signalling equipment is attached adjacent to, or on the rails, it should be placed so to allow normal track maintenance activities, such as tamping, from being carried out.
- Where signalling equipment is attached adjacent to or on the rails, it must be placed so to allow normal track maintenance activities, to be carried out without the need for disconnection and/or reconnection.
- Components installed on or near the track, shall be suitably designed and protected to minimise the risk of damage from, as well as inconvenience to, normal trackside maintenance activities.
- Where trackside transponders are utilised by the Signalling & Train Control System then these should be designed to allow for safe and efficient replacement as well having an appropriate methodology through design and construction, ensuring they are placed back into the correct location.

- Where it is necessary to mount signalling equipment to the rails it should be connected such that it eliminates the need for the rail to be drilled.

4.1.5 Safety

The Maintenance organisation has a fundamental commitment to the health, safety and wellbeing efficiency of all of its employees engaged in maintenance activities on the assets. The introduction of a major signalling upgrade offers a unique opportunity to ensure that the hazards associated with signal maintenance activities are either eliminated entirely or are reduced as low as is reasonable practicable (ALARP), through the implementation of effective design management.

It should be recognised that the operational railway can be a demanding environment in which to work, particularly under abnormal, degraded or emergency modes. In this regard a greater emphasis should be placed upon the system designers to ensure that the risk of human error is mitigated and the potential for accidental loss reduced.

Designs which prevent inadvertent connections from being made are seen as an important aspect in guarding against human error. As an example, the Signalling & Train Control System should be designed in such way to prevent installation of incorrect interchangeable components and electrical connections should be formed by using plug-in units as far as practicable with a single possible orientation of the unit to prevent incorrect connection.

4.2 Operational Context

The purpose of this section is to provide supplementary information that builds on the core principles already outlined in the Maintenance vision. It is intended to give a view on how the maintenance organisation intends to operate within the context of the DTUP signalling system. For reference, a full description of some of the maintenance levels outlined in this section is provided in Section 5 ‘Maintenance Levels (Definition)’.

4.2.1 General

The expected key benefits in respect to maintenance of the new Signalling & Control System assets will be a significant improvement in the reliability and maintainability of the railway as a system and therefore a reduction of the future operating cost (Opex) of any maintenance activity including renewals, upgrades and failure/fault rectification.

Emphasis is placed upon the adoption of new technology which will allow the signal maintenance organisation to become proactive in its approach rather than the traditional reactive response. In addition, technology will be able to provide signal maintenance with a greater capability to diagnose and resolve incidents in a far more efficient manner than it has previously been able to achieve.

Importance too is placed upon the use of new materials to ensure that the new system is as maintenance free as possible thus allowing a greater focus on assets which are critical to the operation of the railway.

4.2.2 The Future Vision for the Control Centre

This maintenance vision is based on the assumption that the individual line Control Rooms for each of the DTUP lines will be based at the same location. Although part of the DTUP Operational Control Centre they are expected to be separate entities and not amalgamated to form one ‘all encompassing’ Control Room.

It is envisaged that there will be a maintenance presence in each of the Control Rooms which will provide 24 hour coverage. These personnel will perform a critical role and will act as a pivotal point between the operations and maintenance teams.

Two key maintenance roles have been identified for each Control Room. These roles will cover the maintenance activities associated with the following sub-systems:

- Signalling & Train Control

The primary Control Room role associated with the activity of maintaining the Signalling & Train Control System will be that of the 'Control Room Signal Technician' (CRST). Each Line Technician will be expected to monitor the health status of the signalling system across the whole line and ensure that everything is under control and working as desired.

As part of their general duties, each Control Room Signal Technician will also be responsible for dealing with all first-line incidents and planned maintenance activities associated with the Control Room elements of the S&TC system.

- Train & Trainborne Signalling assets

Trainborne assets, inclusive of those introduced onto the trains as part of the signalling system at GOA2, will be the responsibility of Fleet Maintenance. Due to the limited 'train to wayside' transmission capability at GOA1, it is expected that Rolling Stock event notifications which relate to the condition and health status of the trainborne systems will be sent to the Control Centre for initial processing.

This initial processing function is expected to be undertaken by a Centralised Train Technician who are located within the DTUP line Control Rooms. They will also have responsibility for monitoring fleet performance whilst in operational service and in co-ordinating asset response activities with the operational control staff in the event of problems.

Once the desired train to control system transmission capability has been attained it is foreseen that the Centralised Train Technician presence in the line Control Rooms will recede and they will become an integral part of the Local Performance Centre(s) structure.

Further information on the Fleet vision and the principles behind the use of Local Performance Centres can be obtained through the Fleet & Depot Maintenance Concept.

- Operational Control System

Responsibility for ensuring the continued operation of the Operational Control System will become the duty of the Control Room Signal Technician (CRST). The CRST will be responsible for dealing with all first-line incidents and planned maintenance activities associated with the line Control Room elements of the OCS system. The Control Room Signal Technician will also serve as an interface between train control teams and field based teams when dealing with signal related faults and incidents.

This approach represents a new approach towards the OCS Maintainer role. This function has traditionally been undertaken by Control and Information Engineers due to the specialist knowledge required for telecommunications based systems. However, with the technologies being used for signalling and the OCS systems becoming increasingly comparable, there is now the opportunity to integrate the roles of the Control Room Signal Technician and the OCS Maintainer.

In supporting this role, the Control Room Signal Technician should be provided with a dedicated OCS Maintenance Interface which allows them to undertake all the functions expected of their role in respect to monitoring OCS health status, failure diagnosis and rectification.

The Control Room Signal Technician will therefore serve as the main interface between the Operational Control staff and the Signalling Maintenance organisation when dealing with S&TCS and/or OCS related faults and incidents.

Recent signalling upgrades have tended towards combining the Control Room function and signalling control system in the same building. Indeed, the Sub-surface, Jubilee and Northern lines upgrades have incorporated the interlocking's at a central location. This arrangement is seen to be ideal from a maintenance perspective as it facilities a quick response towards faulting as well as

placing a significant quantity of equipment in one place allowing for an efficient use of time when undertaking planned maintenance interventions by negating the need for travelling to various sites.

However, it is recognised that the suggested architecture for DTUP's Operational Control Centre deviates from this arrangement by placing the line Control Room in a separate location from the signalling control equipment. This is currently being termed as a 'campus' arrangement.

Whilst there are benefits associated with the adoption of this arrangement, careful consideration will need to be given to the location of the control system equipment. If the Control Room is placed a significant distance from the control system then the maintenance organisation will need to provide coverage at both the Control Room and the Control system locations if TTS targets are to be met. In addition, it is likely that call depot facilities will need to be provided adjacent to the equipment room(s) which allow for the requisite incident response coverage.

Clearly the introduction of additional staff & 'call depot' facilities will erode some of the benefits that would be expected from a Control Room / Control system combined in one place (or separate within a reasonable distance).

4.2.3 The Future Vision for Signalling Incident Response

It is envisaged that a line based 'Call Depot' strategy towards signalling incident response is likely to continue following the introduction of the S&TC system. This structure has been founded upon a set of sound organisational principles and has adapted and evolved in order to meet the stringent TTS & TTF requirements expected of London Underground. However, the adoption of a standardised signalling system across the four DTUP lines does provide the opportunity for the development of a flexible workforce capable of working across each line, with line based Depot locations being strategically selected based upon a 'four line network' basis rather than on just a 'single line' model. This approach has already been successfully adopted on both BCV and JNP and has kept operational costs down through the efficient use of the resources available.

4.2.4 The Future Vision for Signalling Preventive Maintenance

Whilst it is a core principle that the level of planned, periodic maintenance activities are likely to decrease significantly with the introduction of the new signalling systems, it remains highly likely that signalling maintenance Depots will continue to operate due to the need to maintain the point equipment on the four lines. As with the vision for incident response it is expected that standardisation of equipment will provide the mechanism towards attaining the desire to achieve maximum flexibility in the workforce.

4.2.5 The Future Vision for a 'Centre of Excellence'

Traditionally the '2nd line' repair and overhaul maintenance function has been conducted 'in-house' utilising the Railway Engineering Workshop (REW) located at Acton Works. However, various signalling upgrades have led to the development of multiple 'bespoke' facilities for the overhaul and repair of different types of signalling and train control equipment.

By their nature, these facilities have tended to become 'line-centric' and have located at various sites across the London Underground network. Whilst it is recognised that these facilities have often grown organically in order to meet specific needs, the approach doesn't represent the most efficient use of resources or lends itself towards the co-ordinated and standardised approach which ensures that serviceable spares are made readily available to the railway.

DTUP represents an opportunity to prevent any further diversification from occurring and facilitate in the attainment of the future maintenance vision of the development of a 'Centre of Excellence' which will be capable of undertaking all 2nd line signalling maintenance activities in one location.

To facilitate this vision, there will be a need to ensure that the 'Centre of Excellence' will be furnished by the programme, the capability to undertake any designated 2nd line maintenance

activity. It is expected that this will comprise of manufacturers information, test rigs, diagnostic tools, software and so on.

Despite the vision for a ‘Centre of Excellence’ it is recognised that it may be may be difficult to establish a contractual agreement for the maintenance of ‘sealed units’ with a Supplier. Moreover, it may be found to be more expedient and cost effective for repair and overhaul to be outsourced. Once the Programme progresses and the position of the potential suppliers in the marketplace are fully understood, then an informed decision can be made.

4.2.6 Desired S&TCS Maintenance Functions

Figure 1 assumes a diagram of the future S&TC system for the DTUP railway. The letters A-G used in the diagram are listed below and are used to highlight desired system functionality seen as necessary to fulfil the future vision of the maintenance organisation.

Although broadly based upon the structure outlined in the Operational Concept, the diagram is not intended to prescribe any specific architecture or connectivity. It remains imperative that flexibility in system design is afforded to the DTUP programme in collaboration with its Supplier’s so that a ‘best fit’ solution for the Underground is found.

