# London Underground

# Project:

## Tunnel Cleaning Train (TCT) Replacement

## Business Case Narrative

## VLU-PVEC-BCV-BUC-0001

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# 1 Document Control

## *1.1 Owner*

Fleet and Depot Sponsor

## *1.2 Document Summary & Purpose*

This is the Business Case for the Tunnel Cleaning Train (TCT) Replacement Vehicle Project. This document is a statement produced by the Project Sponsor, stating the financial and non-financial case for the project in terms of costs, benefits and risks.

## *1.3 Document History*

| Version | Date | Change since previous issue |
|---|---|---|
| V0.1 | 22 Sep 2009 | First draft for Sponsor Review |
| V0.2 | 7 Oct 2009 | Amendments arising from Stakeholder review |
| V0.3 | 29 April 2010 | Working Draft |
| V1 | July 2010 | Final Version for Gate 2 Review |
| V2 | November 2011 | Amended for CGAP Gate D resubmission |

## *1.4 Document signed off by:*

| | Signature | Date |
|---|---|---|
| **Fleet & Depots Sponsor**<br>Adrian McCrow | [redacted] | 7/11/2011 |

# 2 Executive Summary

The Replacement Tunnel Cleaning Train (TCT) project includes the design, development, testing and commissioning of a new tunnel cleaning train for operation on all LU lines (except W&C due to access). The vehicle will be operated, maintained by Transplant under agreed terms & conditions.

Substantial cost benefits are expected. This is supported by past experience on LU and direct experience from other analogous metro system operators. All world class metro systems utilise some form of mechanised cleaning system, and the common experience is that this is beneficial. Indeed, New York and Beijing have recently placed large orders for new vehicles.

Further to the fiscal benefits owing to less reliance on (largely ineffectual) manual cleaning activities, operational benefits are expected in the form of reduced HSE incidents such as track fires and injuries and improved asset reliability. The project will positively impact LU reputation and eliminate the public perception that the tube is polluted and is an unhealthy environment.

# 3 Project Description

The project is described more fully in the Project Requirements. In summary the project includes the design, development, testing and commissioning of a new tunnel cleaning train for operation on both LUs deep tube and sub-surface networks. The vehicle will be operated and maintained by Transplant under agreed terms & conditions.

# 4 Background

## *4.1 London Underground Environment*

Tunnel dust and dirt affects the performance of the LU fleet and provides a poor environment for passengers and our staff. It also has the potential to cause fire and smoke incidents.

The dust is primarily iron-based (from the wheel rail interface), hence can be electrically conductive under certain circumstances. Accumulation of the dust is therefore a contributory factor in electrical asset failures such as insulated block joints between track sections. The metal content of the dust is also suspected to reduce the effectiveness of transmission-based equipment, which will be of increasing concern in the upgraded railway. The combustible constituents of the dust combines with oil/grease (wheel rail lubrication), which means the dust can smoulder freely when it gathers together. This increases the risk of hot spots and track fires, and can exacerbate/prolong those fires caused by other factors.

## *4.2 Tunnel Cleaning*

The cleaning of tunnels is governed by standard 1-166 (formerly TE-MTS-0901-A2). The standard lists all areas of track, tunnels, and station grounds within LUL which are to be cleaned. It also lists how often these areas are to be cleaned and to what level of cleanliness

In 1976 LUL brought into service a tunnel cleaning train to meet the cleaning requirements. This train was based around the chassis of a 1938 tube stock. The train used forced air to disturb dust and dirt followed by a vacuum to remove it. The vehicle removed between 5-10 tonnes of waste per kilometre in some of the more heavily contaminated areas, however it required multiple passes to clean a single section of tunnel. The train was successful at cleaning tunnels but went out of operation due to high maintenance and operating costs and unreliability. The Standard requirement for cleaning tunnels using the Tunnel Cleaning Train is based on the ability of the existing TCT (when it was working) to get around the LU Network as opposed to any specification for cleaning quality or volume of material removed. The proposal is that a dedicated machine should be developed in conjunction with a supplier so that the optimum balance between cleaning speed (distance cleaned per Engineering Hours Shift) and cleaning efficiency is obtained.

A concession to the above standard was issued which meant that manual cleaning would temporarily substitute the train with the expectation that the tunnel cleaning train would be brought back into service. The concession permits LU to deliver cleaning activities that are not in accordance with and fall short of the standard. LU have been carrying out manual cleaning using deep clean and station sweep teams along with litter pickers to keep the tunnels free from dust and dirt, since the concession was issued.

## 4.3 Current Issues

The contract with Bombardier, for the supply and maintenance of new rolling stock has within it a requirement for LU to maintain tunnel cleanliness to the above referenced standard which is currently being achieved manually on the VLUP. Even though compliance to this standard is being achieved, the different configuration (airflow pattern) of the both the 09TS and S-Stocks may means that LU will incur costs due to additional maintenance required on the new rolling. It is therefore not known if the current tunnel cleaning levels are sufficient to avoid liability for warranty issues arising on the new 09TS and S-Stock.

The Victoria Line Upgrade Project Team has spent considerable time and resources in an effort to clean the line in preparation of the introduction of new rolling stock. About £400k has been spent on manual cleaning (47km) per annum, with little resulting long term benefit (dust resettles too quickly). Indeed, despite, the cleaning have been recent incidents on 09ts where dust has been released into the saloon environment which has an appearance similar to smoke. This has caused several high profile incidents on the line, resulting in 47,000 lost customer hours. Unless the dust is physically removed from the network, similar unit costs are likely to be incurred on future upgrades (Piccadilly, Bakerloo, Central, etc) and will not guarantee a clean tunnel environment. Higher unit costs are being experienced on SSR upgrade owing to the use a spray suppressant to lock existing dust/debris (it doesn’t eliminate the problem and there is a concern that the suppressant will deteriorate over time).

