Transport for London
London Underground

Formal Investigation Report

Operational and Customer Service Response to Power Loss on 28 August 2003

MAYOR OF LONDON

UNDERGROUND

Content Page

Cover Photographs: Evacuation of Bond Street Station with emergency lighting on 28 August 2003, with acknowledgement to Gary Davis

1.0 Executive Summary

This report concerns the operational and customer service response to the sudden and widespread loss of power from the National Grid on Thursday 28th August 2003 which severely affected London Underground (LU).

This report should be read in conjunction with the Technical Investigation Report prepared by the Energy Contracts Management Team (ECMT), who have assessed the performance of the electricity supply network and its contingencies against such failures.

Our response in evacuating the areas affected by the power failure was successful in that no one was hurt and no one was left in darkness. No one left the system in an uncontrolled way and there were no self-detrainments.

Some detrainments were delayed by communications problems and by the amount of trains stalled on certain lines.

In the context of such a dramatic impact, the conduct of many of our staff on the ground was exemplary. Given the general condition of many assets, a problem-free restoration of service was unlikely.

However, the prolonged delay before some Lines could resume, and our poor performance in sharing information, has brought into sharp focus inherent weaknesses in network co-ordination and communication.

Some weaknesses are related to systems and basic infrastructure – many of these are being tackled already. However, deeper organisational issues concerning roles and responsibilities, preparedness, and our use of communication channels, also played a part.

62 trains in total came to a halt between stations. 8 trains were detrained via the track, following procedures, with 1 200 passengers assisted to platforms. Another 54 were stalled between stations with a total of 17 000 people on board. These were moved to platforms when power was restored. The last of these was not fully evacuated until 20.20, two hours after power failed.

The degree of asset failure varied across Lines. All Line Control offices lost signalling diagrams and in most cases their ability to locate and communicate with trains.

Reserve batteries performed well on stations. Certain back-up systems for communications and signalling failed however. On restoration of power, many assets returned to availability automatically but others needed manual attention to reset. Support from the Infrastructure maintenance companies and Private Finance Initiative companies was satisfactory, but lacked predictability and thus delayed the reintroduction of services.

When power was lost, the Lines' reactions were dictated by their circumstances. Key information did emerge about the extent and effects of the failure, plus the likely timetable of power restoration, and this helped with decisions about detrainments. However, there were inconsistencies in how this information was disseminated and used. Again, equipment failure was an issue but a more disciplined process is needed.

Similarly, service restoration was impeded by poor communication between functions, lack of readiness in some areas, and our capability to co-ordinate decisions and information. This was compounded by a very restricted external flow of information to stakeholders.

The Network Control Centre suffered an overload of inbound telephone calls, and proactive outbound messages were insufficiently prioritised. Immediately following the failure, the focus at Line and network level was on operational information and co-ordination. This was essential but in that period our neglect of external channels was to the detriment of customer service and the cause of confusion at stations.

Stakeholder communication was achieved through the Chief Operating Officer and Transport for London Safety and Contingency Planning Manager. Their presence enabled the Mayor's office and Commissioner's office to be directly briefed and agencies such as the London Resilience Team to be regularly updated.

Our command and control structure was put under severe pressure. The principle of devolved operational decision-making worked well. However, overall supervision of the Line teams was inhibited by our limited communications capability. Co-ordination was not readily accomplished through a clear and unambiguous chain of command since decision makers were unable to gain enough situational awareness to support strategic decision-making.

This report recommends a fundamental reappraisal of the purpose and concept of the Network Control facility. It advocates a much more explicit and active role for this function at the apex of the command and control hierarchy. This should be allied to a service information capability that matches customer and other stakeholder needs.

It also addresses our immediate requirements to manage the detail of the assurance process to test the resilience of existing equipment, plus the imperative to review the procedures and contingencies that were tested.

In 2006, the Private Finance Initiative (PFI) CONNECT is scheduled to complete delivery of a high-capacity and fully integrated radio system. This will overcome the majority of communication problems that delayed our service restoration.

The response to the power failure of 28th August highlights problems in dealing with smaller scale disruption. The recommendations will therefore improve day to day performance.

2.0 Introduction

This Investigation Report examines London Underground's performance in responding to the large-scale failure of power supplies on Thursday 28th August. Its purpose is to identify the root causes of performance issues and to recommend improvement actions.

The Report follows the format of the London Underground Formal Investigation Report template.

Following a brief chronology of events, the existing contingency plans for power failure are outlined. Our actual response is then described and analysed.

The recommendations have been agreed with the relevant manager who has confirmed there are resources to complete the work required. This will be tracked through the established mechanisms.

3.0. Incident Information

3.1. Chronology

In outline, power failure occurred at 18.20 and events on 28th August unfolded as follows:

18.20 In the affected area, trains stop and station lighting drops to emergency levels. Only the Metropolitan Line remains operational from Wembley Park northwards

18.26 Network Control Centre contacts Rostered Duty Officer

18.45 First of eight trains to be evacuated via tracks begins procedure at Morden - completes at 19.04

18.49 Traction power returns to Central Line – service resumes to stations east of Holborn and west of White City from 19.05

18.50 District Line resumes shuttle service to all stations between Whitechapel and Upminster

19.05 Traction power returns to Northern Line, service progressively restored from 19.30

19.11 East London Line services resumes with full service available

19.55 Bakerloo line resumes Queen's Park to Harrow and Wealdstone

20.00 Last of eight trains to be evacuated via tracks completes procedure at Stockwell - started at 19.30

20.00 Victoria Line resumes, King's Cross St Pancras to Walthamstow

20.00 Piccadilly Line resumes Green Park to Cockfosters, Acton town to Rayners Lane

20.40 Jubilee Line resumes in two portions: Stanmore to Finchley Road, Stratford to London Bridge

20.40 Power returns to affected part of Victoria Line (south of Victoria). Stations progressively reopen, Victoria the last at 22.45

20.45 Metropolitan and Hammersmith and City Lines resumes

21.17 Piccadilly Line resumes Cockfosters to Heathrow

21.42 Victoria Line extended to Warren Street

22.05 District Line service resumes Tower Hill to Wimbledon

22.34 Bakerloo line resumes to all destinations

22.45 Victoria line running to all stations

00.30 All last trains operate to schedule

3.2. Background Information

London Underground is supplied with electrical power through interfaces among:

National Grid Transco (NGT) – the transmission system operator

Electricitie de France (EdF) – the distributor for the London area

Seeboard Power Link (SPL) – the PFI manager of LU's internal network.

These parties configure their networks to ensure resilient supplies match LU's demands. Power arrives through a series of Bulk Supply Points (BSPs) which are arranged to ensure there is always spare capacity.

LU has a range of asset and operating contingencies to maintain safety should power supplies fail. These include alternative sources, redundancy in key systems and staff training in handling effects such as evacuations.

Appendix A contains a more detailed description of power supply arrangements.

The early evening peak of Thursday 28th August was unremarkable with near-normal services operating. The Piccadilly Line was recovering from a suspension and the Central Line had fewer trains in service than scheduled.

It was a wet evening with temperatures somewhat cooler following a lengthy spell of hot weather.

Customer numbers were normal for the summer holiday period and there were no significant closures in force.

3.3. Incident Information – The Immediate Impact

3.3.1. The National Grid and Electricitie de France

At 18.20 on Thursday 28th August, National Grid Transco experienced failures in its transmission system that was supplying power to the energy distributor, EdF. In turn, EdF supplies were lost to around half a million customers in south London including National Rail and London Underground through one Bulk Supply Point.