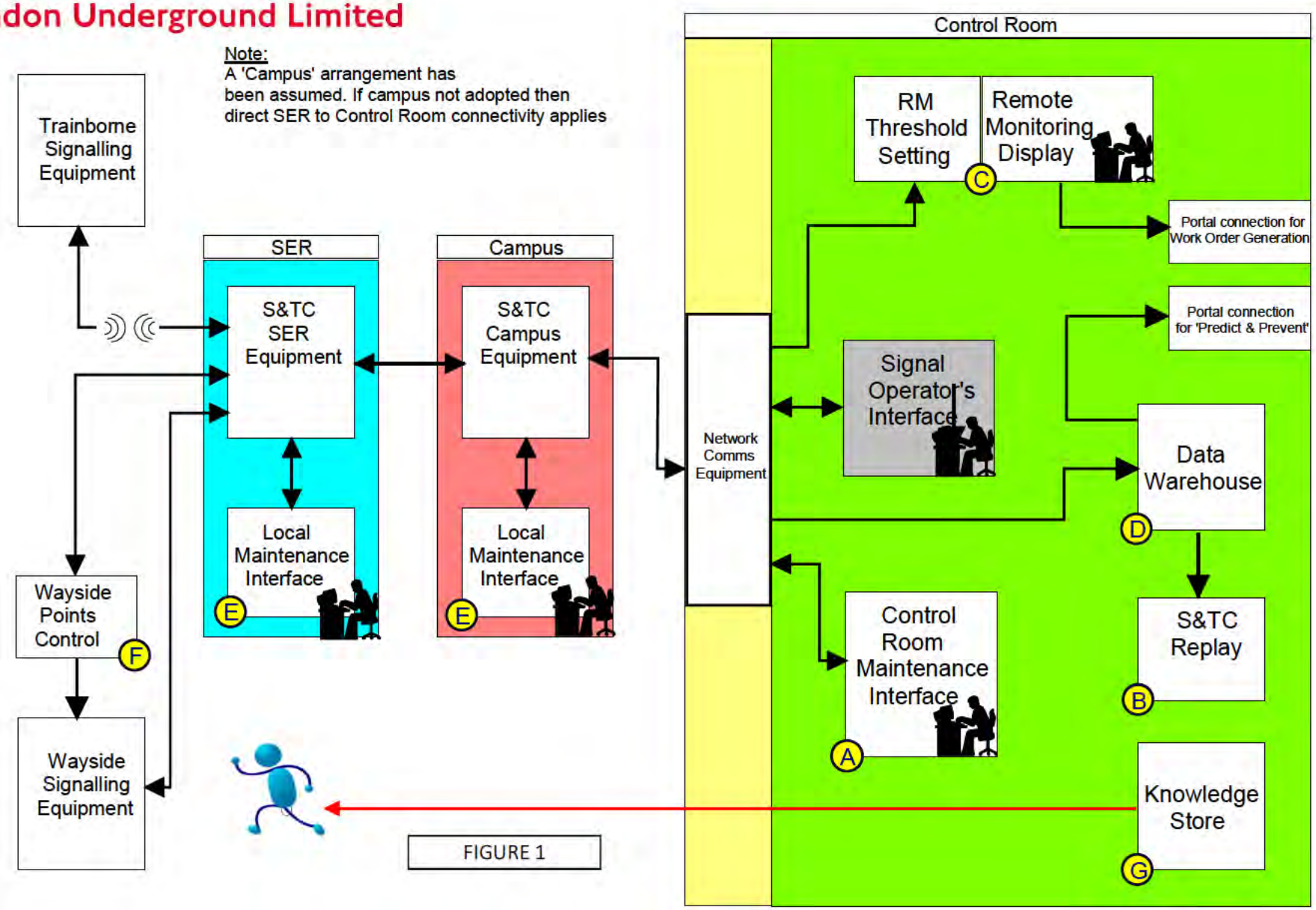


FIGURE 1

4.2.7 Control Room Maintenance Interface

It is envisaged that S&TC system information is provided to a dedicated Maintainers Interface (termed hereafter in this document as the 'Control Room Maintenance Interface'). A Maintainers Interface is expected to be located in each of the line Control Rooms (Piccadilly, Bakerloo, Waterloo & City and Central lines) and positioned on a dedicated 'Maintenance desk'.

The purpose of the interface is to provide the Maintainer with the ability to monitor and interrogate the Signalling & Train Control System for each line.

- Equipment Status monitoring

In order to ensure the continuous availability of the signalling system, it will be necessary for the Signalling & Train Control System to have the capability to monitor, report and provide alerts regarding both its own health status and those of its sub-systems in 'real-time'. This capability should be applicable to any active 'on-line' systems as well as any 'stand-by' systems where redundancy has been built in as part of the overall design.

As the Control Room Maintenance Interface will essentially be used to monitor the signalling system from a line/network perspective, it should be capable of providing the health status information on all equipment associated with the S&TCS Control Room, as well as the health status of S&TCS equipment associated with any Control Room 'campus' or local SER's (inclusive of any communication network equipment).

Due to the need to monitor multiple sites, it should be recognised that the Control Room Maintenance Interface will need the ability to display information through the use of multiple screens or through 'software switching' capability.

It is envisaged that the interface will provide a set of highly intuitive graphical representations of the health status of the Signalling & Train Control System at both Control Room and SER level allowing a Maintainer to quickly identify a problem in the system before assessing its impact and determining the appropriate maintenance action.

- Equipment Diagnostics & Interrogation

In addition to status monitoring, the Control Room Maintenance Interface should possess diagnostic capabilities for fault-finding on all aspects of the Signalling and Train Control System. This should also include the ability to remotely interrogate the equipment at each remote site such that the Control Room Maintenance Interface is capable of providing the same diagnostic features that would be afforded to Maintainers via any Local Maintenance Interface, including the ability to interrogate any interlocking 'ladder logic' remotely.

This capability will allow fault finding and diagnostic activities to commence via the Control Room Maintenance Interface the moment a fault occurs and which can continue whilst a Maintainer travels to site. It is envisaged that in using this technology that the fault will be diagnosed before the Maintainer arrives on site allowing them to proceed directly to the rectification stage.

It is not envisaged that the Maintainer's Control Room Interface will give access for controlling the signalling system from the Control Room. However, there will be a need for the Control Room Maintainer to impose certain maintenance inhibits on the signalling system (i.e. Temporary Speed Restrictions) that ensure the safety and integrity of the railway. It is envisaged that the Maintainer's Control Room Interface will become the conduit for this critical safety function.

In order to ensure that only the maintainer can implement and remove such inhibits on the S&TC system, the Maintainer's Control Room Interface will need to be protected such that only those with 'access rights' can operate the terminal.

Due to the amount of information expected to be drawn through this interface, it should be seen as a separate entity and realistically shouldn't form part of monitoring/diagnostic interfaces associated with other RCS sub-systems such as the OCS.

4.2.8 S&TCS Replay Facility

One of the key features when undertaking failure investigations, or when assessing alleged irregularities, is to understand the precise circumstances under which the fault or irregularity occurred. With most signalling designs being based on logical sequences, it is vital that the system has the capability to provide a 'playback facility' which will show a historical, yet chronologically accurate, reflection of the interactions and interfaces at the time of an incident.

It is envisaged that the 'playback facility' will graphically represent the railway as if it were being viewed in 'real-time', and will show the positions of each train, signal status and so on at the time of the incident.

The 'playback facility' should be considered as a function of the Maintainer's desk and be available to the Control Room of each line. Controls for setting defined dates and times to replay should be simple and intuitive and allow for immediate retrieval from the systems 'memory'. The playback facility should be capable of accessing historical information for a minimum of 72 hours after an event. Beyond this time all data should be stored in a data warehouse for future retrieval.

4.2.9 Remote Condition Monitoring

One of the cornerstones of the S&TCS Maintenance Concept is to reduce the number of Service Affecting Failures (SAF's) whilst also reducing the number of planned and periodic maintenance interventions. Whilst it could be argued that these represent two diametrically opposed needs, it is believed that a combination of reliable system design, working in conjunction with an effective asset monitoring capability, will allow the time between planned maintenance interventions to be increased whilst still being able to 'predict and prevent' failures before they have any operational impact.

The provision of an intelligent remote conditioning monitoring solution capable of capturing asset data such that it is possible to recognise a decline and/or a rate of decline in the Signalling & Train Control System condition or performance will facilitate the development of a 'just in time' maintenance intervention strategy.

With a system capable of prioritising information according to how a potential failure may criticality affect the operation of the Signalling & Train Control System, it is envisaged that assets demonstrating fault symptoms are brought immediately to the attention of the Control Room Maintainer through an appropriate alarm strategy. The Maintainer will be able to interrogate the S&TC system, allowing them to verify the problem and to assess the impacts associated with immediate asset failure. Any critical item identified can then be dealt with through the immediate dispatch of a Maintainer to site.

For non-critical items, the remote condition monitoring solution should be capable of automatically generating 'work orders' for equipment identified as requiring attention. These

should naturally be sent directly to the nominated maintenance Depots but could also be potentially sent directly to Maintainers through the use of a personal mobile device.

To maximise its effectiveness, the remote condition monitoring solution should be capable of 'settable' criteria and thresholds. It is envisaged that the threshold criteria will be initially set to align with the Supplier's RAM data, but should allow for future custom settings to be inputted by the Maintainer.

As a means of developing RAM's figures that are truly reflective of the environment in which they operate, the Signalling & Train Control System should be designed so that it is capable of providing statistics for the operational usage of systems and equipment. This information would provide a rich information source for analysis and would allow for;

- Visualisation and reporting on the accrued data allowing for asset behaviours and trends to be identified so that the associated risks can be assessed and mitigated against,
- Creation of a rationalised set of alerts and risk based recommendations for the business to respond to,
- Use historic data to develop the knowledge and understanding of S&TCS assets and the ongoing effectiveness of the maintenance regimes.

It is expected that whatever the remote condition monitoring solution will be, it should be designed and installed using LUL's Guidance Document G0213 'Condition Monitoring' so as to remain in line with the requirements of LUL's Cat 1 Standard S1213 'Condition Monitoring'.

4.2.10 Data Warehouse 

Access to historical data will be an important aspect in the establishment and verification of accurate S&TCS RAM figures. Similarly, data may need to be accessible to support any future investigations such as signalling irregularities.

In this respect there will need to be a mechanism by which the recorded asset data can be stored in the longer term. It is envisaged that a large data base of information relating to the operation and behaviour of the S&TC system will be stored in a 'Data Warehouse' alongside the data drawn from other systems such as the Operational Control System (OCS) and any future [redacted] Communication connectivity.

The Data Warehouse will be a critical resource for London Underground's Maintenance Modernisation Programme who will able to use the information to:

- Assess asset data in order improve future maintenance and management activities,
- Implement informed changes to the maintenance regimes,
- Apply a systems approach to the assets which make up the network
- Implement the business changes which make the benefits associated with condition monitoring sustainable

Although the Data Warehouse will most likely be placed at a single location (nominally the Control Centre) it should have the capability of being accessed remotely by various users through a web-based interface.

4.2.11 Local Maintenance Interface

The purpose of the Local Maintenance Interface is to provide the Maintainer with the ability to monitor and interrogate the on-site Signalling & Train Control System.

It is expected that a Local Maintenance Interface will be provided at all Signalling Equipment Rooms (and Campus sites, if applicable) and should be capable of providing a site specific line diagram allowing for an overview of the Signalling & Train Control System status for that area.

The Local Maintenance Interface should be capable of providing site specific equipment states and the general status for that area. It should serve as the Maintainer's main fault-finding tool and provide a significant level of diagnostic interrogation of the local S&TC system.

Unlike the Control Room Maintainer's Interface, the Local Maintainers Interface should provide a Maintainer with the ability to control the signalling in the local area to facilitate testing during Engineering Hours. In keeping with basic signalling principles, selection of a 'local operating mode' should ensure the 'locking-out' of the Control Room operation (for that site) ensuring that there is only one controlling entity at any given time. Once maintenance has been completed then this function can be switched out and control returned to the Control Room which in turn 'locks-out' the Local Maintenance Interface signal control capability.

4.2.12 Wayside Control Capability

Periodic Point Maintenance requires that the final gauging is performed 'on power'. For Electro-Pneumatically (EP) operated points this does not represent a major issue as the Maintainer has the capability of operating the points locally from the trackside valves. However, this provision isn't available to electrically powered points which can only be controlled through the Control Room or through a local control terminal/panel in the SER.

With SER's becoming ever more dispersed, it means that a Maintainer may have to travel a significant distance to be able to undertake a 'powered throw' for final gauging purposes. This naturally would introduce a significant amount of 'dead-time' to the maintenance activity and thereby reduces efficiency. Moreover, the added distances involved will take the Maintainer away from visual and aural contact with their maintenance teams, increasing the risk of accidents and incidents when the points are thrown 'blind'.

To mitigate against these situations, it is envisaged that there is a means of locally controlling electrically operated points for gauging purposes whilst continuing to remain in visual and aural contact with the worksite. This would ideally be a fixed trackside installation that can be 'switched-in' for maintenance purposes and will safely 'lock-out' the Control Room and SER control capability preventing any unwanted operation. Once maintenance has been complete, then this function can be switched out and control returned to the Control Room/SER.