## 4.4 Worldwide Experience

A UITP Study on “Cleaning of Underground Railway Tunnels in the Extended Track Vicinity” was published in 2006 and summarises the findings of a questionnaire circulated to 17 worldwide underground railway operators (11 from Europe, 3 from Asia and 3 from America). The railways range in scale and complexity, age, vehicle type and power supply. They range from as little as a few kilometres to the largest of 431km and were constructed between 1860 and 2004. The following summarises the key findings that are likely to pertain to LU. (Contact the Sponsor for access to the complete report).

a) Cleaning of the tunnel and track facilities was for all Metros an important factor in being able to ensure safe and reliable operation. It also influenced customer satisfaction.

b) In most Metros, there were found to be niches, opening, galleries and spaces of different size and configuration, much like the LU network.

c) Ballastless permanent way predominated, but ballasted track was very common.

d) Damage cause by dirty tunnels was widespread; there were some 510 fires in the previous 5 years and problems due to dirt had been encountered on equipment including signals and points. Train delays and cancellations were also noted impacts.

e) Cleaning regimes varied considerably from daily litter picking to monthly cycles. Track adjacent to platforms was generally cleaned on a 2-3 weekly cycle. Over ground track was generally cleaned between 4-6 months. Tunnels were generally cleaned on a monthly basis.

f) All Metros use some form of mechanical aid – tongs, non-track guided vehicles, vacuum cleaners and cleaning trains were common items of equipment. All but one Metro supplemented mechanised cleaning with some level of manual cleaning.

g) 11 of the 17 Metros use some form of tunnel cleaning train. 8 metros use bespoke cleaning trains, 1 uses a standard vacuum cleaning train, whilst the remaining 2 use vacuum equipment on specially modified legacy trains. All cleaning trains are operable in both directions. The remaining six metros use rail-guided or non-guided vacuum cleaners.

h) Cleaning is generally undertaken during nightly shut-downs, but in some cases during normal working hours. Cleaning speeds vary between 1km/h to 20km/h, with a maximum line speed of 65km/h.

i) Waste mainly comprised of paper, tin cans, bottles, small waste (cigarette butts) and dust. Dust contributed between 6 – 76% of total waste. Dust is removed as part of vacuum or washing activities within the context of regular track cleaning.

The decision to purchase a tunnel cleaning train was not entirely dependant upon economic viability, but rather on the case of a fundamental decision (strategic imperative) or government requirement. However, where economic considerations were taken into account, they were often justified after purchase and use of the vehicle.

In summary, the study concluded that those using mechanical cleaning vehicles assessed their operation as positive. In all but one case, the vehicles did not completely eliminate manual cleaning.

# 5 Project Objectives

The primary project objectives (identified at the outset of project definition) are covered in the Project Requirements and are replicated below:

a) Design, build and commission a replacement tunnel cleaning train which is capable of cleaning deep tube tunnels and sub-surface line to the standard and frequency required.

The intention will be to undertake an initial deep clean of all SSL and BCV track and tunnels within one year of commissioning and JNP within 3 years and then subject all lines to a regular cleaning programme (3-4 times per annum). The minutes of the first Access/Logistics Workshop are held by the project team.

The vehicle will be capable of cleaning up to 360º in deep tube, and penetrating deep into the ballast, neither of which can currently be achieved with manual cleaning.

# 6 Options Examined

The original Tunnel Cleaning Train Replacement Strategy drafted in 2007 was never formally issued due to difficulties in getting adequate involvement and information from Tube Lines on the potential benefits the vehicle would offer their operation. However, based upon BCV and SSL assumed benefits a number of options were put forward and assessed. These are provided in Appendix A. At that time the solution proposed was:

*"The considered option of the Plant Strategy Group is that the preferred option would be to work with a supplier … to develop a dedicated TCT that could cover all Lines on the Underground network. Whilst all parties agree that there are a number of failure modes that can be attributed to the build-up of tunnel dust these alone are insufficient to generate a business case which meets the Internal rate of return required by the private investment rules of the Infracos. There are however a number of un-quantifiable benefits to health and safety we need to be taken into account. As a result the proposal from the Plant Strategy Group is that LU should fund the initial capital investment as "Strategic Plant" given that they can probably borrow the initial capital cost at a lower rate of return, and the Infracos would then purchase a minimum number of shifts per year".*

### *6.1 Recommended Option*

**Option 1** (the preferred option) is to proceed with the detailed design, development, testing and commissioning of a tunnel cleaning train replacement. The supplier shall provide the tunnel cleaning unit (TCU), whilst the motive and power units (MPU) will be provided by LU via conversion of legacy fleets. This permits the supplier to focus on the cleaning aspects of the project. LU will retain systems integration responsibility which is perceived to be a high risk for the supplier and therefore costly. Maintaining the legacy motive and power units will become more difficult over time, but LU has the domain skills and competencies to ensure safe and reliable operation.