National Grid established promptly that the failures were technical, although this information was not explicitly communicated to London Underground as the principal priority was to restore supplies as early as possible. Through reconfiguring supplies, electricity was gradually restored between 18.32 and 19.01 to all EdF customers[1].

National Rail services were suspended across a wide area south of the Thames as traction power was lost.

[1] EdF Energy Networks Branch, Final Draft Report, page 4

Roads were significantly disrupted as traffic signals failed and the emergency services were overwhelmed with calls. The scale of the incident triggered intense media interest, especially as its cause was initially not clear.

3.3.2 London Underground

At 18.20, the LU Power Control Room (PCR) became aware from multiple simultaneous alarms and indication changes on various displays that a serious loss of power had occurred and began to investigate.

Line Control offices experienced extensive equipment failure. All emergency lighting worked but much communications equipment and all signalling diagrams failed. Train location monitoring was severely compromised.

The cause and extent of the loss was not immediately apparent. Supply failures to signalling and traction systems was extensive and from indications at Line Control offices, the power failure was more or less total.

Some 290 trains were in the area affected and lost traction power. Operators coasted towards stations or stopped if they were leaving platforms. 62 trains came to a halt between stations. Most train radio was unavailable or badly degraded as these systems are not yet upgraded. As expected, all signals went to their danger modes.

On stations, the power loss was evident when lighting dropped to emergency levels as back up supplies switched in. This is designed to happen within 0.25 seconds and was accomplished successfully everywhere, as planned[2]. Staff radios are battery powered and continued to work, as did fire alarm and public address equipment. Closed Circuit Television (CCTV) images, however, were lost.

The Network Control Centre (NCC) was immediately swamped with telephone calls reporting the situation and seeking information.

Appendix B maps the geographical extent of the power failure on the LU network.

[2] One of the batteries at Borough station exhausted earlier than expected due to an unauthorised load being connected. This did not affect the power supply during the evacuation.

3.4. Incident Information – Planned and Actual Response

3.4.1. Power Supplies and The Power Control Function

3.4.1.1 The Contingency Plan for Power Failure

Responsibility for power control is split between LU, who control switching for traction current and lighting supplies, and SPL who control the remainder of the network including high voltage distribution, traction conversion plant, signalling supplies and compressed air.

Contingencies for loss of supplies are jointly evaluated continuously as plant maintenance and other planned downtime affects availability of power feeds.

To guard against the loss of one or more BSPs, contingencies for switching supplies through the remainder are agreed in advance. Should this not be possible, a stand-by generating facility known as the Central Emergency Power Supply (CEPS) can be brought on line within twenty minutes.

This supplies enough power for light and other systems to manage evacuation of the network, but does not have the capacity to move trains. Restoration of secure EdF supplies is therefore always the preferred option.

CEPS is routinely operated to test its readiness. Additionally, a number of large-scale exercises known as 'Operation Hood' and 'Operation Bismarck' have been performed over the last decade to better understand the effects of losing and restoring power.

3.4.1.2 The Response to Power Failure

Power Control staff became aware of the incident following over 1 000 alarms and plant state indication changes on various control displays. These were analysed to determine there was loss of power to one BSP.

The EdF Control Room was contacted and they confirmed this was due to a fault on the National Grid (NG) network. EdF could not explain the nature of the failure or confirm when supplies would be restored.

With this uncertainty, and the remaining BSPs unaffected, LU and SPL jointly agreed to implement the appropriate contingency plan to switch EdF supplies through an alternative BSP. As this would provide sufficient energy for traction power, the use of CEPS was discounted. This investigation and planning sequence took seven minutes from the initial power loss.

The LU Network Control Centre was advised of the restoration plans .

Switching to an alternative BSP took about twenty minutes from the initial power loss and restored full lighting, including those tunnel lights that were not available previously. In line with normal procedures, signalling supplies were restored first, then air compressors - which operate points - and finally traction current (to allow train movement).

Unlike other supplies, traction current has to be recharged in conjunction with individual Line Controllers to ensure that it is safe to re-liven the tracks. This is to ensure power is not restored where people are present.

This required all traction current circuit breakers to be opened, traction supply equipment to be switched back on, and circuit breakers to be then individually restored with permission from Line Controllers. Hundreds of plant operations were needed to restore full traction supplies with the last, to the District Line, restored by 19:40hrs.

A Technical Investigation Report prepared by the LU Energy Contracts Management Team provides more detail including reviews of reports produced by SPL, NGT and EdF. Appendix A explains CEPS in greater depth.

3.4.2. Operations

3.4.2.1 Contingency Plans for Power Failure

Assets

With few exceptions, the only Line assets with back-up electricity supplies are those needed for station evacuation in the event of a power failure. These include station lighting, fire systems, public address, lift winding gear and staff radio, all of which are fed by batteries. Trains also have batteries with enough power to run some functions including lighting and communication for several hours.

These supplies will not exhaust before power is restored - for example through alternative BSPs - or CEPS. In the worst case, CEPS will, within twenty minutes, provide power for tunnel and station lights, station radio and public address plus some deep level lifts and escalators. CEPS will enable lighting and basic systems for station or train evacuation, but not train movement.

Generally, other assets are not backed-up. Signals fail-safe (all systems demand power otherwise trains are halted) and are not required until traction current is restored.

Train radio relies on networks of amplifiers and base stations with local power feeds. Uninterruptible Power Supplies (UPS) are being introduced as these systems are modernised but current systems are not expected to operate fully in a power failure. The new fully integrated CONNECT radio system with multiple channels and backed up power supplies will be implemented in 2006.

In the meantime, signal and tunnel telephones allow Train Operators to communicate with controllers if radio is unavailable, and these are battery-backed or have dual fed supplies.

Similarly, train location monitoring systems will be provided with UPS as they are modernised. Now, computerised systems produce logs of train positions every 30 seconds. Non-computerised Lines keep manual records of movements.

Line control rooms and signal cabins have battery-backed lighting and telephones. Each also has a contingency plan should they need to be evacuated themselves.

On stations, CCTV will fail along with escalators and lifts where these do not coast to landings.

All telephones are battery-backed.

The Lines

The emergency plan contingency for power failure is to evacuate the affected areas until a secure supply is restored. This takes account of our current communications capability.

On stations, the trigger for evacuation is lights falling to the 25% emergency level.

Train Operators will notice traction Ioss and should halt trains in stations, if possible, by braking or coasting. They are expected to await guidance unless there are any immediate hazards, in which case they should use train radio, tunnel or signal telephones, or seek assistance from station staff.

Control staff should establish the cause, extent and likely duration of the failure by contacting the LU Network Control Centre (NCC). The NCC should be in contact with the LU Power Control Room to determine which contingency is to be implemented and the forecast time to provide supplies.

The NCC is expected to lead stakeholder and customer communication in a power failure and to co-ordinate with the emergency services. Further details about the NCC are given in the next section.

Control staff should also monitor the status of trains to decide if, when and how they will be evacuated.

Customers can be evacuated from trains by travelling to stations when power is restored, or by detraining and walking along tracks, guided by staff.

Detrainments must be authorised by control staff and can take considerable time when trains are heavily loaded. Since people must be clear of the tracks before traction current can be recharged, it is only expected to be chosen during lengthy delays or when customers are likely to be at greater risk by waiting on board.