4.2.13 Knowledge Store

Although not an integral part of the S&TC system, the 'knowledge store' is seen as an important element in ensuring efficient information management.

With many modern signalling systems now becoming a combination of bespoke and 'Commercial off the Shelf' equipment, technical information on systems tend to be assembled through the provision of several discrete manufacturers' technical manuals.

By their nature these manuals tend to be fairly generic and are rarely practical in the context of a broader signalling system application. Moreover, these manuals are rarely logically linked together, making it extremely difficult to quickly and efficiently pinpoint the requisite information. This becomes particularly pertinent in a failure situation. Apart from it being largely impractical to transport complete suites of technical manuals around and on-site, the extraction of the necessary information from them has become increasingly difficult, frustrating and extremely time-consuming.

To this end it is envisaged that all technical information for the signalling system (Book-wirings, Operations & Maintenance Manuals, fault finding guides, work instructions etc.) will be held in a central electronic 'knowledge store'. The 'knowledge store' can then be accessed at any site location through a suitable mobile device.

Each document would ideally be 'bookmarked' to allow efficient accessibility to other appropriate manuals/reference points/pages to assist the Maintainer and facilitate improved response times.

The system could potentially be adapted to allow limited mobile device access to Station staff who could then utilise the information to ascertain and feedback basic status information. This could take the form of a series of 'preliminary status checklists' which, as an example, may seek such basic information as '*confirm through the touch-pad (on the mobile device) what indication lights are currently being displayed on equipment X'*.

Provision of such information would prove invaluable to the Control Centre in assessing the potential impact of a failure, whilst the feedback will also give a Maintainer, who may be travelling to site, a 'head-start' or insight into what the root cause of the problem may be.

Provision of a centralised 'knowledge store' will also facilitate effective version control ensuring that any information being accessed by a mobile device is always up-to-date.

4.3 Back-Up Control

The DTUP Operations Vision & Transformation Statement (Vol.1 Part 2 of OMC) outlines the need for a Back-up Control Capability that will enable continued operation of the railway should access to, or operation of, the primary OCC not be possible. In order to support continued operation it is important that the BUCC is also equipped with the same maintenance capability as that found at the Control Centre. The Control Room elements of the maintenance capability are described within sections 4.2.7 through 4.2.13 of this Concept.

4.4 Required Reliability, Availability, Maintainability Performance

A declared strategic objective of the DTUP is improved railway reliability while increasing railway capacity, reducing journey times, lowering life cycle costs and improving customer experience. To ensure these objectives are achieved, DTUP are following the general guidelines of EN BS 50126 Railway Applications – The specification of Reliability, Availability, Maintainability and Safety (RAMS) and EN BS 50128 Railway Applications – Communications, signalling and processing systems: Software for railway control and protection systems.

The System Definition is now made up of the Programme Requirements Specification (baseline 0.8) and the System Requirements Specification (baseline 1.4). These now contain the RAM targets for DTUP within the relevant RAM module and define high level RAM targets for the Bakerloo, Central, Piccadilly and Waterloo and City lines for [redacted]. These targets are expressed as annualised rates of Service Affecting Failures (SAFs) resulting in a delay of 2 minutes or more plus Platform Wait Time (PWT) and On Train Time (OTT) targets.

The System Definition also includes consideration of:

- Customer influences (not a DTUP responsibility)
- Staff influences (not a DTUP responsibility)
- Traction and Auxiliary Power
- Platform / Train Interface equipment
- Railway Control System (Signalling & Train Control plus Operational Control)
- Rolling stock
- Track & Civils (minor DTUP input only)
- Station infrastructure (not a DTUP responsibility)
- Operational influences

The System Definition considers all modifications within the DTUP scope of work associated with the future upgrades and how such changes will influence the overall Railway Level RAM performance.

A RAM Strategy has been published to outline the processes by which the DTUP RAM requirements are determined, delivered and validated. It defines how RAM will be managed to meet the DTUP RAM requirements defined in the SPR documents, including the RAM contribution to life cycle cost reduction. The document describes the organisational arrangements for RAM management, the approach to be adopted and the activities to be performed to identify, implement and assure compliance with the RAM requirements.

The DTUP RAM Strategy also describes the methods by which the RAM objectives will be controlled, as defined within the RAM Management Plan and how RAM will be progressed to ensure that all RAM considerations are taken fully into account during the design and optimisation of whole life asset performance.

The DTUP RAM Strategy is supported by a RAM Management Plan, which provides a description of the DTUP RAM roles and responsibilities and, for each identified line upgrade, the RAM tasks to be carried out to successfully deliver them.

The aim of the detailed RAM activities identified is to assess the design specification against the RAM requirements and targets.

The RAM work is intended to influence the overall operational reliability of the railway and therefore the RAM activities specifically include consideration of all factors that may affect service performance. This includes not only failure of hardware but also operational and maintenance issues that may contribute to reliability.

Detailed targets are presented within the System Definition for all routes (lines) along with formal classification and acceptance criteria for each phase of the project [redacted]

5 MAINTENANCE LEVELS (DEFINITION)

There are various types of maintenance interventions that have to be undertaken on the Signalling and Train Control System and it is recognised that there are different, often interchangeable terms used across the network, to describe the various levels of maintenance intervention. For this reason, and to promote a common recognition of the terms used throughout this document, these interventions have been categorised into three levels; first-line, second-line and third-line.

In the context of this document, first-line maintenance has been sub-divided to encompass response and corrective maintenance activities, whilst second-line and third-line maintenance is used to describe the particular pathways taken in the repair and overhaul of signalling equipment that is 'returned from the field' following a first-line maintenance intervention. The below table (Fig 2) indicates where each type of maintenance intervention lies in respect of first-line, second-line and third-line and a set of definitions is also provided for clarification purposes.

Category	Maintenance Activity
1st Line Incident	1st Line Response
	1st Line Corrective
1st Line Preventive	Planned, Periodic Maintenance
	Preventive Corrective
	Routine Change
2nd Line Maintenance	'In-house' Overhaul & Repair
3rd Line Maintenance	'Out-sourced' Overhaul & Repair

Fig 2 – Maintenance Intervention Categorisation

5.1.1 First-Line Maintenance (Definition)

First-line maintenance has been sub-divided to form two distinct categories of maintenance activity; first-line incident and first-line preventive.

5.1.2 First-line Incident (Definition)

'Incident' comprises both 'first-line response' and 'first-line corrective' maintenance activities and is primarily associated with the diagnosis and rectification of those faults and failures which are, or have the potential to become, Service Affecting Failures (SAF's).

It is necessary here to make the distinction between 'first-line response' and 'first-line corrective' activities. These have largely been drawn as a function of the current signal response structure which has been organised such that it offers the capability of providing 24 hour response coverage toward signalling related incidents.

As other maintenance departments do not generally need, or possess this level of coverage, the first-line response role is often fulfilled by an available Signal Maintainer who is primarily tasked with the identification of a fault.

Naturally if a fault is subsequently found to be within the Signal Maintainer's own area of expertise, then a first-line corrective action will be taken to rectify the fault.

However, due to the integrated nature of signalling systems, it may be the case that the root cause of the fault is found to be within a sub-system outside the Maintainer's area of expertise. In this instance the Signal Maintainer may attempt a first-line corrective action unless rectification is felt to be beyond their capabilities and/or limits of authority. In this event the fault will be followed up by a discipline specific person who will complete the first-line corrective action.

5.1.3 First-line Preventive (Definition)

In this context, *preventive* relates to the planned, periodic maintenance activities seen as necessary to ensure the continued and effective operation of the system.

It also relates to the activity of 'Routine Change' and as the name implies this, is the activity associated with routinely changing-out assets which are due for overhaul, as well as assets that are identified as requiring to be replaced due to excessive wear or where they have been found to be problematic.

5.1.4 Second-Line Maintenance (Definition)

Second-line maintenance describes the process for repair and overhaul when equipment, returned following a first-line maintenance intervention, is sent to an 'in-house' facility equipped with the capability of undertaking the work. Traditionally the full repair and overhaul of legacy signalling equipment has been undertaken utilising London Underground's Railway Engineering Workshop (REW) based at Acton works. Once overhauled, this equipment is subsequently returned to a centralised store ready to be returned into operational service.

5.2 Third-Line Maintenance (Definition)

Third-line maintenance is considered to be the repair/overhaul of equipment returned from a first-line maintenance intervention which is undertaken by the Supplier or a nominated sub-contractor with Supplier involvement. Under this arrangement there is seen to be no second-line maintenance involvement other than the equipment passing through the Underground's 'in-house' maintenance facility which is used as a 'staging-point' to facilitate the recording and storage of defective items prior to Supplier collection and their subsequent return

As modern signalling systems have evolved, the equipment has tended more toward the adoption of 'black box' technology (hereafter referred to as Line Replaceable Units or LRU's). This approach facilitates quick fault diagnosis and rectification at a first-line maintenance level, allowing units to be replaced without the need for rectification at component level. However, due to its specialised nature any further examination of returned equipment often requires the use of bespoke diagnostic and testing rigs.

In some cases it has been found to be more expedient to return defective Line Replaceable Units (LRU's) directly back to the Supplier for repair and overhaul. This ensures that failed equipment is restored to a serviceable state as quickly and cost-effectively as possible. The 'direct first-line to third-line' approach may also be dictated by the conditions of the supply

contract and subsequently prohibits the opening of an LRU by outside parties through the immediate invalidation of its warranty.

6 MAINTENANCE APPROACH TO DTUP MIGRATION - [redacted]

6.1 S & TCS Maintenance Concept – Grade of Automation 1

First-Line Maintenance

The changes made following the introduction of the GOA1 stage are not expected to significantly alter the way in which S&TCS maintenance is currently conducted today. Preliminary analysis of the signalling immunisation works indicates that there is no signalling equipment being introduced that is new and novel.

In this respect it is envisaged that the signalling maintenance structures currently being operated will remain and therefore there will be no changes in the defined maintenance responsibilities at either first, second or third-line.

However, it is recognised that the GOA1 stage may introduce additional assets which are required to facilitate operation of the new train (i.e. in-cab One Person Operation). And it is envisaged that the maintenance of these new assets will be performed by the same maintenance teams that are currently in place, unless it is found to be more expedient, from either a technical or commercial perspective, to maintain the 'specialised' elements of the system through a maintenance support contract.

6.1.1 Second-Line Maintenance

As the S&TCS is not expected to be introduced at this stage of the Programme, there is no envisaged impact on the current second-line maintenance structure.

6.1.2 Third-Line Maintenance

As the S&TCS is not expected to be introduced at this stage of the Programme, there is no envisaged impact on the current third-line maintenance structure.

6.2 S & TCS Maintenance Concept – Grade of Automation 2

6.2.1 First-Line Maintenance

At GOA2 it is expected that first-line incident response on the S&TC system will continue to be undertaken 'in house' using London Underground's signal staff.

A level of support will be expected from the Supplier in the first instance, which will enable the maintenance organisation to call upon the knowledge and expertise of the supply chain to support LU in resolving ongoing Signalling and Train Control issues which are not clearly understood, or which cannot be resolved through first-line maintenance intervention. It is envisaged that the level of support will be high during the first few months following the first site commissioning but will reduce as the maintenance organisation familiarises itself with the systems operation and nuances.