### *6.2 Alternate Options*

The **Base Option (Do Nothing)** continues with current manual cleaning activities and falls short of the standard. Staff will continue to be susceptible to health and safety risks (eg slips/trips/falls and asbestos containing materials). There will be no reduction in track fires or improvement in asset performance and assets will be subject to long term performance issues as a result of tunnel dust/debris, imposing a high future maintenance/operating cost.

**Option 2** is to proceed with the detailed design, development, testing and commissioning of a tunnel cleaning train replacement. The motive and power interface will provided by the supplier in a single train consist. This exposes LU to high risk due to potential non-delivery of an approved/ compliant solution, adds significant costs (eg EMC), but eliminates the need to convert legacy vehicles. Project timescales will be longer owing to the approvals process and the benefits are as per those in Option 1.

## 7 Main Items of Scope

### *7.1 Current (Base Option)*

The current manual cleaning regime consists of the following:

a) Litter picking of tube station suicide pits across the network at an interval of no greater than 48 hours. These teams remove visible debris such as paper, cans, etc.

b) Sub surface stations litter picked weekly or twice weekly with running tunnels litter picked weekly.

c) Tube Station Sweep teams at weekly intervals. These teams use vacuums and remove grease (including the insulators) along the track and for 50m either side of the platform.

d) Metal picking teams across the entire network (excluding Central line) and as necessary (risk based) in some areas. These teams use ‘wands’ to remove metallic particles generated by the track-train interface and only deal with blockjoints and the track 1m either side of the blockjoint.

b) Historically, deep clean teams at an interval of 2 years on the BCV network. However within the recently awarded TPS contract, it has been confirmed that the contractor has priced for bi-annual cleaning at a cost of £780kpa. This consists of a team people who manually clean and remove grease. They predominately clean the track bed and do not clean cables or walls.

In addition LU will incur the following ‘one-off’ costs as part of Line Upgrades if it does not have a tunnel cleaning train. These are based on cost incurred to date on the VLU (the line was cleaned three times during the upgrade at a cost of £400k per clean) and the SSR which has incurred £250k for 13km of track.

e) SSR Upgrade (2012 – 2015); Circle and District Lines “tunnels” cleaned two times during upgrade at a cost of £532k per annum (28km @ £19k/km). Note that Metropolitan is excluded as TCT will not be available in time.

f) Bakerloo Line Upgrade (pre 2025); tunnels manually cleaned three times during upgrade at a cost of £195k per annum (23km @ £8.5k/km)

g) Piccadilly Line Upgrade (pre 2025); tunnels manually cleaned three times during upgrade at a cost of £442k per annum (52km @ £8.5k/km)

h) Central Line Upgrade (pre 2025); tunnels manually cleaned three times during upgrade at a cost of £425k per annum (50km @ £8.5k/km)

## *7.2 Proposal*

The main items of scope for the preferred solution (Option 1) are as follows:

a) Procure of a new tunnel cleaning unit (TCU)

b) Design and build motive and power units (MPU). This is likely to include conversion of LU legacy vehicles.

c) Testing of TCU at a location external to the LU network

d) Testing of MPU on the LU network

e) Testing of the complete cleaning consist (TCU + MPU) on the LU network

f) Deliver appropriate depot improvements to facilitate waste removal from the tunnel cleaning train

# 8 Explanation of Financial Costs

## *8.1 Capex*

### 8.1.1 Option 1 (LU Provide Motive/Power Unit)

Capital costs for the new tunnel cleaning train used in the original business case were based on the information received from the OJEU notice published by LU in 2008, CAMM papers submitted in July and December 2008 and a professional view based on the current requirements specifications. The revised estimate that is now in this business case is based on actual TCU contract award price and improved estimates for the provision of the MPU.

The most current estimate of costs are summarised below:

| | |
|---|---|
| £1,000k | Project Management / Engineering / Systems Integration |
| £3,500k | Motive Power Units (MPU) |
| £5,500k | Tunnel Cleaning Unit (TCU) |
| £1,000k | Depot improvements |
| *£11,000k* | *Total Baseline* |

The TCU will be designed with a minimum 25 year life, so no additional capex for refurbishments/mid-life interventions is anticipated, but the cleaning vehicle shall be designed to allow its upgrade in the future if required.

### 8.1.2 Option 2 (Supplier provides complete consist)

This is similar to Option 2, but requires the supplier to provide the complete consist. It was not expected that the supplier will be able to provide the solution for a cost lower than described above and therefore eliminated as an option from the tender process.

This option has additional cost and delivery risk due to the potential inability of the supplier to meet LU systems and safety requirements. There will also be additional cost of the installation and integration of LU-specific emergency equipment and signalling systems which the supplier would not have specific competence to specify and assure. The additional cost burden was estimated at 20% more than that of the preferred option. The programme timescales were estimated to be 50% higher.

## *8.2 Opex*

### 8.2.1 Option 1 (LU Provide Motive/Power Unit)

The tunnel cleaning train will not eliminate all manual cleaning activities. Specifically it will not eliminate Litter Picking, Station Sweep or Metal Picking detailed in 7.1. However all BCV tunnel cleaning could be eliminated. The current annual cost of the Deep Clean in TPS is c£780kpa. Savings amounting to £580kpa are already included in Track maintenance efficiencies plan (MCP). It is assumed that the remaining £200k can be saved following the initial deep clean of the network.

The operation and maintenance costs for the vehicle have been estimated in conjunction with Transplant representatives and with reference to other bespoke engineering type plant (such as ballast cleaners, rail adhesion trains, asset inspection trains, etc). The annual operating and service control cost is estimated at £400k per annum, whilst the maintenance cost is £192k per annum (these costs are included in the Transplant costs). Waste disposal costs are assumed as £133k pa.