Factors to consider before authorising a detrainment include the numbers and status of passengers, the ambient temperature and other weather conditions, the availability of staff to assist, the distance to the nearest station, the number of trains affected and presence of other hazards such as junctions and bridges.

Control staff are expected to take these factors and the expected duration of the power failure into account in considering whether to authorise detrainments.

When power is available and any train evacuations complete, Lines are expected to restore services as soon as it is safe to do so.

Power control staff may only recharge traction power when told to do so by Line Controllers.

Network Command and Control and the Network Control Centre

Operational command is devolved to individual Line Control offices. Should a serious incident occur, such as a large network power failure, an on-call senior manager known as the Rostered Duty Officer (RDO) is notified by the NCC.

For any incident, the RDO advises the relevant Duty Operations Managers (DOMs) the senior official in charge of each line control centre[3], taking overall 'Gold Control' command, if necessary. The RDO takes a strategic overview of an incident, its management and impact. She or he co-ordinates the network response, calling in assistance if needed, and oversees service restoration.

The NCC provides communications support to the RDO and fulfils a number of other roles:

- communcates incident details to all Line Control staff using an instant electronic system
- broadcasts service information externally and internally
- co-ordinates with emergency services, including the British Transport Police. This includes their attendance, as necessary, to assist with evacuations
- notifies directors, other managers and the Press Office
- informs stakeholders such as TfL, the GLA[4], HMRI[5] and the London Resilience Team

The NCC is specifically expected to co-ordinate the LU response to flooding, terrorism incidents and large-scale power failure. Contingencies are rehearsed for each of these, including attendance of NCC Duty Managers at table top exercises.

3.4.2.2. The Response to Power Failure

Assets

All lighting systems worked as expected and provided illumination to emergency standards in all affected areas. Rolling stock batteries were effective and the trains themselves regained power and movement without problems.

Generally, communications assets behaved as anticipated, causing loss of availability over parts of each Line.

[3] Lines vary in the title given to the duty manager in overall command, some having a Duty Line Control Manager and others a DOM. For simplicity, the abbreviation 'DOM' is used in this report to mean all such posts.
[4] The Greater London Authority
[5] Her Majesty's Railway Inspectorate

There were unexpected problems with the Victoria Line train radio which was quickly traced to a faulty relay in an Uninterruptible Power Supply system. Jubilee Line radio was out of service for a considerable time despite the UPS installed on the extension.

Station radio, London Fire Brigade (LFB) radio and British Transport Police (BTP) radio worked well without any reported problems and battery back-ups to Public Address systems all worked. CCTV was lost on stations, as expected, and at Line Control offices. There were no reported problems with the internal telephone system.

Unexpected indications of tunnel telephone operation at Line Control offices and the Power Control Room indicated supply problems, potentially through faulty batteries or sticking relays.

The Lines

Loss of supply from any Bulk Supply Point will affect Lines differently according to the nature and location of the equipment it feeds. The BSP affected on 28th August supplied traction current and power to stations over a wide area, as Appendix B shows, and also most Lines' train control equipment, including signals and radio.

At 18.20, therefore, Lines were quickly paralysed. Stations were evacuated, as planned, and control staff sought to establish what was affected, when power would be restored and train locations.

All Lines successfully contacted the NCC in the early stages but most found contact increasingly difficult to maintain as telephones were rapidly congested. Some circumvented this channel by speaking directly to the Power Control Room staff.

Information did emerge about the contingency switching operations and likely effects on power availability. However, this was not a uniform or rehearsed process.

As a result, some Lines used this knowledge to plan their approach to evacuation and restoration. Others knew less about how and when power was to be restored and its effects.

This caused uncertainty and meant train evacuations and service restorations were not planned with any precision but improvised as circumstances dictated. Thus 5 evacuations via the track were co-ordinated by Controllers or Managers, but 3 were initiated by local staff following procedures.

This variability of approach in the intial stages affected the quality of service restorations as several lines struggled to co-ordinate resources. Variability in the failure's effect and speed of restoration were also critical factors. For example, the Central and East London Lines resumed by 19.05 but around this time the DOM on the District Line was planning to withdraw services for the remainder of the day.

Other factors that accounted for variability in response were poor communications, the number of trains to evacuate on each Line, local problems resetting equipment and the absence of a network command presence. These problems were compounded by restricted use of manual computerised train location back up systems.

A more detailed description of Line responses is attached as Appendix C.

Evacuation

Stations were successfully evacuated, as planned, by 18.40 despite crowded trains stuck in platforms and stalled escalators.

Most stations reported that passengers were calm, although some concern was caused where automated evacuation announcements were activated. This includes the phrase, 'because of a reported emergency...' which led passengers to believe something other than power failure had occurred.

Only one lift was stalled between landings and this was at Lambeth North station with three customers inside. These were released by 19.15 with the assistance of Infraco staff.

Some 290 trains were in the area affected and 62 of these were stalled between stations. Following procedures, 8 were detrained of 1 200 passengers in total. The other 54 were moved to the nearest stations once power was restored, and some 17 000 people evacuated, with the latest completed by 20.20.

There were three instances of Operators leaving trains to seek help from station staff. In each case, passengers were temporarily without direct supervision but were informed by Operators about their actions. There are no allegations that this caused alarm. Each train maintained lighting and, as expected, tunnel lights were restored before detrainments began.

All detrainments were assisted by station staff and – on the Victoria line – by British Transport Police officers. No injuries were reported.

In 2 cases on the Jubilee and Northern Lines, trains were near platforms. On the Bakerloo Line, 3 detrainments were authorised since it was known that restoring the signalling system could take time because of particular problems with this Line.

The remaining 3 were Victoria Line trains. One was near the platform at Brixton station and the other two were approaching Stockwell. Here, there was some poor co-ordination between train, station and control staff, and recharging traction current was delayed whilst safety checks were made.

Of the 54 stalled trains evacuated via platforms, those which took over an hour were concentrated on the Piccadilly and District Lines. These were dealt with sequentially, as normal, but the volume of trains stalled on the western branches meant inevitable delays before the last received attention. The latest train took two hours to evacuate since nearby points needed manual attention before it was safe to move.

In summary, there were no self-detrainments by passengers and every evacuation was a controlled process with no risk of staff or customers being exposed to traction current. There were some instances of poor co-ordination and long delays where large numbers of trains were involved.

Network Command and Control and the Network Control Centre

From 18.20, the NCC answered a stream of telephone calls reporting power failure and querying the cause. The Duty Manager rang the Power Control Room who confirmed that a widespread failure was being investigated. The Power Control Room called back at 18.26 to report that the power feeds were being switched to an alternative source.

At 18.26 the NCC alerted the RDO who contacted the manager responsible for the Power Control Room. He established that the switching process would be complete by approximately 18.42. He realised this meant supplies would then be gradually recharged and called the NCC to advise Lines not to rush to detrainment.

The NCC attempted to pass this message to Lines. This was impeded by telephone congestion both there and at Line Control offices where reports of failures and requests for information continued to flood telephone lines. The NCC had broadcast a message asking for urgent calls only but this was not received or heeded everywhere.

The NCC briefed the Press Office at 18.30 but then failed to prioritise information dissemination. Instead, the Duty Manager gave precedence to answering the continuous heavy volume of calls as he believed it likely that some may have been reporting safety incidents. This turned out not to be the case - most were fault reports, information requests or offers of help.