First-line preventative maintenance of the signalling system is also expected to be retained as an 'in-house' function. This will allow for the continuation of an effective 'whole system' maintenance regime for a system comprised of new signalling operating in conjunction with existing legacy assets such as points.

However, there may be assets in the new system which would better served through a maintenance support contract with an appropriate external Supplier. These are essentially assets where a level of specialist skill or equipment is required and may therefore not be economically viable to retain as an 'in-house' maintenance function. This approach has already been adopted on the Victoria Line system where maintenance of the radiating cable and repair of fibre optic cables has been outsourced. The extent of these assets will be known once a system architecture is defined and from where a view can be taken.

ATC equipment fitted to rolling stock is expected to be serviced by the Fleet team to the extent that the changing of line replaceable units to a fixed procedure can be carried out. The overall system and the analysis of faults, including the management of any safety signalling related software, will be the responsibility of Signals.

6.2.2 Second-Line Maintenance

As outlined in section 4.2.5 it remains the vision that following the installation post-warranty period that the repair and overhaul of S&TCS equipment (inclusive of train-borne signalling equipment), is conducted 'in-house' utilising the 'Centre of Excellence. However, further information will need to be obtained from the various S&TCS suppliers before a final decision can be made.

6.2.3 Third-Line Maintenance

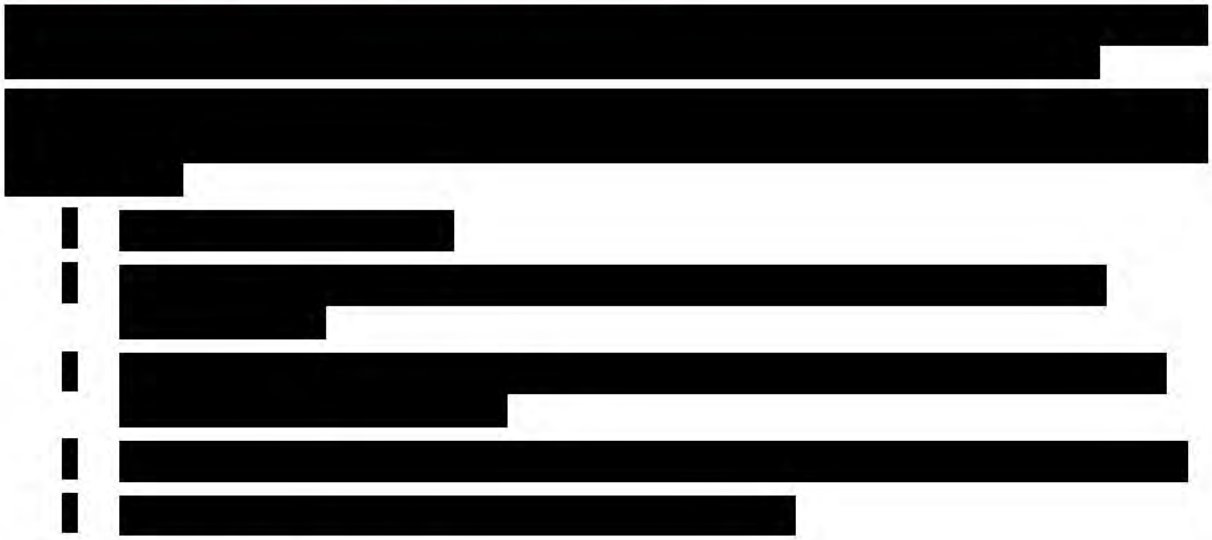
As outlined in section 4.2.5 it remains the vision that following the installation post-warranty period that the repair and overhaul of S&TCS equipment (inclusive of train-borne signalling equipment), is conducted 'in-house' utilising the 'Centre of Excellence. However, further information will need to be obtained from the various S&TCS suppliers before a final decision can be made.

overhaul is adopted, then it will become a requirement that LU Operations (Assets) is furnished with the equipment necessary to be able undertake these pre and post-tests.

6.3 S & TCS Maintenance Concept – [redacted]

6.3.1 First-Line Maintenance

[redacted]



6.3.2 Second-Line Maintenance

Please refer to section 4.2.5

6.3.3 Third-Line Maintenance

Please refer to section 4.2.5

7 S&TCS TRAINING REQUIREMENTS

S&TCS training for maintenance personnel is expected to continue utilising the type of training facility that has already been adopted for the Victoria, Northern, Jubilee and Sub-Surface lines.

This approach provides a complementary mix of theoretical and practical training which effectively imparts knowledge of the signalling principles involved whilst also providing a high degree of practical 'hands-on' experience within in a safe learning environment.

This method has proven to be successful in developing a highly skilled workforce capable of responding to various faults conditions as well as the capability of undertaking preventive maintenance interventions across broad range of assets.

It is recognised that the emergence of simulation and virtual reality technology provides a unique opportunity to develop a 'system wide' S&TCS training facility which retains the core equipment but provides a virtual railway system which the equipment interacts with. It is anticipated that the S&TCS training facility will combine these elements to create an S&TCS training capability that is unsurpassed in the railway industry.

A comprehensive set of requirements for the S&TCS training facility has been developed by the DTUP in collaboration with Key Stakeholders from LUL's Operational Learning Department. Supporting these requirements is a 'Training Philosophy' document which provides the narrative and rationale for the preferred training approach for DTUP.

8 S&TCS MAINTENANCE INVOLVEMENT IN THE DTUP PROGRAMME

8.1 Operational Upgrades & Asset Development Team

The Operational Upgrades & Asset Development Department (OU&AD) has a core team embedded into the DTUP programme. From an S&TCS perspective this team will serve as the day to day interface between the Programme and the wider maintenance community. This team should be considered as the 'first point of contact' with LUL Operations (Assets). Where the team has delegated authority from the various asset disciplines, then it will provide direct input into the programme. If not, then OU&AD will subsequently ensure that the appropriate representation is provided to the programme.

In order for this approach to be effective it is the responsibility of the Programme to ensure that its sub-programmes and projects plan effectively for when maintenance involvement is necessary. It is imperative that sufficient notice is given to allow the designated maintenance representatives to plan for the necessary time.

In this regard, it is expected that each project will embed into their schedule all activities which involve input from the maintenance organisation. The maintenance organisation will subsequently require that projects needs are 'rolled up' by the Programme and are presented to the OU&AD Team on a rolling one month 'look-ahead' basis. This look-ahead should provide clear information on what the planned activity is and what asset groups are affected.

8.2 Maintenance Introduction Group

Following the successful use of embedded Maintainers working collaboratively with the Supplier's on the Victoria Line Upgrade and 4LM, Operations (Assets) would be keen on adopting a similar approach on DTUP. This will be a small team (nominally 6-8 people, but actual numbers will be dependent upon DTUP's adopted signalling migration strategy) who are drawn from those lines where DTUP Signalling & Train Control assets will be installed. Their prime function will be to provide the programme with knowledge and experience of maintenance processes.

Use of a Maintenance Introduction Group offers a personal development opportunity to those involved, as well as providing LU Operations (Assets) with a resource who will have gained a greater depth of specialist knowledge and a level of experience than that which could normally be expected from a formal training programme. A broad outline of their intended remit and the perceived benefits are provided below:

- Design and Build

Working with the Supplier's and using knowledge and experience the Maintenance Introduction Group will be able to offer advice on the design and build to ensure maintainability of the system which will include installation, testing requirements and replacement of equipment.

- Human Factors Integration

The MIG team working with a Human Factors Specialist will ensure the signalling system meets human factor requirements for maintenance.

- Support of Factory Testing

Supporting factory testing will give the MIG team early and in-depth experience of the operational parameters of the system being provided, also allowing early feedback to the designers and input to the maintenance manuals.

- Review of Maintenance Manuals

Good quality manuals will be integral to producing maintenance procedures and instructions as well as forming the basis of training courses. The MIG team will review maintenance manuals to ensure they are correctly formatted and that they supply sufficient and detailed information to allow maintenance of the system.

- Document Review

The MIG team will be able to provide valuable input into as well as providing additional resource in reviewing the technical documentation for content and suitability for maintenance requirements.

- Involvement in Maintenance Demonstrations

The MIG team through supporting maintenance demonstrations will allow Maintainers to practically confirm the quality of the information contained within the maintenance manuals to ensure that it meets the requirements for producing maintenance procedures.

- Training Support

Training will be critical to ensuring all staff are competent to work on the new Signalling and Train Control system. Using in-depth knowledge gained from involvement in the DTUP Programme will allow the MIG team to assist in the development of the Training Needs Analysis (TNA) and to feed-back into the training requirements and maintenance course production. Their use has been seen to be particularly beneficial in assisting in the development of operational rules, which are traditionally not provided in the Supplier 'train the trainer' training packages, but are necessary to embed as part of end-user training delivery.

The MIG team will also be capable of covering roles for those who are required to attend training in support of future DTUP commissioning's. This will allow Operations (Assets) to be able to develop a staged training delivery programme which is seen as the preferred approach toward preparing maintenance staff for the delivery of assets into service whilst ensuring that there is sufficient coverage on the operational railway. This is particularly pertinent where staged signalling migrations are implemented and where there is likely to be a mix of skills needed to deal with both legacy and new signalling systems. Installation

Installation will fall in to two categories, Infrastructure Works (e.g. new points and crossings for End State Track Layout) and S&TC system Installation, both of which will benefit from MIG team involvement whilst expanding the knowledge base of the MIG itself.

- Testing and Commissioning

The MIG team, supporting the testing and commissioning of the assets will allow LU Operations (Assets) to gain further detailed knowledge and experience of local site information and how the system performs in the real world.

- Assurance

Supporting the project with LU Operations (Assets) staff early in the process will enable maintenance acceptance requirements to be clearly defined, ensuring a smooth handover

whilst also providing assurance and confidence that LU Operations (Assets) are ready to accept and maintain the new system.

- Supporting Maintenance Activities Post-Commissioning

After the first commissioning the MIG team will revert back directly to LU Operations (Assets) where they will directly support the maintenance requirements of the newly commissioned system. Their initial role will be responding to faults and failures and will also carry out preventative maintenance activities ensuring maximum availability of the new system. During subsequent section commissioning they will directly support the line based Maintainers, acting as mentors and dealing with repeat faults.

9 HANDOVER OF ASSETS INTO MAINTENANCE

The handover of assets into maintenance will be in accordance with Pathway. As part of the Pathway process, LU Operations (Assets) are key stakeholders in the development of the Pathway products involving Maintenance. In this respect, Operations (Assets) should be considered in the development of each Project's Pathway Product Management Plan (PPMP) so that it may understand its future obligations. The ongoing process for the management of these obligations should follow the requirements laid out in the future Programme level (Gate C) Maintenance Readiness Plan.

Effective Maintenance Readiness Plans alongside the considered development and effective management of the Mandatory Asset Information Deliverables (MAID's) are expected to form the cornerstones which facilitate the efficient transition of assets into maintenance by providing specific information to each project on what maintenance will require for effective asset maintenance in future.

It is recognised that there are circumstances in which certain maintenance information (such as 'as built' drawings) cannot be made available at the time of an asset being brought into operational use. Under the Pathway structure, this would essentially mean that the requirements necessary to sign the requisite Project Completion & Handover Certificate (PC&HC) have not been met.

Under these circumstances, and where it is absolutely necessary to ensure that maintenance coverage is available once an asset has been brought into use, then an Interim Maintenance Readiness Statement should be developed and agreed between the project and maintenance well in advance of any future commissioning's. This document will serve to ensure that sufficient provisions are in place to enable maintenance to be undertaken in lieu of a set of finalised PC&HC requirements.