There are no other significant cost savings or reductions. Therefore the net increase in annual costs is:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| £400k | + | £192k | + | £133k | - | £200k | - | £100k | = | £425k |
| Operating Cost pa | | Maintenance Cost pa | | Waste Disposal Cost pa | | Track Cleaning Reduction pa* | | Train Cleaning Reduction pa | | Net Increase pa |

Note * - Approximately £585kpa of manual cleaning costs are already embedded within track maintenance efficiencies. The remaining savings will be achieved following the initial deep clean of the network.

### 8.2.2 Option 2 (Supplier provides complete consist)

This is the same at Option 1. It is assumed that the combined operating and maintenance cost of a complete consist provided by the supplier is that same as a cleaning consist provided by the supplier and the motive/power unit provided by LU.

# 9 Explanation of Benefits

## *9.1 Fires*

A review of track fire data indicates that a reduction of 22.5% of track fires in tunnels and 'cut and cover' sections could be realised (probably more, as 50% of tunnel fires have no discernable root cause, and CMO's view is that the real figure is much higher). In open sections this benefit is less (circa 10%) as the key source of track fires is litter which would accumulate and be removed at a frequency greater than that of the TCT Operational Plan.

Significant lost customer hours and operational impacts are associated with fires. Fires (or clouds of dust mistaken for fires) lead to trains being withdrawn from service, cancellations of services or closures of sections of the railway. There are 20-30 incidents a year. As a minimum it is necessary to halt services while a station supervisor walks to site to investigate, typically causing 2,000 LCH per incident. Detrainments can also be required in these incidents which causes further cost and risk to passengers. It is often necessary to obtain London Fire Brigade involvement (typically 5,000 LCH depending on location). Assuming there are 30 incidents per year (10x LFB, 20x normal), and that 22.5% can be removed by a cleaning train, the monetised benefit have been calculated as £3.1m, creating demand revenue of £0.8m over the appraisal period (25 years).

Further to the effect on the operational railway there are lengthy post incident reviews/reporting. In many cases there are also costs associated with repair of damage to assets, but are not included in the analysis. Costs are also incurred by the LFEPA (part of the GLA group) in respect of response to and investigation of fire incidents but are also not included in the analysis.

The reduction in probability of tunnel fires has a calculated safety cost benefit of £10k per annum, but this is purely in terms of harm to people. This figure is lower than might be imagined, due to the advances in fire management since the Kings Cross fire in 1987.

The accumulation of grease and dust on the underframe of rolling stock presents a potential fire risk. Underframe cleaning is undertaken at regular intervals to ensure that the build of this debris is removed. However recent events (Bakerloo Line 19th July) have demonstrated that this is not foolproof. An accumulation of debris adjacent to a compressor began smouldering and resulted in a line closure from 17:45 to 18:33. Severe delays continued until 19:40 and a good service was not restored until 21:20. This incident accrued almost 9000 LCH (which equals almost £80k in passenger disbenefit (which is greater than the 72ts reliability benefits being claimed in Section 9.4 below)

## *9.2 Health & Safety*

Airborne dust levels in the LU network has been a subject of debate, media attention and medical articles (such as Seaton et al, 2005). The underground is an engineering environment and generation of airborne contamination cannot be avoided. However modern rolling stock relies less on friction braking than ever before, so brake block dust is lower than it has ever been. Also management approach to the wheel rail interface is improving so the generation of iron based contaminates should also be expected to decline. At present most scientists currently agree that the air quality on the LU network does not pose a significant short-term or long term risk to workers or commuters. This in part is due to the fact that the concentrations of ultra-fine particles are lower than those above ground in central London and in part due to the composition of tunnel dust. Tunnel dust is coarser, consisting largely of iron oxides with concentrations well below that of allowable workplace limits for welding fume (also iron oxide), which has been identified as the most suitable dust to compare tunnel dust with, from the occupational exposure point of view*. Nevertheless, it is preferable to reduce the levels of dust where possible. The public perception of risk is such that an active programme to reduce dust levels is advisable.

*Seaton, A., Cherrie, J., Dennekamp, M., Donaldson, K., Hurley, J.F., Tran, C.L. (2005) The London Underground: dust and hazards to health. Occupational and Environmental Medicine 62, 355-362

*Note: It should be noted that European Directives 1999/30/EC and 96/62/EC set maximum allowable levels of airborne particulates in ambient air (meaning outdoor air in the troposphere, excluding work places) and therefore do not apply to the underground environment.*

Passenger perception of LU network cleanliness impacts LU reputation. The network is ‘dirty’ in the majority of locations, particularly in the deep tube and above the cable runs where existing manual cleaning activities do not venture (compare the appearance of the Jubilee Line following the JLE to any existing line and the contrast is considerable). Any pollution on publicly visible surfaces (such as walls opposite platforms) and the haze sometimes seen on platforms contributes to public perception that the tube is polluted and is an unhealthy environment. This perspective will be perpetuated in the media despite medical conclusions that currently show otherwise (but may change in the future). Consequently, potential commuters may actively decide to avoid the tube in preference for other modes of transport (walking, bus), resulting in loss of revenue.