This failure meant the LU Customer Service Centre (CSC) and various TfL information services were not able to advise customers of the impact of the power loss until after 20.00.

From 18.50, senior managers began to arrive in the NCC led by Mike Brown, LU Chief Operating Officer, and Nick Agnew of TfL.

At 18.55, Nick Agnew reported the status to Peter Hendy, Acting Commisioner for Transport, who was in the TfL Press Office and who directly informed the Mayor's office. Nick Agnew also spoke to the London Resilience Team's Duty Officer who in turn briefed other agencies such as the Department for Transport.

As the RDO was still making his way to the NCC, Mike Brown appointed another RDO as interim Gold Control. He also spoke to other senior managers and asked them to take an overview of their areas in liaison with Gold Control.

None of these managers could establish a strategic, overview of the network until after 20.00. Communication was often slow and with the Lines themselves very busy co-ordinating operations, an accurate picture was difficult to obtain and maintain in a rapidly changing, complex situation.

From 21.00 a larger team of managers assembled in the NCC. The RDOs concentrated on the Lines with pro-longed problems and then ensuring the

service was ready for the next day. Others reviewed the resilience of power supplies and briefed stakeholders.

The NCC also struggled to contact the emergency services. The London Ambulance Service was able to attend train evacuations, but the London Fire Brigade (LFB) were more difficult to contact. The NCC is equipped with a dedicated telephone line to the LFB but such was the pressure on this service, some calls took time to be answered.

3.5. Information to Customers and Stakeholders

The quantity and quality of information passed to customers and stakeholders for the first part of the evening was poor.

Station and train staff were ignorant of the extent and nature of the failure for some time. They were also unaware of the contingencies being implemented at the Power Control Room, how this would effect the restoration of supplies to their locations and how, and when, train services would begin.

This caused a great deal of confusion.

Communication between stations, Line Control offices and the NCC was ineffective and even basic information was difficult to gather. No one established the situation sufficiently to take an overview.

Paradoxically, the widespread, and understandable, appetite for information was a chief cause of the severely restricted effectiveness of communication channels. But underlying this cause is a customary reliance on one-to-one telephone conversations and the want of a disciplined process to control the flow of calls.

The NCC did make an early broadcast requesting that no non-urgent calls be made, and there is evidence that Line Control offices took similar steps. Both were ineffective. Whether or not staff heard these messages, they continued to telephone one or both centres.

Communication with agencies such as the Press Office was insufficiently prioritised. Although media enquiries were intense in the first hour, the Press Office could only provide a holding line that there had been a major power failure and many evacuations. The Mayor's Press Office was informed shortly after 18.30.

Other stakeholders were not directly contacted by the NCC but the arrival of Mike Brown and Nick Agnew ensured that Peter Hendy, TfL Acting Commissioner for Transport, was briefed and able to relay reports to the Mayor's office. Similarly, the Managing Director and London Resilience Team were contacted and kept up to date, enabling other agencies to be informed.

More detailed information was passed to the Press Office by the NCC from 19.30 with the first media statement finalised at 19.50. Spokespeople were provided for interviews from about 21.00.

The restricted flow from the NCC also profoundly affected the service offered by TfL's Group Travel Information teams. These include the 'Real Time Team' providing information through the media (including teletext and

ceefax), the Travel Information Call Centre (which handled some 14 000 calls) and Travel Information Centres.

This failure was further compounded by loss of the internet link between the Real Time Team and the Nexus Alpha system which relays messages to corporate intranets, web sites and media organisations.

Some customers e-mailed the Customer Service Centre but did not receive a prompt reply as in-coming contact is dealt with sequentially, not real-time.

An explanation and apology poster message was dispatched electronically but did not reach around 40 per cent of the plotters. This was generally caused by the plotters not being maintained in a state of readiness.

3.6. Infraco and PFI Supplier Responses

Infraco and CONNECT PFI staff were required to help reset certain equipment when power was restored.

Experience from earlier tests and more routine failures was helpful in prioritising their attendance and CONNECT staff in particular were pro-active in determining where faults were likely to occur.

There were several areas where better preparation by LU and Inracos would have reduced delays. Escalators on the Northern Line's southern stations could not be restarted by operating staff and needed individual attention from engineers.

Power was not restored to Brixton station on the Victoria Line until 22.30 and this made a material difference to the quality of service restored.

Both issues had been exposed in the earlier tests of power failure and restoration.

Whereas the delay restoring the Bakerloo Line's signals was predicted, these other problems were not expected. This suggests further local tests of power loss scenarios would be valuable, along with greater staff familiarisation. This is addressed in this report's recommendations.

3.7. Customer Responses

The LU Customer Service Centre was contacted by almost 200 customers who recorded:

- 170 complaints
- 18 commendations
- 11 general enquiries

A large proportion of complaints related to information issues, such as: poor real-time information on the TfL website, lack of information from Train Operators, and general confusion about what was happening.

Several customers also contacted the CSC to request compensation for taxi fares and theatre tickets. After careful consideration, taking into account that the cause of the disruption lay with the power supply organisations, it was decided that compensation would not generally be granted.

4.0 Analysis of Response to Power Failure

The purpose of this section is to highlight issues underlying our response to the power failure, as outlined in this report, and to assess root causes.

Details of people consulted by the Formal Investigation Team appears as Appendix D.

4.1 Network Command and Control and The Network Control Centre

The NCC was ill-equipped to deal with an incident on this scale. There were serious shortcomings in its preparedness:

- the managers on duty were not experienced or fully trained for their role
- Mike Brown and Nick Agnew found basic materials and stakeholder information difficult to locate
- the communications capability was inadequate
- steps taken to manage in-coming telephone calls were not robust
- communication from key functions such as the Power Control Room and Line Control offices did not always receive priority
- information dissemination to staff and customers was weak
- staff could not easily be deployed on priority tasks owing to limitations in the layout of the room and its equipment.

The network command and control arrangements were also stretched beyond the point that effective strategic decision making was possible. Like the NCC, this reflected some inherent design limitations:

- DOMs are not supervised unless they report an incident to the NCC
- during a network incident, support for each DOM will be limited by the RDO's span of control
- DOMs are unable to take a network perspective
- out of office hours, the RDO may be off the network and limited to communication through a mobile telephone
- as DOMs and the NCC could not pool information, both the RDO and Mike Brown were primarily concerned with tactical rather than strategic decisions for a considerable period
- the overriding focus of the RDO is on safety, followed by incident management and service restoration; typically this can lead to stakeholder and customer information taking a lower priority in the early stages of an incident.

Both the NCC and RDO arrangements result from design decisions made over the last two decades in conjunction with devolution of accountability for operational control to Line-based offices. However, during this period, network perspectives on Line command and control and service information have been repeatedly raised as issues following significant incidents. Lines transfer operational command to the RDO during incidents, and information requires network and off-system dissemination, so a form of

centralised support has always been needed although the NCC is not designed to achieve this end.

The day-to-day function of the NCC is to collate and pass messages and provide an assortment of peripheral co-ordination and support activities such as the staff-taxi booking service. Duty Managers are not expected to take any operational decisions except during serious flooding, terrorism incidents and power failure.

The NCC is more active in information dissemination, accountable for alerting staff to problems on and off the network. But even here, external information is filtered through the TfL Real Time Team – remote and under different management – before it reaches areas such as the Customer Service Centre and the media.