Interim Maintenance Readiness Statements are expected to have a 'shelf-life' associated with them which gives a project time to gather the full suite of maintenance requirements. Once this 'shelf-life' has expired, then responsibility for the assets maintenance will be returned back to the project.

10 SPARES & TOOLS

10.1 Spares - General

The provision of spares is an important aspect in the maintenance of the S&TC system. Spares need to be stored in locations that would minimise 'Time-to-Fix' times as well as

being accessible to facilitate the planned, periodic maintenance of the various parts of the system.

These two differing demands necessitate a combination of both a centralised store, expected to hold a full range of spares to satisfy planned maintenance needs, and a series of ‘satellite stores’ capable of holding a small amount of critical spares that support the requisite 'Time to Fix' times.

Although yet to be determined through the production of the system architecture, the location of the store(s) will need to be strategically placed so as to increase accessibility on a ‘round the clock’ basis thereby reducing the potential for delays to the Underground in the event of a failure.

In order to reduce costs it is envisaged that ‘Satellite Stores’ will not be separate buildings but are instead expected to become an integral part of the equipment rooms used by the system. These will include local SER’s and any Control Room SER’s. The DTUP programme will need to ensure that this requirement is included in the design of equipment rooms

The quantity of spares held is an important factor, particularly for the satellite stores where space is likely to be at a premium. It is therefore crucial that the right level of spares is identified and where they are best held. To facilitate the development of this, a ‘spares listing’ is seen as a critical output from the DTUP programme.

10.2 Spares Listing

Identification of a logical stock profile becomes extremely important for effective stores management. The development of a spares listing forms the basis of a risk based spares strategy and must be determined through a study of the reliance of the equipment, its criticality to the functionality of the system and the present and future availability of the parts.

Naturally there is heavy reliance placed upon the Manufacturers/Supplier to provide recommendations for spares in the first instance.

However, it is vital that these recommendations are fully considered and that the Supplier is provided with ‘scoring’ criteria to optimize the quality of any recommendations made to LU.

Considerations for the ‘scoring’ criteria are:

- Does the equipment represent a single point of failure?
- What is the likelihood of failure of the equipment based upon its most vulnerable component (reliability/redundancy)?
- How critical is the equipment to the operation of the system?
- What is the expected vulnerability of the equipment? Is it in an exposed place where damage/deterioration is likely
- What are the envisaged lead /turnaround times of supply for each item of equipment?
- Is there any contractual or warranty requirement to use the Supplier’s Assets or can similar equipment be bought commercially ‘off the shelf’?
- Can existing spares be used?
- Is the asset perishable? If so, what is the shelf life?

- Are there any special storage arrangements required? i.e. humidity/temperature controlled environment
- What are the expected sizes and weights of spares items

It is envisaged that under the terms of the Suppliers contract there will be a requirement to provide 'system' spares which from previous Programme's have been quantified against a contractually agreed value. It is important that the scoring criteria developed is both robust and rigidly applied because failure to do so could result in the Supplier providing uncritical, perishable and bulky expensive-to-store equipment as part of the system spares list.

10.3 Development of an Equipment 'Reliability' Database

Suggested spares are often evidenced through the Manufacturer/Supplier's Failure Mode and Effects Analysis documentation (FMEA) and RAM data. Whilst this information does provide a logical baseline on which to determine a preliminary spares list, it is quite often the case that the data will be based upon the findings of controlled factory test results and may not be truly reflective of the fault modes of equipment operating under the variable environmental conditions found 'in the field'.

In this respect it is vital that equipment failure modes are continuously monitored and recorded to build a database of actual failure trends of 'real world' equipment. Equipment should therefore be monitored on a site by site/ train by train basis to capture both generic trend data as well as being used to identify 'localised' problems.

The development of this database will become critical in determining the appropriate stock profile outside of those suggested by the Suppliers RAM data.

It is expected that the database is initially developed by the DTUP Programme and should capture RAM data once the equipment has been 'powered-up' for testing purposes, facilitating the potential to identify early mortality rates for various items of equipment.

10.4 Tools

It is imperative that maintenance activities are undertaken using appropriate tools, ensuring the equipment is effectively maintained and preventing accidental asset damage or injury to the user. An understanding of the system tasks through Human Factors task analysis, will determine what actual tooling is required to maintain the new S&TC system. This analysis should also identify what items are currently used by maintenance and a simple 'gap' analysis should then be undertaken to determine an appropriate tools listing.

Specialist tools should also be identified by the Supplier along with the quantity required which will be determined by the staff levels and their geographical distribution.

Once developed, the tool listing will also highlight any equipment that requires specialist support, such as calibration, software licences for analytical data and so on. Similarly, the tool listing also provides the opportunity to identify any training that may need to be considered in the use and operation of tooling.

11 WHOLE LIFE COSTS

In order to maximise the expected benefits from the introduction of the new Signalling System, the DTUP programme should always consider the associated whole life cost of it to London Underground Limited.

Reductions in future maintenance costs are an important component in achieving lower whole life costs. These reductions can be attained through properly considered designs such that cost savings become an inherent part of them. This concept has already outlined several means by which appropriate designs will improve efficiency, however further consideration should also be given to the following:

- All signalling system components shall be designed to have a long life with overhaul requirements defined by the whole life cost model under full operational conditions.
- The Signalling & Train Control System should be designed such that all cables are maintenance free as far as possible.
- Cables are accessible and have convenient test points frequently located to aid 'end to end' testing.
- Where feasible, software should be bought and available to all, not limited by licence use.
- Redundant assets shall be decommissioned and removed, unless otherwise agreed with the Sponsor.
- The Signalling & Train Control System should be built to ensure the system has sufficient capacity so that any future expansion can be achieved without the need for significant equipment upgrades.

The principle to reduce Whole Life Cost forms part of the Sponsors Requirements and is a key DTUP Programme objective. Whilst it remains the responsibility of LU Operations (Assets) to manage the costs effectively once the system has been accepted into maintenance, it remains the DTUP Programme responsibility to ensure that the relevant Sponsor is involved with any business case evaluations regarding whole life cost. This requirement is to include any changes to programme scope where the LU Operations (Assets) are materially impacted; (or example, changes to operating efficiency or maintenance contracts.

12 WARRANTIES

It is recognised that there will be a warranty period associated with the S&TC system hardware and software. Management of these warranties is expected to be the responsibility of the Maintenance Organisation once the system is brought into use on the operational railway.

The terms of these warranties have, through experience, been such that they have often expired long before the associated equipment has been brought into operational use, thereby inhibiting the maintenance organisation obtaining the necessary repair or replacement of defective items of equipment, or to remedy any software errors.

To ensure that recourse (through warranty) for defective equipment or software remains available at the point of bringing into operational use, it is vital that LU Operations (Assets) are afforded time to review the warranty before it is agreed. The warranty should therefore provide for opportunities for amendments both from the Supplier and LUL to reflect any changes in the delivery of relevant products.

Warranties should provide absolute clarity for both the Supplier and LUL on;

- What is covered by each warranty

- What won't be covered by each warranty
- The point at which each warranty will commence
- The point at which each warranty will end

13 OBSOLESCENCE

It is a fundamental requirement that the Supplier commits to managing obsolescence so that the maintenance organisation retains the capability of ensuring a safe and reliable railway. It is therefore imperative that spares of any specialist equipment that is developed for use by the S&TC system remains available, along with a commitment to provide support on an on-going basis and throughout the expected asset life of 40 years.

However, it is recognised that the final signalling solution will inevitably involve many computer and processor based sub-systems which are expected to be bought 'commercially off the shelf' by the Supplier. Given the pace of technological advancement in this area, it would be unrealistic for a Supplier to guarantee the availability of a particular computer or processor over the requisite 40 year life span.

Whilst this could be mitigated through securing a large quantity of spares, this would be contrary to the maintenance philosophy where the emphasis is on reducing stock holdings recognised as being inherently expensive to the organisation to support.

In this respect, consideration should be given to the provision of a 'mid-life' upgrade, which will see each of the computers and other processor based equipment being replaced with modern equivalents, thus ensuring a guaranteed spares availability in future. The Supplier should be capable of recommending the point at which the mid-life equipment upgrade is undertaken based upon a combination of its RAM's figures and knowledge of the market from where it secures its COTS equipment.

14 ONGOING SUPPLIER SUPPORT

Given the specialist nature of the Signalling & Train Control system, and in particular the software developed for its operation, the maintenance organisation will often require ongoing technical support from Supplier's. It is envisaged that there will be several areas where the option to seek ongoing technical support from the Supplier(s) may be considered prudent, if not necessary, to ensure effective coverage that supports the Underground's operation from the moment the DTUP first migration area is brought into use on the operational railway.

A brief description of the expected type of support options are provided below:

14.1 Design Authority Support

This ensures that the Supplier is capable of providing long-term technical knowledge and expertise so as to continue as the Design Authority for any required changes to the Signalling & Train Control System post-warranty.

14.2 Technical Advice Support

The purpose of this will be to provide LU Operations (Assets) with access to the Supplier's technical experts who will be able to offer advice and guidance on all aspects of the S&TCS. This will be a crucial element for the first-line maintainer, particularly in the formative stages when familiarising themselves with the system. It is envisaged that there will be an on-site

support capability available in the initial stages of the system being brought into use, progressing towards a remote support structure at a later date.

14.3 Technical Investigation Support

This service will be necessary in providing the maintenance organisation with the capability to call upon the knowledge and expertise of the supply chain in resolving ongoing Signalling and Train Control issues which are not clearly understood, or which cannot be resolved through first-line maintenance intervention.

Technical Investigation Support is expected to provide LU Operations (Assets) with the means by which the root causes of regularly occurring faults can be established and eradicated.

14.4 Technical Information Support

To support the maintenance organisation, the Supplier is required to manage the technical information for the S&TCS by maintaining an electronic library (Including documents provided by LU, Operations (Assets) including assurance submissions and background information.

This will ensure that any book wirings, manuals and so on, are updated in line with any change in software/hardware made by the Supplier during migration, change in Grades of Automation or any other post commissioning refinements.

14.5 Engineering & Maintenance Support

This service is to enable the supply chain to support modifications, performance initiatives and maintenance efficiencies during the operation of the Signalling & Train Control System and would allow for such items as the provision of advice in connection with any recommended modifications to the system intended to improve maintenance efficiency and reduce whole life costs.

Technical support will also need to be available to cover any corrective changes, updates or amendments to the system's software. This support is expected to be available throughout the expected life-span of the system (40 years) and should provide coverage for all aspects of the S&TC system.

This would then be expected to extend to the Supplier acting as the Design Authority (and providing Design Authority Assurance therein) when implementing any agreed software/ hardware modifications.

14.6 Training Facilities Support

Ongoing technical support will be required to ensure that any S&TCS training facilities developed by the Supplier for use by the maintenance organisation remains fully functional and continues to develop and evolve in line with the railway system that it should be reflective of.

In this respect there will be a need for Supplier support to undertake the diagnosis and rectification of any hardware or software faults occurring in the training system (inclusive of any simulated environments) which cannot be remedied by LU Operations (Assets). Supplier support will also be required where any future changes in the system are necessary or where there is a particular fault or scenario emerging from the operational railway which may need to be 'programmed' into the system to enhance the realism of the training facility.

14.7 Repair & Overhaul Support

Dependent upon the selection of a 2nd or 3rd line maintenance approach, different support will be required. These are portrayed under the following scenarios:

- Scenario 1

As outlined in Section 4.2.5 it remains the vision of LU Operations (Assets) that 2nd line maintenance function will be undertaken 'in-house'. If this vision is realised then there will be a requirement to secure supplier support which can provide specialist advice to the 'Centre of Excellence' when required.