Reduction in LTI risk exposure associated with cleaning activities. There is no data demonstrating the number of LTIs directly associated with manual cleaning activities. However, slips/trips/falls are an inherent risk that is proportionate to the number of manhours spent in the tunnel environment. If the manual cleaning arrangements can be rationalised, then there will be a net reduction in LU risk exposure and LTIs

## 9.3 Cleanliness & Ambience

Station and Train maintenance staff spend considerable time cleaning station and train interiors. The removal of airborne and settled dust from the tunnel environment will reduce the level of dust contamination on station platforms and train surfaces. Initially, this means that less effort will be required to sustain a level of cleanliness and in the longer term may permit the rationalisation of cleaning headcount requirements.

The combined SSL/BCV cleaning budget exceeds £40m per annum. In relation to platforms the accumulation of dust is more heavily related to passenger footfall, so there will be limited opportunity to rationalise platform cleaning. Equally, there is expected to be little change in station ambience scores.

In relation to fleet, advice from the Fleet Ambience Manager is that the external cleanliness measure could rise by 3 points if the tunnels were cleaner as this would reduce the dirty streaking that is visible on many trains. The impact of this has been modelled in accordance with the BCDM and creates passenger benefit of £163k per annum as summarised below. Note that this figure is flatlined in future years, but would actually increase each year owing to increased demand for the tube and the impact of major upgrades:

| **Fleet / Line** | **Current Score** | **Target Score** | **Passenger Benefit (£s)** |
|---|---|---|---|
| A Stock / Met | 51.2 | 54.2 | 7,115 |
| C Stock / Cir & H&C | 46.0 | 49.0 | 13,520 |
| D Stock / Dis | 53.5 | 56.5 | 21,623 |
| Bakerloo | 58.3 | 61.3 | 11,022 |
| Central | 52.7 | 55.7 | 25,042 |
| Victoria | 55.2 | 58.2 | 19,558 |
| Jubilee | 58.6 | 61.6 | 18,283 |
| Northern | 53.2 | 56.2 | 25,708 |
| Piccadilly | 52.2 | 55.2 | 20,901 |
| | | Total | 162,773 |

In addition, the Fleet Ambience Manager has indicated that the exterior manual cleans could be extended from twice yearly to every 18 months if dust levels were generally reduced as the automatic train washes would sustain overall cleanliness without manual intervention. The annual cost of exterior train cleaning is c£150kpa. If the interval was extended to every 18 months then the annual cost would reduce by £100k pa.

Finally, dust that accumulates on the tunnel walls and ceilings can hinder access to equipment and impact visual condition inspections undertaken by civils teams. Removal of this dust would permit more efficient use of this resource and would avoid structural problems potentially being missed. This benefit is difficult to quantify.

## 9.4 Fleet Reliability

Evidence from the introduction of 92TS on the Central Line and, more recently, 09TS on the Victoria Line indicates that dust will present an issue during and following the line upgrades.

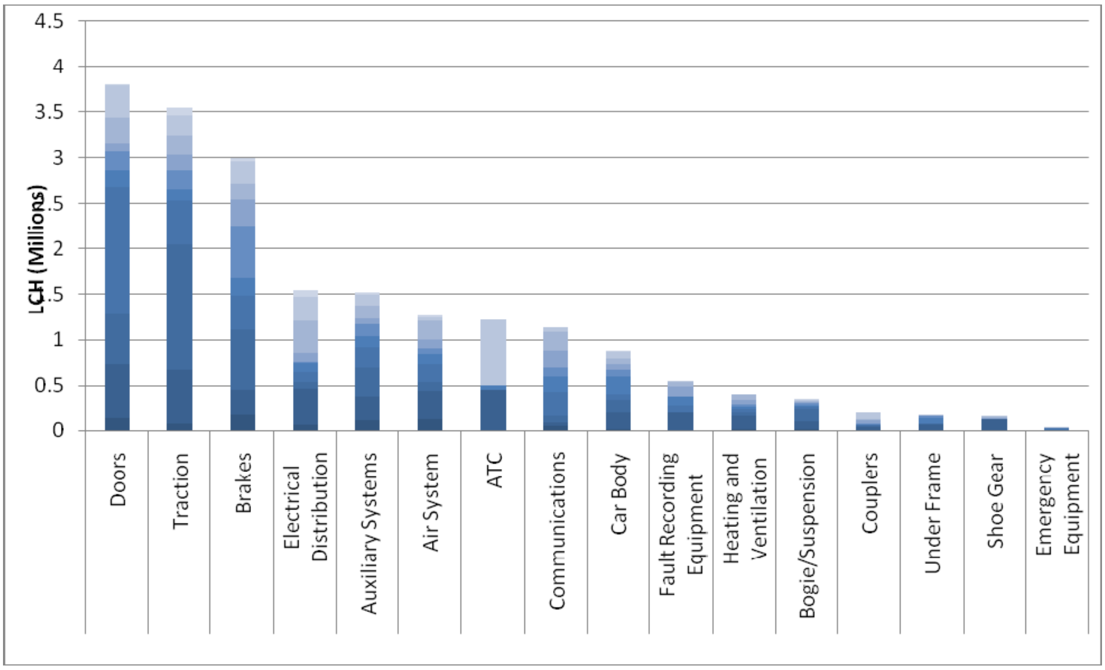
On the Central Line, the new 92TS suffered significant dust build up in filters, pressure ventilators (fans) and other areas. Professional opinion is that the dust led to reliability problems on this fleet for 5-10 years following its introduction.