On 28th August the NCC quickly became the centre to which managers gravitated. This reveals its utility as a communications centre and the best place from which to co-ordinate Lines.

Re-aligning the NCC Duty Manager to co-ordinate network operations at the apex of the command and control structure is critical.

- a 'Network Operations Manager' role should replace the RDO for first-line support for DOMs
- relationships with Line Control offices and the Power Control Room should be strengthened and protocols routinely tested
- incident debriefing should be more robust. RDOs seldom have the capacity to initiate immediate debriefings with staff involved in an incident. This limits opportunities to learn, amend plans, share lessons and give immediate feedback.
- table-top style training tends to be restricted to known up-coming events and infrequent large scale incidents. Regular practice of more routine contingencies has been regularly noted as a component of improved service reliability and incident management.

This addresses some of the root causes of the design weaknesses in the response of the NCC and RDO by strengthening Line co-ordination and network operations management.

Service information also needs to be addressed.

4.2. Information to Customers and Other Stakeholders

Good quality service information is a high priority for improvement. In response, a number of steps have already been taken:

- development of new media through the internet and mobile telephones
- development of information systems including recorded real-time Line updates
- installation of networked computers
- introduction of performance measures for real time information
- new assets within the Public-Private Partnership (PPP) contract
- a strategy for new station control facilities (known as FOCUS)
- greater staff and management focus

- implementation of measurement and feedback processes
- Capability will be enhanced when the CONNECT radio network is available.

Key learning points from this incident are that:

- using telephones to pass status information is unreliable
- telephone communication does not quickly enable access to information by customers, is not measurable and is difficult to keep up to date
- the NCC has limited communications capability
- London Underground needs a one-to-many electronic system to share service information efficiently.

Local input of service information should be automatically routed, as required, and interrogated real-time by anyone with access, in a similar way to the current Intranet system. Messages from key subsribers such as the Power Control Centre should be prioritised. Customers and other stakeholders should also receive relevant feeds.

The Director of Information Management is exploring the short term steps and medium term goals to move decisively towards this information capability demanded by staff and customers alike.

Within the NCC, there is a mismatch between the priority of service information and the resources in place.

At present, with limits on how much information it can process, the NCC can become a bottleneck not a catalyst for swift, accurate, information flows. To put our commitment to quality service information into action, restructuring is necessary. A dedicated team of information specialists should complement the NCC network operations management function. This will provide a direct link to Line information teams and should directly feed external channels.

These staff should rotate between roles in the NCC and on Lines to strengthen relationships and sharpen their exposure to customer demands for information.

Refocusing the NCC around operations management and information will mirror at network level the functional design of Line Control offices. This will complete and streamline both disciplines for local focus and network overview.

4.3. The Lines

Lines were generally unprepared for the effects of the power failure and there were significant weaknesses in restoring equipment and services.

The standard emergency reaction to initiate evacuation served Lines well. Performance could have been improved had train location back-up systems been in a better state of readiness but the main problems were caused by basic infrastructure weaknesses and the number of stalled trains.

Closing down the network is a relatively uncomplicated task in comparison to restarting services.

Knowledge of the contingency arrangements for reintroducing power was not good. Lines were not generally able to predict when trains would be able to move and thus to orchestrate resources.

Communication was severely restricted by overuse of telephones. Network-level co-ordination and guidance was only slowly established.

Poor performance of train radio was expected and the contingency procedures worked well. The need for the current investment in the CONNECT radio system was amply demonstrated.

Lines had not fully used learning from the previous tests of power failure conditions. The Technical Investigation Report makes recommendations to undertake a business wide review of the requirements, risk and scope of future tests and these are supported by this investigation.

One of the most serious consequences of the power failure for Lines was loss of train location information. Lines with computerised signalling systems should refer to a location log generated automatically every 30 seconds. Non-computerised Lines keep hand-written records.

In both cases, there was little evidence that these were in a state of readiness to be effective. This has been flagged as an immediate issue for Lines to tackle and a review of the monitoring and assurance regimes forms a recommendation of this investigation.

4.4. Train Evacuation Protocols

Protocols for train evacuation were reviewed recently after incidents involving crowded trains that were stalled for long periods. Also, concern has been expressed about the effects of prolonged delays during hot weather.

Judging if detrainments are needed is often difficult for Line Control staff. Once an evacuation is started, a long delay can be expected before it is safe to re-energise the tracks, with serious knock-on effects for resuming services.

Holding customers on trains will not pose danger under most circumstances. But on crowded trains, risk will steadily increase with time.

In both cases, confidence in the likely duration of the delay is key, as is provision of information to those on the train.

Before the recent review on detrainments, the prevailing advice to staff was to consider evacuation if a train was stalled for 30 minutes.

However, experience showed this cut-off point was overly rigid in some situations. Instead, Line Control staff now review the circumstances of each stalled train every fifteen minutes after the start of an incident, physically recording reasons for deciding whether or not to authorise detrainment. This guarantees a conscious decision is taken.

The Investigation finds that this more flexible approach has not been fully appreciated by all the staff affected. Furthermore the new protocol assumes open communication channels with operators and a good knowledge of train positions.

4.5. Previous Incidents and Investigations

The Investigation Team has evaluated reviews of earlier power failures and drawn on knowledge of network-wide incidents such as severe weather and large events. Specifically, the team has analysed reviews of:

- power supply failures 23rd to 29th November 1993
- Lots Road generating station power supply failure, 20th November 1996 (reference S(97) - 12)
- cable damage and power failure incident, 6th April 1996 (reference 48/05/96)
- Neasden power failure, 20th March 1997 (reference 97/016/348)
- the lessons learned in returning the Central Line to service following the Chancery Lane accident[6].

The second and third incidents were similar to that of 28th August in their scale and suddenness, if not their cause. Some common themes emerge: knowledge of contingency and timing of power restoration was not strong and this affected Lines' responses; preparedness was variable; planned asset resilience showed flaws; and communication was especially weak.

For example, the second review notes, 'problem areas appear related to the volume of incoming calls to various control centres'.[7] And the third makes some familiar observations: 'immediate network response was hampered by the overwhelming amount of telephone calls received in the NCC', and, 'continuous requests for information meant the Duty Manager found it virtually impossible to manage the incident effectively and to make outgoing calls'[8].

There were also similar problems with stalled trains, monitoring train location, train radio and resetting equipment when power was restored. And indeed the time taken to restore makeshift services was around three hours on both occasions - suggesting that our performance in 2003 matched that in these earlier incidents.

Recommendations in all three reports addressed the power supply network and radio communication systems. In many respects, the current configuration of the Power PFI and supply network was shaped by these demonstrations of the declining reliability of Lots Road generating station.

The condition of the train radio system was well understood by this time and plans for a £1.5bn PFI were well advanced. This culminated in the CONNECT system which is scheduled to be implemented by 2006.

Action was put in hand to address preparedness and specifically the communication overload issues. As now, the impact of this problem on the effectiveness of command and control was recognised: 'the flow of information to the NCC…should be reviewed to ensure that the NCC is able to adopt its strategic role'[9].

As a result, further training for NCC Duty Managers and RDOs, plus improved communications tools have been delivered. However, events of 28 August 2003 show that these have not been effective in addressing the root causes.