- Scenario 2

Should it be found that the vision for an 'in-house' 2nd line maintenance facility is not achievable, or that the repair and overhaul element is better outsourced as a 3rd line function then a maintenance support contract will be needed which supports this requirement for the expected lifetime of the asset.

14.8 'Mid-Life' Obsolescence Support (Option)

As most S&TC systems are now processor based, there remains a risk that several of these assets may become technologically obsolete well before their expected life-cycle is reached.

An option for mitigation against this situation could be to implement a Support agreement which requires the Supplier's to 'upgrade' processor based equipment at pre-defined periods. This will ensure that S&TCS capability can develop in line with future advancements in technology whilst retaining a system where obsolescence risk is eliminated.

Transport for London
London Underground Limited

DTUP OMC Volume 2, Part 5
Operational Control System
Maintenance Concept

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TABLE OF CONTENTS

1. Introduction

The Deep Tube Upgrade Programme (DTUP) will provide extra capacity through the renewal of ageing assets on the Bakerloo, Central, Piccadilly and Waterloo and City lines.

DTUP's core scope is the delivery of new rolling stock and signalling assets. The new trains, operating in conjunction with a new signalling system capable of Automatic Train Control (ATC) operation, will facilitate the business vision of a more frequent and reliable and cost efficient service.

With the addition of modernised train depots, up-rated power supplies and optimised track layouts, the DTUP railway will provide London with a transport facility capable of keeping pace with an ever-growing capital city over the next 40 years.

As part of the upgrade package, the DTUP is expected to deliver a Railway Control System (RCS) comprising two discrete sub-systems; a Signal & Train Control System (S&TCS), which will enable the ATC signalling capability, and an Operational Control System (OCS) which will offer a centralised control & information capability for other systems outside of those afforded by the signalling control system but nevertheless remain critical to the running of the operational railway.

The OCS element of the RCS is envisaged to deliver a secure data communications network which possesses a high level of reliability and is tolerant to fault conditions. The OCS is expected to support the immediate operational business through the provision of a system capable of delivering control commands to external equipment from the Line Control Room(s) environment and also in the transmission of the returning equipment status information.

In addition, the data transmitted via, or self-generated by the OCS, should be capable of being accessible as a 'read only' function to other users 'outside the walls' of the Line Control Room(s). This data will provide a rich source of both operational and asset information to the wider London Underground business.

Ease of connection will be an important aspect in the design of the OCS. Connectivity to the OCS network should facilitate the introduction of additional equipment in future and also provide the capability to connect into the network for the real-time streaming of, or the subsequent retrieval of historical data, from anywhere across the LU network.

The purpose of this particular Maintenance Concept is to describe the maintenance vision for the Operational Control System elements of the Railway Control System.

The Document seeks to provide a concept that outlines the intended use of the OCS (from a Maintenance perspective), how the OCS it is expected to be maintained throughout its lifecycle and what elements will be required to support that ongoing process. Its purpose is to clarify the maintenance vision and to provide a set of rationales which support the development of any subsequent Maintenance User Requirements.

2. Document Boundaries and Exclusions

2.1 Document Scope

This Concept forms Volume 2, Part 5 of the Deep Tube Upgrade Programme Operations & Maintenance Concept (O&M). It is focussed on the maintenance aspects associated with the Operational Control System element of the Railway Control System to be introduced on the operational railways of the Piccadilly, Central, Bakerloo and the Waterloo & City lines by the Capital Programme Directorate Deep Tube Upgrade Programme. The document should be considered as being applicable for all Grades of Automation (GOA).

2.2 Document Exclusions

The OCS Maintenance Concept does not provide specific information on the maintainability of the Signalling & Train Control System nor does it deal specifically with the supporting 'enabling' infrastructure (buildings, power supplies, CRMS etc.) expected to be installed in support of the OCS system.

In respect of supporting 'enabling' assets; as the current approach toward the maintenance of them is not likely to change in future, it is envisaged that further maintenance concept documentation will not be required or provided. However, it should be recognised that any new or novel infrastructure intended to support the OCS will ultimately have its own associated set of user requirements.

The OCS Maintenance Concept is intended to outline the Maintenance vision for the OCS. The narrative of this Concept provides an outline, but does not provide detail in respect of Operational concepts associated with Line Service Control or any wider Business Operations. The DTU Programme should therefore identify and seek input from these Key Stakeholders to ensure completeness in respect of user requirements.

2.3 Planned revisions and how the document will be updated

The Operational Control System Maintenance Concept forms the Volume 2, Part 5 component of the DTUP Operations and Maintenance Concept (OMC).

The OMC is a configuration managed document that will evolve as the DTUP programme progresses. Elements of the existing volumes, including this OCS Maintenance Concept, will require greater development and future volumes are dependent upon a greater level of system knowledge. As such, the OMC will be updated, and re-released as required, to incorporate new developments as the programme evolves.

All releases will be executed in line with the Change process outlined in Volume 1, Part 1, Section 7 of the DTUP Operations and Maintenance Concept (OMC).

3. The Maintenance Vision for DTUP's OCS System

3.1 Core Maintenance Principles

The four core maintenance principles on which this OCS Maintenance Concept is based are those of Reliability, Availability, Maintainability and Safety. The DTUP programme should consistently apply each of these principles during the procurement, design and installation stages of the future system. This approach will be vital in ensuring an OCS that is fit for purpose, safe to maintain and will fully realise the benefits expected from such a large upgrade programme.

3.1.1 Reliability

It is a fundamental requirement that the OCS system remains dependable in operational use and performs consistently in line with its agreed specification. The system should be developed to achieve high reliability rates and designed with a high level of fault tolerance.

3.1.2 Availability

In order to mitigate against the impact of such occurrences, prime consideration will need to be given in ensuring that the OCS system is sufficiently resilient so that in the event of failure the railway is able to sustain the timetabled level of service until the failing condition can be resolved.

In this respect, asset availability is a fundamental design consideration. Single points of failure should be eliminated where practicable and there should be a significant level of redundancy designed into the system which affords time for Maintenance to both respond to and

subsequently rectify the failing condition without affecting the ongoing operation of the railway service.

3.1.3 Maintainability

Whilst ensuring an inherently high level of reliability it is also important that this reliability is not dependent upon high levels of maintenance. The OCS should be designed such that the required level of maintenance associated with the system is kept as low as practicable thus ensuring that the cost of ongoing planned, preventative maintenance is similarly kept low.

Although a key principle of this maintenance concept is to reduce, as far as possible, the number of failures through inherent system reliability and availability, it is recognised that there will inevitably be failures that occur over the lifetime of the assets.

It is therefore essential that faults can be identified easily and faulty equipment changed quickly and efficiently. Whilst there are currently no established maintainability targets for what will be a fundamentally new system, the importance of the OCS in assisting with operational railway decisions should dictate that the system is capable of being repaired within a reasonable time frame. Subject to the development of a RAM analysis, the time which the OCS system should capable of being restored to operational status after a failure occurs, should be assumed to align with the current benchmark for S&TCS Service Affecting Failures (SAF) which has a 'Time to Fix' time of 20 minutes.

Where periodic maintenance is a necessity there should be a design focus ensuring that the times between planned maintenance activities are extended as far as possible without increasing the risk of failure to the OCS.

3.1.4 Safety

London Underground has a fundamental commitment to the health, safety and wellbeing of all employees engaged in maintenance activities on the assets. The introduction of a major upgrade offers a unique opportunity to ensure that the hazards associated with any maintenance activities are either eliminated entirely or are reduced as low as is reasonable practicable (ALARP), through the implementation of effective design management.

However, it should be recognised that the operational railway can be a demanding environment in which to work, particularly under abnormal, degraded or emergency modes. In this regard a greater emphasis should be placed upon the system designers to ensure that the risk of human error is mitigated and the potential for accidental loss reduced.

4. Use of the OCS System

The OCS will be a critical element in ensuring that each DTUP line continues to operate effectively through normal, abnormal, degraded and emergency modes. This will be achieved through a secure communications network capable of providing control and information functionality between various railway assets and the Line Control Room(s). The control element will allow for remote switching capability on selective assets, whilst the information element will provide real time asset health and status data drawn from the various railway sub-systems. This OCS information stream is expected to inform the DTUP Line Control Room(s) of the status of the immediate railway environment outside of those already provided through the S&TCS control and information conduit. This information will be fundamental in establishing the current operational picture which will in turn, facilitate the appropriate and most effective operational and maintenance management response.

The introduction of a DTUP OCS also offers a significant opportunity for the wider LU business. Essentially the OCS can be viewed as a communications conduit which not only has the potential to transport data to the Line Control Room(s), where ‘packets’ of real-time information can be ‘siphoned off’ to provide the relevant data according to the various Operator roles, but could also then extend beyond the boundaries of the Line Control Room so that it can be accessed by other users, external to the Line Control Room, that would have an interest in the data being transported via the conduit.

This conduit also presents an opportunity to distribute not only the ‘traditional’ OCS data usually required by the users in the Line Control Room(s), but also the data drawn from other assets, which could then be distributed across the wider organisation and provide the capability to monitor the current state of the railway and its assets, provide notifications regarding the health of various sub-systems, diagnose faults and predict the maintenance needs of these systems in a far more pro-active way than that afforded in the past.

In this respect the DTUP OCS should be seen as one of the supporting pillars in the creation of a much broader corporate 'big data' network which allows data generated from DTUP assets to be accessed by various stakeholders across London Underground for the purposes of improving its services. Indeed, London Underground's Maintenance Modernisation Team is currently developing a future maintenance strategy based around this principle. The "Predict and Prevent" strategy emphasises the need to capture and store asset data which can be analysed and inform any subsequent decisions in improving asset performance. Further details of the Predict & Prevent approach is provided in the DTUP Operations Vision and Transformation Statement (Vol 1, Part 2, section 4.1.4) of the OMC.

It is envisaged that the OCS will be designed to be a secure data network which is both scalable and flexible enough to allow equipment in the future to be easily connected to the 'front-end' of the conduit allowing the requisite equipment data to flow through, and beyond, the walls of the Line Control Room.