In relation to the Victoria Line, pre-production trains were being cleaned nightly to remove dust that is disturbed due to the different aerodynamic shape. This will be further exacerbated following the signalling upgrade as existing and new stock run together at new line speeds. Further to this, the saloon forced air ventilation and the traction/auxiliary systems cooling fans are known to force settled dust from the ballast when the train is stationary at signals and in sidings. Tunnel dust entering the saloon has caused several high profile incidents and significant lost customer hours. Since introduction there have been 10 service affecting failures, accruing 47,500 LCH and creating an average delay of 7.3 mins. This is equivalent to two (2) years worth of benefit on the 09ts in the following reliability analysis that follows.

These types of issues have been independently identified by Montreal and Singapore Metros. Although Singapore did not measure reliability figures before and after tunnel cleaning, they did identify that a number of on-board systems were adversely affected by the tunnel dust. These included smoke detectors, saloon doors, header assemblies and air-conditioning filters. It should be noted that the Singapore door systems are similar to that on SSR. Montreal also indicated that a noticeable reduction in train reliability was experienced following a period when the cleaning train was not available.

It is considered that the TCT will mitigate against a decline in reliability (and therefore lost customer hours) of new fleets and should progressively improve the reliability of existing fleets compared with having no TCT and manual cleaning. The following is LCH data taken for all LU fleets in 2009/10. As is evident, doors, traction, brakes, electrical distribution and auxiliary systems are the main cause of rolling stock LCH and contribute almost 70% of all LCH. These are the systems that are most prone to tunnel dust contamination and reliability problems. However other systems are also impacted such as heat & ventilation, communications and ATC. In fact there are very few train systems that are not impacted by accumulation of tunnel dust, for example:

- Dust builds up on lubricated surfaces, wearing guidance systems (bearings) and can interfere with normal system operation causing failures (eg doors).
- Accumulation of fibrous material on intake grills or filters progressively reduces airflow causing traction equipment to shut down.
- Metallis debris drawn into high voltage electrical equipment causes short circuits resulting in loss of vital system (eg brakes) and damage to electrical systems.
- Underframe components such as compressors can operate at high temperatures causing the debris/dust to ignite (along with grease).
- Fine particles can bypass the filter and then accumulate within valves and pipework. Contamination then impacts valve operation / performance leading to failures and potentially wrong side (unsafe) safety failures (e.g. Door failures).
- Dust / debris accumulates on electrical control systems and components including push buttons, PEAs, rotary switches, master control switches, micro switches, relays and contactors and key pads.
- Failure of electronic boards (PCBs) from tracking of currents due to presence of metallic dust. This problem has become more noticeable in last 15 years with the progressive introduction of electronics into key train systems such as ATP, ATO, traction and brakes.
- Corrosion of dissimilar metals (galvanic) arising from iron dust deposits resulting in reduced asset life and component failure.




Based on discussions with professional engineers, review of historical failures and noteworthy events the following benefits will be achieved:

a) LU will mitigate against failures on the new fleets. Failures would be expected on doors, electrical and electronic components & systems, air conditioning filters, cab air conditioning systems and traction/auxilliary filters. From LU and mainline experience doors systems, electronic systems and air-conditioning will cause the majority of train failures. Therefore it is estimated that a reduction in tunnel dust could improve post upgrade LCH by 5%.

b) For legacy fleets, these vehicles already operate in the current environment. Existing maintenance activities already account for ingrained dust/debris and are therefore difficult to isolate as specific cleaning activities. However, by cleaning tunnels and maintaining the cleanliness there should be a progressive reduction in failures and associated costs on DC traction systems, filters and electrical push buttons/switches. Dust and contamination of DC traction systems is a well established failure mode (causing a short-circuit or 'flashover') and it is estimated that an improvement of 3% of LCH is achievable.

## *9.5 Other Assets*

Tunnel dust will also affect signals, stations, communications and information systems, track, ventilation and power assets, but none of the reliability benefits have been considered within the analysis.

Because of the insidious nature of dust accumulation and the difficulty of identifying direct causation it is sometimes difficult to quantify benefits. Consequently a cautious and conservative approach has been adopted and no presumption of a direct cost saving has been made for many of the issues mentioned here (ie reduced planned maintenance and repairs of dust-affected assets). The selection of issues highlighted does not purport to be exhaustive. In particular, assets other than fleet are also affected by dust but only fleet reliability has been considered as information sources are better.

# 10 Risk & Contingency

### 10.1.1 Option 1 (LU Provide Motive/Power Unit)

High level risks and issues are provided in the Project Requirements.

Business and Technical Requirements for the replacement TCT were developed following the OJEU notice. It is probable that the responses received did not consider some of the more bespoke requirements associated with the LU network. Some requirements are yet to be properly defined, for example the standard of cleanliness to be delivered, so when these are articulated into specific engineering needs, there may be additional costs. The P50 risk is estimated at £1,000k which is 9% of the project baseline.

Costs are summarised below:

| | |
|---|---|
| £11,000k | Baseline |
| £1000k | Risk |
| *£12,000k* | *EFC* |

### 10.1.2 Option 2 (Supplier provides complete consist)

Similar to Option 1, but a higher level of risk is assumed. This is estimated at £2,000k risk. The delivery of the vehicle would also take longer than Option 2 by another 50% due to the approvals process.

# 11 Quantified Analysis

A summary of the incremental costs and benefits is shown below for Option 1 (against base option of Do Nothing). The base option is ignored on the basis that it does not achieve corporate objectives and cannot address the problems of dust embedded deep in the ballast.