[6] *Turner and Townsend Group, July 2003*
[7] *SMR S(97) - 12 page 6*
[8] *SMR 48/05/96 page 7*
[9] *SMR 48/05/96 page 10*

Current recommendations must be implemented to greater effect than those of prior investigations. Although Lots Road is no longer a factor, the risk of power failure is now demonstrated as still valid. Our capability to respond the security incidents will also depend to a degree on our readiness to co-ordinate a network response.

4.6. Asset Resilience to Power Failure and Future Plans

Weaknesses in train radio were universally recognised by 1997. A modernised and fully-integrated radio network is now being installed under the CONNECT PFI contract.

This upgrade is still awaited hence performance of the legacy systems in 2003 did not differ greatly from our experience in the earlier incidents.

Backing up our radio systems, signal post telephones and tunnel telephones turned out to be unreliable in some areas, although they were not generally needed by Train Operators.

Initial inquiries into this problem will be continued by the Chief Engineer based on the recommendations made here.

Longer term, the key to secure resilience to power failure lies in upgrade projects under the PPP contracts. Line upgrades will include backed-up signalling systems, control diagrams and train position monitoring.

In the interim, new software to help train location monitoring such as the Tracker and Train Identifcation and Management Information System (TIMIS) projects can help. Manual train logging is being computerised and the readiness of local back-up records is to be reassessed with robust monitoring introduced.

Also, the recommendations of this investigation suggests that the assurance process and standards for key assets needs to be reviewed for resilience against power failure.

This work must include individual components of key systems, as well as routine interactions between engineering and operations staff. For example, the unhelpful activation of emergency evacuation announcement from station fire systems was evidently caused by poor reporting of flat back-up batteries. This equipment fails-safe when power is lost by triggering an evacuation, however in the circumstances, the tone and wording was unhelpful.

The weak points of all such assurances systems need regular exposure to guarantee compliance.

5.0 Summary of Loss

Details of injury/time lost

Stand-by ambulance staff were needed to assist customers at three stations and only one of these – the victim of an asthma attack – required further treatment.

No staff time was lost directly but staff assaults occurred where customer frustration with the level of service and quality of information appears to have been a factor. There was no time lost or service impact from these assaults.

Details of service lost

As outlined in the Assessment of Response, considerable services were lost on all Lines with only a much reduced frequency offered. On the Waterloo and City and Circle Lines plus the Rayners Lane branch of the Piccadilly Line, no trains ran.

Services began as normal on Friday 29th August.

Details of Property Damage

There are no reports of property damage and no equipment suffered long term harm.

Details of Environmental Loss

There was no environment loss as a result of this incident.

6.0 Immediate Causes

Sub-standard Action

Sub-standard action 12, 'improper fitting' was subsequently shown by the National Grid Transco enquiry as the cause of the original power supply failure when a back-up system failed unexpectedly.

Sub-standard Conditions

On London Underground, there was evidence of sub-standard condition 3, 'defective tools, equipment or materials' when certain equipment failed.

Also, condition 4, 'congestion or restricted action', applied to communications, was an immediate cause of the slow recovery and poor customer information.

7.0 Basic Causes

As the orginal fault was outside London Underground's control, there is a case here for assigning basic cause 16, 'external forces outside LUL control'.

The assessment has shown that the initial response to evacuate was handled well but that the service resumption process was slow owing to some local

difficulties resetting equipment and poor communications. This could be described as basic cause 1, 'inadequate training/instruction'.

The poor communications throughout the incident has been shown to be hindered by reliance on a telephone system that was not best suited to the needs, hence basic cause 12, 'inadequate standard of design', is also relevant.

8.0 Cost of the Incident

The financial effect of this incident has been calculated by assessing the typical revenue take for comparable Thursday from the time of the incident. The figure derived is £140 000.

There were minor expenses in some locations such as bottled water for customers during evacuations, taxis, and a few instances of overtime worked that could be attributed to the incident.

Loss due to damage to our reputation, customer confidence and stakeholder advocacy has not been taken into account in this estimate.

9.0 Review of Appropriate Risk Assessments

No risk assessments have been reviewed by this investigation which has considered the overall response to the power failure and the issues of principle that the root causes reveal.

Where necessary, local managers have been contacted to ensure specific learning points have been captured for reviews of risk assessments.

Additionally, the Operational Response Manager has agreed terms of reference with the Chief Operating Officer for a review of appropriate emergency plans. This will, inter alia, include a review of appropriate risk assessments.

10.0 Conclusions

Although there were no significant safety consequences, this was a serious incident that caused very significant disruption. It revealed a number of weaknesses in the robustness of key equipment and processes, including the readiness of back-up arrangements.

Under pressure, our communications capability was shown to be inadequate and an inhibition to a clear and unambiguous chain of command. Some failings were caused by deficient infrastructure; others were rooted in a less than rigorously disciplined use of the available equipment.

This meant effective communication and co-ordination between all the functions, and decision-making were made difficult with the result that information to customers and other stakeholders was generally poor.

Early notification of the Mayor's office via TfL and good contact with the London Resilience Team were helpful. But these relied on senior managers being present and was not part of a drilled response.

The chances of more power failures on this scale in the future are thought to be remote. There is already work in hand (discussed more fully in the Technical Investigation Report) to reduce the chances of a repetition and to better mitigate impacts.

Plans are also well advanced for much more robust and effective systems for managing critical activities. These include significantly improved radio communication across the whole network by the end of 2005/06 through the CONNECT PFI and train location monitoring.

However, it would be complacent to rely on future capabilities. This incident tested our ability to respond to serious network incidents whatever their cause, and in crucial areas the response was unsatisfactory.

These conclusions are in the context of network disruption from, for example, real or threatened terrorist activity, or any other cause. It is also worth emphasising again that many of the features of our response on 28th August are common to more routine causes of degraded operations.

10.1 The Network Control Centre

The performance of the NCC reflected the limitations of its design. This applies to the layout of the room, the functionality and integration of equipment and the training and status of its staff.

Some immediate focus on basic preparations will improve communications and readiness to respond to another large-scale incident.

However, uplifting the NCC to achieve strategic network command and control plus provision of service information to enable co-ordinated decision-making and effective customer and stakeholder communication, will require a longer-term development plan.

The Investigation Team concludes that the NCC should be redesigned around the twin functions of operations management and service information. The Team recommends the NCC be equipped to exhibit the following features:

- explicit command and control of the Lines through creation of a Network Operations Manager - to replace the NCC Duty Manager – populated by experienced Duty Operations Managers

- this command to be light during normal operations with devolved decision-making at Line level retained for all but serious incidents and those with an effect on other Lines, when this post replaces the current RDO arrangements for Gold Control

- incident response co-ordination through Gold Support on a permanently ready basis

- repositioning of the NCC as a centre for operations excellence and learning, including:
    - instant incident debriefings for lessons learned, recognition and communication
    - continuous incident re-runs and table-top exercises for command and control readiness training
    - third party involvement if necessary, for example other modes, the emergency services and London Resilience Team

- reallocation of non-core activities in favour of fully-focused service information co-ordinators who:
    - are dedicated to Lines and rotate between Line Control offices and stations
    - manage all external and cross-Line service information flows

- specialist senior management of command and control and the NCC reporting line amended.

Taken together, these suggestions represent far-reaching change with knock-on effects outside the NCC. It is right, therefore, that they form part of a wider review of the Operational Support function that has been commissioned at the time of finalising this report.

10.2 The Command and Control Structure

So long as the current arrangements for command and control remain in force, the same weakness evidenced on 28th August will potentially hinder our response to a serious network incident.