Connectivity beyond the Line Control Room(s) could be facilitated by the DTUP through the provision of network portal(s). The use of portal(s) will give an inherent flexibility in the system sufficient enough to allow any future connectivity required by London Underground to be established

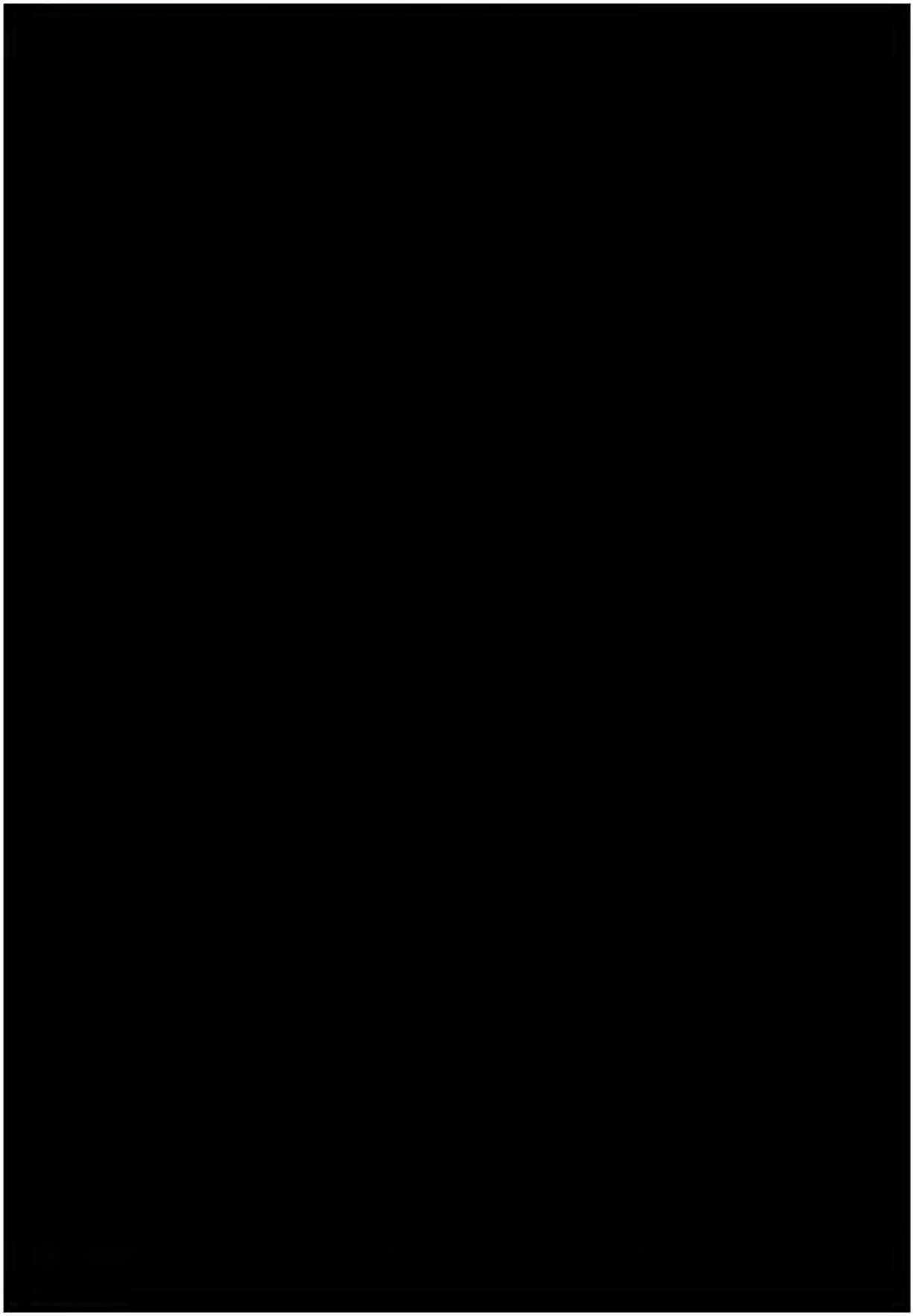
Portals should allow for connection into the 'real-time' data feed or into a Data Warehouse (described in OMC Part 4 & 5), allowing for the later retrieval of stored data if required.

5. Desired OCS Maintenance Functions

Figure 1 assumes a block diagram of the future OCS system for the DTUP railway. The letters A-F indicated in the diagram should be used in conjunction with the following text which provides a rationale and highlights desired system functionality.

It should be recognised that the diagram is not intended to prescribe any specific design solution, or to prescribe any particular equipment location. It remains imperative that flexibility in system design is afforded to the DTUP Programme in collaboration with its Supplier's so that an optimised solution for the Underground is found. In addition, the names used for various aspects

of the system should only be considered as a reference used to assist in the understanding of the concepts outlined in this document.



5.1 The OCS 'Network Monitoring Tool' A

Effective asset management of the Operational Control System (OCS) will be a critical element in ensuring that each DTUP line continues to function at its optimum levels. A key element towards achieving this goal is the capability to continuously monitor the status and performance of the system.

To facilitate this need it will be necessary to provide a type of 'Network Monitoring Tool' which has the capability to continuously monitor the operation of the equipment associated with the OCS Communication conduit. The OCS Network Monitoring Tool should include the following functionality:

5.1.1 OCS System Status Monitoring

The OCS 'Network Monitoring Tool' is expected to provide a 'real-time' system condition status monitoring which will indicate both healthy and failed OCS system equipment. It is envisaged that this information will be displayed at the Operational Control Centre using an appropriate Human Machine Interface (HMI) /Graphical User Interface (GUI)

The 'condition status' element should be capable of instantaneously providing an indication highlighting the failure of any active 'on-line' systems as well as any 'stand-by' systems. This indication should be supported by the provision of a set of time-stamped and prioritised alarms which allows for the immediate assessment and response to the reported fault.

5.1.2 OCS System Health Monitoring

The provision of an intelligent health conditioning monitoring solution as part of the OCS Network Monitoring Tool is also required. This component of the overall condition monitoring package is expected to be capable of recognising a decline and/or a rate of decline in OCS performance at both a system or asset level will be an important element in the development of a desired 'just in time' maintenance intervention strategy.

5.1.3 OCS System Diagnostics, Interrogation & Equipment Configuration Capability

In addition to the condition monitoring functionality, the OCS Network Monitoring Tool is envisaged to provide a system interrogation diagnostics capability which supports fault-finding on all aspects of the OCS in the event of a failure.

Another desired aspect is the capability to configure equipment remotely. Although most equipment is expected to be of the 'plug & play' type, where this is not possible then it would be desirable to be able to configure any replaced equipment associated with the OCS communications conduit directly from the Control Room without the need to undertake these activities on site.

5.2 OCS Maintenance Interface 

The information from the Network Monitoring Tool is envisaged to be displayed on a dedicated OCS Maintenance Interface. This interface will become the principle means by which a Maintainer will interact with the OCS and allows them to undertake all the functions that can reasonably be expected of their role in respect to monitoring OCS health status, system interrogation, ascertaining current configuration data, failure diagnosis and rectification. For ease of use and effective issue identification, this information is envisioned to display a graphical representation of OCS operation at both network and sub-systems level.

5.2.1 OCS Maintenance Interface Distribution

In the event of Line Control Rooms being placed at different geographical locations, then an OCS Maintenance Interface should be provided at each individual Line Control Room so that the status of each OCS pathway can be monitored at those locations. This approach would also be appropriate where temporary Line Control Rooms are required to facilitate a DTUP Programme Migration Strategy solution.

Conversely, if all Line Control Rooms are sited at one location then there remains a possibility that a single OCS Maintenance Interface may be sufficient for monitoring of the whole OCS system.

5.3 OCS Portal(s) C

The capability to draw information passing through the OCS conduit so that it is accessible to users outside of the Line Control Room is an extremely important element to future OCS capability. With the business drive towards an efficient and integrated incident management approach, the Network Operation's team needs to liaise closely with each of the Line Control Rooms. This requires that both are furnished with information regarding the current status of the railway so they are able to assess arising incidents and respond to them accordingly.

Similarly there is also a need for various user groups to be able to collate asset status information over a period of time which allows a picture to develop regarding the effectiveness of the current maintenance regimes and informs the development of future strategies.

In this respect there is a need to provide a 'real-time' connection which allows various user groups to see operational states 'as it happens' on the railway. Similarly, there should also be a portal which allows for connection into, and any subsequent retrieval of, any historical data stored in the 'Data Warehouse'.

An indicative list of the various users and how they may utilise the data passed via the OCS conduit is outlined below. This list shouldn't be considered as exhaustive.

User	Data Use
London Underground Control Centre (LUCC)	For Alarm and alert Management purposes (specific assets)
Fault Report Centre	For Alarm and alert Management purposes (specific assets)
Building Management Services	For Alarm and alert Management purposes (specific assets)
Maintenance Modernisation (Predict & Prevent Team)	For analytic purposes, reporting and asset investigation
Telecoms and Information and Communication Technology (ICT)	For Analytical purposes and some alert information

Note: - Volume 1, Part 2 (Continuous Improvement) provides further information on potential User groups.

5.4 Data Warehouse (D)

Access to historical data will be an important aspect in building a picture of the reliability of both the OCS itself as well as the external interfaces feeding data through the OCS conduit.

In this respect there should be a mechanism by which all the data can be captured and stored in the longer term. It is envisaged that a large data base of information relating to the operation and behaviour of the OCS system will be stored in a 'Data Warehouse' alongside the historical data drawn from other systems such as the S&TC and [redacted].

To aid subsequent retrieval it will be important that all stored data is readily identifiable and is date and time stamped.

It is envisaged that the Data Warehouse will be accessed routinely to allow for the subsequent reading and writing of data. To facilitate this need, it is expected that the Data Warehouse will be capable of providing unconstrained access for users to run either real-time or non-real-time processes without compromising the Data Warehouse's capability to continue recording real-time operational data.

It is not yet understood how long the data in the Warehouse will need to be stored for. On this basis it should be assumed that the data will need to be capable of being stored for the lifetime of the asset until otherwise determined through the design stages.

Although the Data Warehouse will most likely be placed at a single location (nominally shown as being in the Control Centre- see note below) it should have the capability of being accessed remotely by various users through the portal arrangements outlined in 5.3.

Note:- Although the Data Warehouse in shown in Fig 1 as being an integral part of the OCC, it should be recognised that the actual location of the Data Warehouse should be determined through discussions with the wider LU business. This will establish the corporate vision on how it the business may want to utilise, store and retrieve such data in future.

5.5 OCS Operators Interface/ Other OCS Internal Users

There are several Operational personnel, internal to the Line Control Rooms who are expected to utilise OCS information as part of their role. For conceptual information relating to these users and the intended purpose of the OCS Operators interface(s), please refer to OMC Operational Concept 'DTUP Operations Vision & Transformation Statement Volume 1, Part 2 *'RCS Human-Machine Interface Characteristics'.*

5.6 OCS External Users

In the context of this document, the term 'External Uses' refers to those Stakeholders who are internal to London Underground but are located externally from the Line Control Room(s). External users broadly fall into two categories; those who are integral to the wider railway incident management organisation and those who will need to access data for analytical purposes.

It is envisaged that those involved with incident management will receive information through the provision of a HMI. It is currently understood that major assets including S&TC and Rolling Stock will be procured with their own HMI that can acceptably be used for maintenance alarm management. The maintenance users do not require separate assets to be incorporated into a single HMI. However all notifications of DTUP, either new or upgraded have to be presented to the location where they can be managed. The HMI 'front-end' should therefore be capable of translating the incoming data into an appropriate format suitable for its intended audience and this may include the LUCC and the APCC. The HMI should be capable of generating a prioritised set of alarms which inform the user and allow for the instigation of an appropriate operational response. Alerts are also expected to be provided to other parties who need to be aware of any arising operational issues, but may not form part of the initial response.

It is expected that the DTUP Operational Upgrades & Asset Development Team (OU&AD) will facilitate the development of an alarm strategy which will establish the responsibilities for alarm and alert management between the Line Control Room and various external users. This will be an ongoing process which will be concluded once the capabilities of the full system are understood. During this time the DTUP Railway Control System (RCS) Team will be expected to

work in collaboration with the DTUP Operations Team in developing the technical requirements to support this strategy.

Users who require access to data for analytical purposes will do so with the intention of utilising the information to continuously improve the wider business performance. It is envisaged that these users will utilise 'raw' data and will develop their own bespoke 'front-end' interfaces. The DTUP must ensure engagement with these users so that a compatible message format can be established.

It should be noted that external users are not expected to have any direct control over assets via the OCS Conduit (Read Only).