The incremental financial impact of the TCT (against doing nothing) was modelled in accordance with the Business Case Development Manual. Only quantified benefits have been included; this includes improved train reliability, ambience, elimination of manual tunnel cleaning and the safety benefit owing to a reduction in fires. The impact of reduced injuries is not possible to quantify. The project has a strong BCR of over 5:1.

# 12 Appendix A

| | Description | Additional info | Reference |
|---|---|---|---|
| **Tunnel Cleaning Trains:** | | | |
| SCHORLING BROCK GmbH Tunnel, Track Bed & Station Cleaning Train | A state-of-the-art multi-function tunnel cleaning train that has<br>• adjustable suction heads that can clean tunnel walls and ceilings including automatic sensors which move the heads in/out to avoid tunnel telephones, signals etc.<br>• wieldable hoses for cleaning the cable runs, and trackside equipment,<br>• a dry-ice spray system that can remove grease from rail webbings and conductor pots and vacuum it up, there is also a nozzle to suck dust from the air.<br>The train costs £4.1m and there is also an option to hire it if we use the train for 180 shifts a year. The train also has a special function for cleaning the station track area. | There are add-on options of a rail-grinding facility and double the number of suction hoses. Demonstration trains could be seen in Hannover or Moscow and they can manufacture to LU requirements and gauge. Clearly using the cleaning train as an integrated part of the grinding process – similar to practice on the Hong Kong MTRC, would increase the number of shifts required. | Aaron Hudson – Schweerbau and Schorling Brock GmbH catalogue |
| TMG International Tunnel Cleaning Train | This train is in use on the Sydney Metro and contains a substantial suction facility, the ability to remove ballast and a water spray system. The train is cheaper than the Schorling Brock train at £1.7m. | The train can be seen in action in Sydney. The use of a water spray system however makes it a less than ideal solution for the underground environment. | 'Vacuum Technology' from TMG Rail Products Pty Ltd |
| VOITH Track Cleaning Train | This cleaning train concentrates on removing litter and dust from the 4 foot and has extra large containers to allow it to operate for extended periods of time. There is no facility for cleaning tunnel walls and ceilings or cleaning the rail/track area. | The manufacturing company are based in Heidenheim, Germany and used on the MVG railway there. | VOITH – Track cleaning train of MVG |
| **Tunnel Cleaning Road/Rail Vehicles:** | | | |
| ZAGRO Road/Rail Tunnel Cleaning Vehicle | This is a road/rail lorry with an extending adjustable arm that can clean a strip approximately 1.5m wide. The arm can extend several metres and would be able to clean walls, ceilings or the track area, however it is likely you would need to cover the same area more than once (with the arm in various different positions) to cover all of the tunnel walls and ceilings. This vehicle would be effective at targeting a specific area such as cable runs for example. | Zagro are a German based company that specialise in a variety of multi-purpose road/rail vehicles and are a Systems Partner of DaimlerChrysler AG. Their partner company Zweiweg have also contacted us with pictures of a track-bed cleaning road/rail vehicle. | 'ZAGRO Road/Rail Vehicles' catalogue |
| UNIMOG Track/Tunnel Cleaning Vehicle | UNIMOG provide a Track/Tunnel Cleaning Vehicle with numerous track bed suction nozzles to remove dust and litter from in and around the 4 foot. The vehicle also has an arm on the front of it which can clean approx a 1m strip and could be positioned to clean cable runs for example. | UNIMOG is an American-based company. | UNIMOG Multi-Purpose Track/Catenary Maintenance Vehicles Catalogue |
| SCHORLING BROCK Rail and Ballast Cleaning Vehicle | In addition to the multi-purpose tunnel cleaning train above, Schorling Brock also provides simpler road/rail options – they provide a track-bed cleaning lorry and a lorry with rail head and ballast cleaning equipment. | The vehicles could be demonstrated in action at Schorling Brock's Head Offices in Hannover. | 'Schorling Brock Special Vehicles' brochure |
| **Tunnel Ventilation:** | | | |
| AQUARIUS Fan Rover | This is a trailer that can be towed along the rail and consists of a very large fan. When used in groups the fan rovers can move quantities of air for up to 48 hours at a time with no refuelling. This may be an option for use in clearing a lot of airborne particles towards a ventilation shaft to improve air quality or visibility in tunnels. | AQUARIUS specialise in road rail vehicles, the Fan Rover would need to be towed by another Road/Rail vehicle but may be small enough to be easily moved with a trolley and used with manual cleaning teams. | AQUARIUS website |
| Tunnel and Metro ventilation Fans (FLAKT WOODS) | These mounted fans on the tunnel ceiling could be used to move contaminated air along a tunnel to a ventilation shaft. | FLAKT WOODS is a german company that has used these a lot in road tunnels, there may be difficulty fitting them into rail tunnels, it may only be | FLAKT WOODS website |