Enhanced command and control capability in the NCC, as suggested above, offers a greater chance of clear lines of communication being established straight away. Investing in greater potential here also boosts our readiness to deal with other threats to the network and the inevitable - and long - period of disruption we can expect during the PPP Line Upgrades.

The Investigation Team therefore conclude an overhaul of the command and control structure is justified. Since 28th August the network has experienced several other incidents where these strengthened arrangements would have most probably been of value.

In contemplating this change, the experience and commitment of the current RDO team should not be overlooked. They will be crucial to the transition period. Longer-term, mentoring the new Network Operations Management team and their advocacy for this role on the Lines will be no less important.

10.3 The Lines

Evacuation routines were generally executed very well with a small number of localised communication problems and delays where many trains were stalled. This guaranteed safety but in some respects, implementing our practised routines to close-down the network was the most straightforward challenge.

Restarting the service proved much more difficult. Many key staff were not fully aware of the effects of power failure and the contingency arrangements

and, as a result, many processes were not predictable. Communication was severely restricted by overuse of telephones and network-level co-ordination and guidance was only slowly established.

From this incident, a great deal has been learned at local level about the reaction of equipment to power failure. Preparedness has been improved, although this will require systematic review. This is in the hands of operations managers supported by the Operational Response Manager, the Chief Engineer's work on assurance processes and the power team's progress with further 'Bismarck' type tests.

This investigation highlights weaknesses in communications and in disciplined use of channels, principally telephones. To balance this, many staff performed in an exemplary fashion, including those who used whatever means they could to find information for customers. These staff acted for the right reasons but overloaded a system that was not designed to cope with their demands.

The CONNECT radio system which will be delivered in 2006 will overcome the majority of communications difficulties by providing much greater capacity, flexibility and control.

10.4 Train Evacuation Protocols

Even where trains had no communication and where position monitoring was lost, detrainments were safely handled. Some customers complained about poor information and frustration at the delay, but only a handful reported feeling in any danger.

It is tempting to conclude that existing protocols therefore stood up well to this examination.

Alternatively, had basic functionality such as communication and information been available, and had train location been known, then delays would not have been so protracted, especially on the District and Piccadilly Lines.

Alternatively again, had fewer staff been available to assist evacuation, had the weather continued to be hot and had power restoration taken longer, then it is probable that a larger number of customers may have suffered distress.

The Investigation Team has examined existing plans to address some of these issues through new equipment provided by projects such as CONNECT, TIMIS and the PPP Line Upgrades. Improvement in capability when power is lost is likely to reduce the frequency of incidents in future.

In the meantime, our experience on 28th August suggests greater emphasis on the management of back-up processes and equipment.

Finally, knowledge of the recent changes in evacuation protocols and their application in degraded scenarios needs attention.

10.5 Asset Resilience and Future Plans

Flaws in both older and newly-commissioned systems were exposed by the power failure and played a significant part in the response.

The protracted problems on the Victoria Line demonstrated how failure of just one small component - a relay - led to three detrainments.

The performance of other equipment has similarly shown that the current arrangements for assurance of resilience are inadequate and must be strengthened. Failure modes must be tested, the consequences predictable and mitgations understood.

With respect to future plans, the major planned upgrades do take the possibility of power loss into account in their designs, and will very significantly improve our capability to respond to an event of this magnitude.

10.6 Information to Customers and Other Stakeholders

The design weaknesses of the NCC, the sheer scale of this incident and capacity of our communications systems seriously impeded our performance in providing information.

Some basic readiness checks and training in the NCC have already been actioned.

More fundamentally, the Director of Information Management is charting the development of an information system, using an integrated approach to build on the systems in place.

Redesigning the NCC to be the control hub of information will maximise the value from this and the interim arrangements based on today's infrastructure.

As with so much of the ground covered in this report, events of 28th August brought into sharp focus our need for improvement. And this is equally true of our daily operational performance and incidents of lesser impact.

11.0 Recommendations

Recommendations from this investigation are presented in a number of groups:

11.1 Group A – Strategic Development of the Network Control Centre

A.1 Review the proposals outlined in the conclusions of this investigation as part of the wider analysis of Operations Support functions and the subsequent development plan.

Accountable Manager: Mike Maynard
Completion date: 31 March 2004

11.2 Group B – Short Term: Strengthening of the Network Control Centre

B.1 Ensure the Situation Room and other resources are in a permanent state of readiness to be the centre of command for network incidents. Specifically, ensure a full list of stakeholders' contact information is constantly updated and that supporting materials are available against a pre-defined checklist. Ensure an audit and feedback process is in place to confirm this.

B.2 Establish a process of monitoring use of dedicated telephone lines by unauthorised callers and a means of raising non-compliance with the appropriate manager.

B.3 Liaise with Service Control Managers to develop delay advice protocols, ensure these meet business requirements through involvement of the Quality Service Information Team (QSIT).

Accountable Manager: Iain Rose
Completion date: 31 December 2003

11.3 Group C – Short Term: Command and Control Review

C.1 Review the effectiveness of the RDO function when off-system and options for increasing presence in the NCC or at other locations on the network.

C.2 Clarify the relationship between the RDO and others in the command and control chain with managers who are present in their line management roles during an incident. Ensure a mechanism is in place for all parties to be aware of each other's roles and responsibilities and the limitations on these.

Accountable Manager: Andy Barr
Completion date: 31 December 2003

11.4 Group D – Short Term: Train Location Management

D.1 On Lines equipped with a signalling control computer:

a) establish the availability for use of train logging functionality that would support the identification of train location in the event of a signalling or traction power system failure;

b) investigate and cost any remedial action to make the equipment available for operational use (either directly or via a signal maintenance technician);

c) develop and implement operational guidance for DOMs to obtain such information a) when needed in an incident and b) on a regular basis, to provide assurance of readiness.

D.2 On lines not equipped with a signalling control computer (or ones without train logging functionality):

a) establish the contribution that could be made by modification of Tracker or other systems to provide a log of last known train positions.

Accountable Manager: Simon Pitt
Completion date: 31 March 2004

11.5 Group E – Short Term: Operating Procedures Review

E.1 Review Na 400 – 'Guidelines for Duty Operations Managers When Trains Have Stalled', for robustness in the event of power loss or failures in communication with trains and propose any necessary changes.

E.2 In the interim, ensure staff are reminded of the protocols for commencing train evacuation.

E.3 Ensure power loss and train communication failures are included as scenarios in the wider review of procedures.

E.4 Investigate if, in future power loss scenarios, traction current should be restored before signal mains to enable faster evacuation of stalled trains in some circumstances.

Accountable Manager: Ron French
Completion date: 28 February 2004

11.6 Group F – Information Systems

F.1 Review the features required by a network-wide service status information system, including:

- data input from all appropriate operational locations, i.e. stations, control rooms
- mobile staff and other modes
- templates to minimise data entry
- instant messaging to all users including external stakeholders, routed as required
- messages that demand acknowledgement
- auditability
- resilience to power failure, as far as possible.

F.2 Review the development path towards such a network-wide service information system, including the short and medium term steps and their dependencies.

Accountable Manager: Simon Pitt
Completion date : 31 March 2004

11.7 Group G – Chief Engineer

G.1 Review the arrangements for, and outputs of, the assurance processes to achieve robustness during power failure of the following assets:

- train radio
- signal diagrams
- train position monitoring equipment
- signal post telephones
- tunnel telephones
- fire alarm panels
- lighting supplies to control rooms and signal cabins
- station communications systems

The review should include the appropriateness of standards in these areas.