5.7 Loss of the Operational Control Centre (OCC)

Due to the critical nature of the OCS to the operational railway, it is important that the capability to send/receive transmissions, access/record data, and to monitor the OCS system are retained in the event of a loss of the main Operational Control Centre.

6. Maintenance Levels (Definitions)

There are various types of maintenance interventions that have to be undertaken on the OCS and it is recognised that there are different, often interchangeable terms used across the network, to describe them. For this reason, and to promote a common recognition of the terms used throughout this document, these interventions have been categorised into four levels: system monitoring; First-Line; Second-Line; and Third-Line maintenance activities. These are outlined in the table below (Fig 2).

Category	Maintenance Activity
System Monitoring	Monitoring OCS for Faults
First-Line Maintenance (Incident)	First-Line Response
	First-Line Corrective
First-Line Maintenance (Preventive)	Periodic Maintenance (Planned)
	Preventive Corrective (Unplanned)
	Routine Change (Planned)
Second-Line Maintenance	'In-house' Overhaul & Repair
Third-Line Maintenance	'Out-sourced' Overhaul & Repair

Fig 2 – Maintenance Intervention Categorisation

6.1 System Monitoring

Activities associated with monitoring the ongoing 'in-service' performance of the OCS system and to identify any degradation in system performance, arising faults and failing conditions.

6.2 First-Line Maintenance (Incident)

First-Line maintenance (Incident) has been sub-divided to encompass both response and corrective maintenance. These describe two different reactive activities with first-line response referring to the action of providing the initial investigation into an arising issue whilst first-line corrective refers to the action of actually rectifying the fault. These actions have been separated due to the demarcated responsibilities for assets within the current maintenance organisation. As an example, it may be the case that the first-line response will pin-point a fault and rectify (i.e. complete the first-line Corrective action) or, having located an asset at fault, will need to pass the first-line Corrective element to the owner of the asset who would have the appropriate knowledge, equipment and experience to effect a repair.

6.3 First-Line Maintenance (Preventive)

In this context, *preventive* relates to both the unplanned and planned maintenance activities seen as necessary to ensure the continued and effective operation of the system. Planned maintenance refers to scheduled maintenance activities which takes place on a regular basis.

Unplanned activities are those which arise from assets that are identified as needing additional attention outside of the planned maintenance schedule due to excessive wear or where they have been found to be problematic.

First-line Preventive also relates to the planned activity of 'Routine Change' which, as the name suggests, is the activity associated with the planned routine changing-out assets which are time expired or are due for overhaul.

6.4 Second-Line Maintenance

Second-line maintenance describes the process for repair and overhaul when equipment, returned following a first-line maintenance intervention, is sent to an 'in-house' facility equipped with the capability of undertaking the work.

6.5 Third-Line Maintenance

Third-line maintenance is considered to be the repair/overhaul of equipment, returned from a first-line maintenance intervention, which is undertaken by the Supplier or a nominated sub-contractor with Supplier involvement. Under this arrangement there is seen to be no second-line maintenance involvement other than the equipment passing through the Underground's 'in-house' maintenance stores facility which is used as a 'staging-point' to facilitate the recording and storage of defective items prior to Supplier collection and their subsequent return.

7. Maintenance approach to OCS

7.1 System Monitoring

The primary Control Room role associated with the activity of monitoring the OCS will be that of the OCS Maintainer. As part of their general duties, the OCS Maintainer is expected to be responsible for monitoring the ongoing status and performance of the OCS system and to identify any arising faults and failing conditions.

Maintainer coverage is currently based on the assumption that the individual line Control Rooms for each of the DTUP lines will be based at the same location. Although part of the DTUP

Operational Control Centre, they are expected to be separate entities and not amalgamated to form one ‘all encompassing’ Control Room.

It is envisaged that there will be a maintenance presence in the Control Rooms which will provide monitoring coverage of the OCS on a daily basis. The extent of this coverage will be determined through a subsequent RAMS analysis as to the criticality of the system. It is not yet understood if the OCS maintenance presence will be required for each of the Line Control Rooms or if there will be one core maintenance team which will service the whole OCS network. This will be determined once the key factors of line migration sequences and the extent of OCS line integration are understood.

Although the OCS Maintainer is currently implied as a specific role, it is likely that, in practice, the duties of the OCS Maintainer will be fulfilled by the ‘Control Room Signal Technician’ (CRST). This represents a new approach towards the OCS Maintainer role. This function has traditionally been undertaken by Control and Information Engineers due to the specialist knowledge required for telecommunications based systems. However, with the advancement in technology being used for signalling and OCS systems becoming increasingly comparable, there is the opportunity to integrate the roles of the Control Room Signal Technician and the OCS Maintainer.

Although the integration of the OCS Maintainer and CRST roles remains the aspiration, the final organisational structure will ultimately be dependent upon the development of a Human Factors workload analysis study which will identify if this is feasible.

7.2 First Line Maintenance

It has not yet been determined if the First-Line incident and First-Line planned maintenance activities (see: Maintenance Level Definitions section 6) associated with the OCS system will be undertaken ‘in-house’ or will be outsourced. This will be determined once the hierarchy of the OCS and its complexities are understood.

It should be noted that First-Line maintenance of the sub-systems that providing data into the OCS conduit are not expected to form part of the OCS Maintainers responsibilities, but will instead reside with the existing nominated Asset Stewards, or with those Suppliers who are contracted to maintain sub-systems on behalf of London Underground Limited.

7.3 Second-Line Maintenance

It is expected that the design of the OCS system will comprise existing 'off the shelf' equipment which are relatively low cost whilst also being highly tolerant to obsolescence due to marketplace competition. As a result it is envisaged that this that the most cost effective approach will be to replace rather than to repair any equipment that becomes defective. It is therefore not expected that an 'in-house' second-line maintenance capability will be required to support the OCS. However, a decision on whether a second-line maintenance capability will be needed will be made once the system architecture and equipment is better understood.

7.4 Third-Line Maintenance

It has not yet been determined if an out-sourced Third-Line Maintenance capability will be needed to provide repair and overhaul support to the OCS. It is possible that the introduction of new functionality at Grade of Automation 4 may potentially introduce bespoke equipment onto the OCS network which requires support from an external specialist repair and overhaul function. Once the system architecture and equipment is understood a decision on whether a Third-Line Maintenance capability will be needed. It should be noted that in areas where maintenance may be potentially outsourced that this will include any software amendments.

8. OCS Training Requirements

A comprehensive set of training requirements for the OCS has been developed by the DTUP in collaboration with Key Stakeholders from LUL's Operational Learning Department. Supporting these requirements is a 'Training Philosophy' document which provides the narrative and rationale for the preferred training approach for DTUP.

9. Spares

The quantity of spares held is an important factor, particularly where space is likely to be at a premium. It is therefore crucial that the right level of spares required is identified and also where they are best held. To facilitate the development of this, a 'spares listing' is seen as a critical output from the DTUP programme.

Identification of a logical stock profile becomes extremely important for effective stores management. The development of a spares listing forms the basis of a risk based spares strategy and must be determined through a study of the reliability of the equipment, its criticality to the functionality of the system and the present and future availability of the parts.

Naturally there is heavy reliance placed upon the Manufacturers/Supplier based upon their RAMS analysis to provide recommendations for spares in the first instance.

However, it is vital that these recommendations are considered fully by the Programme so that the recommendations of the Supplier reflect the needs of the Underground. Failure to do so could result in the Supplier providing uncritical, perishable and bulky expensive-to-store equipment as part of the system spares list.

Items for consideration should include:

- Does the equipment represent a single point of failure?
- What is the likelihood of failure of the equipment based upon its most vulnerable component (reliability/redundancy)?
- How critical is the equipment to the operation of the system?
- What is the expected vulnerability of the equipment? Is it in an exposed place where damage/deterioration is likely
- What are the envisaged lead /turnaround times of supply for each item of equipment?
- Is there any contractual or warranty requirement to use the Supplier's Assets or can similar equipment be bought commercially 'off the shelf'?
- Is the asset perishable? If so, what is the shelf life?
- Are there any special storage conditions required for spares

- What are the physical dimensions of the spare item (sufficient to determine 'shelf space')

10. Tools

It is imperative that maintenance activities are undertaken using appropriate tools, ensuring the equipment is effectively maintained thereby preventing accidental asset damage or injury to the user. An understanding of the system tasks through Human Factors task analysis, will determine what actual tooling is required to maintain the OCS system. This analysis should also identify what items are currently used by the maintenance organisation and a simple 'gap' analysis should then be undertaken to determine an appropriate tools listing.

Any specialist tools should also be identified by the Supplier along with the quantity required which will be determined by the staff levels and their geographical distribution.

Once developed, the tool listing will also highlight any equipment that requires specialist support, such as calibration, software licences for analytical data and so on. Similarly, the tool listing also provides the opportunity to identify any training that may need to be considered in the use and operation of tooling.

11. Warranties

It is recognised that there will be a warranty period associated with the OCS system hardware and software. Management of these warranties is expected to be the responsibility of the Maintenance Organisation once the system is brought into use on the operational railway.

In the past, the terms of these warranties have been such that they have often expired long before the associated equipment has been brought into operational use, thereby inhibiting the maintenance organisation obtaining the necessary repair or replacement of defective items of equipment, or to remedy any software errors.

To ensure that recourse (through warranty) for defective equipment or software remains available at the point of bringing into operational use, it is vital that LU Operations (Assets) are afforded time to review the warranty before it is agreed. The warranty should therefore provide

the opportunity for amendments both from the Supplier and LUL to reflect any changes in the delivery of relevant products.

12. Obsolescence

The appropriate obsolescence management strategy for the OCS will be determined once the system architecture is understood. The obsolescence management strategy chosen will align with London Undergrounds Cat 1 Standard S1043 *Obsolescence Management.*

13. Ongoing Supplier Support

The design of the OCS is expected to be a secure data communications network which may, or may not, require a level of ongoing specialist support from the Supplier. There could be several areas where the option to seek ongoing technical support from the Supplier(s) may be considered prudent, if not necessary, to ensure effective coverage that supports the Underground's operation. A brief description of the possible type of support is provided below:

- Design Authority Support

This ensures that the Supplier is capable of providing long-term technical knowledge and expertise so as to continue as the Design Authority for any required changes to the Operational Control System post-warranty.

- Technical Advice Support

The purpose of this will be to provide LU Operations (Assets) with access to the Supplier's technical experts who will be able to offer advice and guidance on all aspects of the OCS. This will be a crucial element for the first-line maintainer, particularly in the formative stages when familiarising themselves with the system.

- Technical Investigation Support

This service will be necessary in providing the maintenance organisation with the capability to call upon the knowledge and expertise of the supply chain in resolving ongoing OCS issues which are not clearly understood, or which cannot be resolved through first-line maintenance

intervention. Technical Investigation Support is expected to provide LU Operations (Assets) with the means by which the root causes of regularly occurring faults can be established and eradicated.

- Engineering & Maintenance Support

This service is to enable the supply chain to support modifications, performance initiatives and maintenance efficiencies during the operation of the Operational Control System and would allow for such items as the provision of advice in connection with any recommended modifications to the system intended to improve maintenance efficiency and reduce whole life costs.

Technical support will also need to be available to cover any corrective changes, updates or amendments to the system's software.

- Training Facilities Support

Ongoing technical support will be required to ensure that any OCS training facility developed by the Supplier for use by the Client organisation remains fully functional and continues to develop and evolve in line with the railway system that it should be reflective of.

It should be noted that the services described remain as options. Once the complexities of the system are understood then a decision will be made in respect to the extent of the future services that may be required.