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| | | possible to use them on some SSL tunnels. | |
| **Grease removal techniques:** | | | |
| Vapour Steam Cleaning Systems | A method of cleaning which may have the advantage over ordinary solvent cleaners as it leaves no residue and is good at removing grease and dried dirt. | It would be possible to adapt the existing de-icing trains to run as steam cleaning de-greasing trains. | Dry Vapor Steam Cleaning Website |
| Dry Ice Blasting | A technique using dry ice (or solid carbon dioxide) pellets which are fed into a stream of compressed air which accelerates it through a nozzle to remove grease. At a temperature of -78 degrees the dry ice turns the grease to powder and this can easily be sucked up using a simple suction pipe. | Dry ice blasting machines are available, these could be used in conjunction with some of the tunnel cleaning vehicles for de-greasing. | CRYOCLEAN Dry Ice Blasting website |
| Water Spray Systems | These are built into some of the tunnel cleaning trains or are available as portable units and use highly pressurised water to remove grease. | The technique could have some problems being adapted for use in the Underground environment due to potential flooding problems. | www.ultimatewasher.com |
| Perfluorinated Cleaning Solvent | Perfluorinated solvents are safe, inert and non-toxic and effective for removing all oils and greases. | Would be effective when pressure sprayed onto greasy surfaces. | PERFLUOROSOLV website |
| Solvent/Air Combination | A popular method for cleaning greasy machine components and portable hand operated tools are available. The process provides a jet of cleaning fluid followed by a brush mechanism and an ‘air blade’ to dry the surface. | Safety-Kleen who supply the described cleaning equipment are already on Metronet’s registered suppliers list. | Safety-Kleen UK Ltd |
| **Related Articles Found:** | | | |
| Cleaning and maintaining tunnels | This article describes a number of agents and materials for cleaning and maintaining the interior of tunnels. Offers specific supplier names and detailed descriptions for cleaning devices, chemicals, ventilation systems, cooling equipment, concrete protection materials and solution, grouts and repair cements, and tunnel cladding and panels. | The article was published in 1990 and mainly concentrated on water spray systems for cleaning road tunnels. | TUNNELS & TUNNELLING Vol. 22 No. 12<br>Publisher: Miller Freeman<br><br>Supplied by the LU Engineering Library. |
| Tunnel cleaning machines | Description of experiments and problems encountered with the special tunnel cleaning machine on 256 km of the London Transport network. | This article described the design of LU’s Tunnel Cleaning Train for use in the 1980s. | Railway Engineer International Vol. 5 No. 5<br>Publisher: Mechanical Engineering Publications.<br><br>Supplied by the LU Engineering Library. |
| Tunnel Cleaning Method | A method has been devised to scrub tunnel surfaces clean by using rotating brushes, water and tunnel washing soap. Proportional Electro-hydraulic Control Valves provide accurate controls for the operator to position boom mounted brush heads on the tunnel surfaces. The four axle, 48,000 GVW carrier vehicle transports 1,000 gallons of water, 700 gallons of soap, operator and driver cabs, as well as all hydraulic components needed to accomplish the task of tunnel washing. Since the speed of operation is related to the amount of contaminant deposited and the surface condition of the tunnel, the effective forward travel speed of the washer varies up to a top speed of 143 ft/min. | This again concentrates on a water cleaning method not likely to be suitable in the Underground environment due to the damage it would cause to wall mounted signalling and comms equipment | California Department of Transportation<br>http://www.dot.ca.gov/<br>Equipment Branch<br>Sacramento, CA USA<br><br>Supplied by the LU Engineering Library |
| Tunnelling and underground space technology Journal | This is an online journal that talks mainly about tunnel structures and design rather than cleaning. | | Tunnelling and Underground Space Technology Website |
| The London Underground: time for a thorough clean-up? | Article commenting on the general state of the air in the underground and a history of complaints and problems. | | www.bmjjournals.com |
| Independent report into tube tunnel dust | This 2003 report drew several conclusions including: Dust on the underground is highly unlikely to cause serious damage to the health of people working in LU tunnels and stations, the travelling public and that there is no need for more research. | The report was commissioned by the IOM and a summary published by Ben Harding. | Metronet General Communications, September 2003 |
| Dust in the London underground | This is a review of the health implications of exposure to tunnel dust from 2001. | This was published before the independent report was commissioned 2 years later. | A report from the Metronet Environmental Team, November 2001 |

# 13 Appendix B

*In a parallel universe, employees work for a leading firm who aspire to be world class. These employees work in an office in a major capital city and have regular visits from their large number of clients. They have access to all the modern conveniences that one would expect and generally provide a good service. The exception is that one day they stop cleaning their office. Rubbish bins are no longer emptied, floors are not vacuumed and spillages are left on the carpet. Before long the rubbish, dirt and debris begins to pile up to unacceptable levels, but the firm chooses to do nothing about it – it can't make a financial case to remove the rubbish.*

*But over time the managers recognise that the organisation is not quite as good as it use to be. Morale is low – no one wants to work in a dirty office – and the many clients who visit the firm begin to question the ability of the firm – after all, if they can't keep their office tidy, then can they actually manage their business? The health of employees is adversely affected and a greater risk of risk of fire and slips/trips/falls exists. Absenteeism rises and the efficiency and effectiveness of the firms operation is adversely impacted. Over time, this becomes the norm as everyone accepts that the office will never be cleaned.*

*One day the firm decides to renovate its office to provide greater capacity for its clients. Enhancements begin, but the office was not cleaned and consequently dust is thrown everywhere – it gets into computers, copiers, printers (and importantly the coffee machine). Soon these devices begin to experience a higher level of failures than existed previously. The new facilities were expected to be world class, but they are not even 'world average'. Everyone realises that rubbish and dirt is causing problems. Although the economics don't stack up, the firm recognises the need to clean the office – health, safety, reliability, morale & pride, client perception, etc. Each of the arguments is real but difficult to measure. But in totality they form a compelling argument for cleaning the office, which is clearly "the right thing to do".*

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