Ensure recommendations from this review are entered onto London Underground Safety Action Tracking System (LUSATS) and monitoring is sufficient to reduce risk from equipment failure to As Low As Reasonably Practicable (ALARP) levels.

Accountable Manager: Keith Beattie
Completion date: 31 March 2004

11.8 Group H – Energy Contracts Management Team

The Energy Contracts Management Team has developed a suite of recommendations. These are attached as Appendix E.

12.0 List of Appendices

A – Description of the London Underground Power Distribution System

B – Areas Affected by Power Failure

C – Summaries of Line reports

D – People Consulted by the Investigation Team

E – Energy Contracts Management Team recommendations

Glossary of Terms

ALARP	-	As Low as Reasonably Practical
BSP	-	Bulk Supply Point
CED	-	Chief Engineer's Directorate
CEPS	-	Central Emergency Power Supply
CSC	-	Customer Service Centre
CCTV	-	Closed Circuit Television
ECMT	-	Energy Contracts Management Team
EdF	-	Electricitie de France
DOM	-	Duty Operations Manager - the duty manager is overall command of a Line
GLA	-	Greater London Authority
LFB	-	London Fire Brigade
LU	-	London Underground
LUSATS	-	London Underground Safety Action Tracking System
LVAC	-	Low Voltage Alternating Current
NCC	-	Network Control Centre
NGT	-	National Grid Transco
OLBI	-	Off-Line Battery Inverter
OPO	-	One Person Operation
PCR	-	Power Control Room
PPP	-	Private Public Partnership
PSC	-	Power Services Contract
QSIT	-	Quality Service Information Team
RDO	-	Rostered Duty Officer
REC	-	Regional Electricity Company
Section 12	-	Stations covered by The Fire Precautions (Sub-Surface Railway Stations) Regulations 1989 stations
SPL	-	Seeboard Power Link
TfL	-	Transport for London
TIMIS	-	Train Identification and Management Information System
UPS	-	Uninterruptible Power Supply

Appendix A

A.1 Description of the London Underground Power Distribution System

A1.1 Bulk Supply Points

The main supplies to the Underground are provided by four 132kV Bulk Supply Points (BSPs) located at strategic points around the network.

The BSPs are connected to the distribution assets at 132kV that are owned and operated by the distribution company, EdF. In addition to the four principal BSPs, there are two independent and lesser connections.

On the evening of the 28th August 2003, one BSP was being fed through one transformer only as the other was out of service for maintenance. Another had both 132kV to 22kV in service, but was supplied by only one up-stream 275kV to 132kV feeder.

The 132kV network is operated and maintained by EdF. London Underground is the counter-party to a Connection Agreement covering the four main BSPs with EdF. The down-stream network supply to the Underground, primarily at 22kV and 11kV, is under the control and stewardship of Seeboard Power Link (SPL) under the terms of the 30-year PFI Power Services Contract (PSC).

EdF had initiated the maintenance works mentioned above and SPL was aware of the supply arrangement to that BSP. It was not, however, aware of the supply arrangements at the second BSP, caused as a result of the activities of NGT at Wimbledon 275kV Sub-Station.

A1.2 SPL 11kV and 22kV Networks

The 11kV and 22kV networks operated by SPL supplies the Underground and consists of a large interconnected electricity network similar in nature to elements of the public electricity supply networks in the UK.

The System consists of:

- a distribution network of high voltage cables at 22kV
- switch-houses, enabling interconnection of the 22kV high voltage cable network and transformation of the 22kV supplies to 11kV
- sub-distribution networks of high voltage cables at 11kV
- approximately 160 substations and transformer rooms which receive their power supply at either 22 or 11 kV and provide power supplies to the Underground network
- computer based control systems enabling remote control of the entire power system down to where the SPL System interfaces with the InfraCo systems, and
- a Central Emergency Power Supply (CEPS) provided by a standby generation facility at Greenwich consisting of 7 rapid response generators that can be fired on gas or oil.

The majority of SPL substations are fed at 11kV, however the western and eastern ends of the Central Line and the Jubilee Line Extension are fed directly from the SPL 22kV network.

A1.3 SPL Substation and Transformer Rooms

At each substation or transformer room, the incoming electrical supply is converted from 22 or 11kV to the following outgoing supplies:

- Direct Current (DC) (630V) supplies for traction and non-traction purposes
- Low Voltage Alternating Current supplies (LVAC supplies)
- signalling supplies and
- compressed air supplies

The SPL low voltage Alternating Current (AC) supply has traditionally been known as the “LU Supply”. This is due to the fact that prior to the Power Service Contract and closure of LU’s power station at Lots Road, this supply originated from an LU generating station. For the purposes of this appendix it will be referred to as the ‘SPL Low Voltage AC Supply’.

A1.4 Power Supplies to the Underground Network

Power supplies to the Underground Network have generally been arranged such that individual equipment failures do not cause interruption of power supplies. This has been achieved by dual redundant feeding arrangements at each level in the power system. Below the substation level this typically involves interconnecting supplies from adjacent substations. Although this principle remains and works very effectively for DC and compressed air supplies, it is not so effective with regard to signalling and low voltage AC power supplies.

A1.5 DC Supplies

Each track is fed separately from the substation concerned. In most cases, they are fed from substations at either end of the section of track. Groups of substations are electrically interconnected via the track to provide a common power supply to a section of the Underground network known as a ‘DC Track Sectionalisation Section’.

Under loss of a single track feeder from an SPL substation, supply of sufficient power is available from adjacent substations to enable trains to move through sections at reduced speed or possibly a provide a limited service.

In addition to traction power, DC supplies are still used in some places to provide power to DC lifts, escalators and depot equipment. DC depot supplies are either provided from dedicated depot substations or from substations supplying the adjacent running line tracks.

A1.6 Low Voltage AC Supplies – Surface Stations

Many of LU's stations are situated above ground and have single local (not BSP derived) public electricity supply company power supplies. These are commonly known as 'REC Street Supplies'. At these stations fire protection systems and emergency escape lighting are supported by battery backup. These supplies have the same arrangement as the main power supply into any conventional surface building in London. A small number of surface stations receive SPL low voltage AC supplies.

A1.7 Low Voltage AC Supplies – Sub-Surface Stations

Stations that are below ground have much more comprehensive power supplies to feed the combination of lighting, ventilation, escalators, lifts and communication systems that they contain. Two principle methods of supply are utilised. The classic method is low voltage cable mains connected between adjacent substations to provide supplies to the stations in between.

The modern method (driven by the higher power consumption at stations for the AC lifts and escalators etc.) is direct AC supplies from either an SPL substation or transformer room. An example of this arrangement is where an SPL transformer room is installed in a modernised station to feed all the low voltage AC equipment including lifts and escalators.

In addition to the SPL (BSP derived) low voltage AC supply to stations, all sub-surface stations (referred to as 'Section 12 Stations') are also provided with a low voltage supply from the local Regional Electricity Company (REC) street supply. These supplies have the same arrangement as the main power supply into any conventional surface building in London. The reason for this supply arrangement is explained below.

A1.8 Emergency Supply to Underground Station Lighting

LU is required by legislation (The Fire Precautions (Sub-Surface Railway Stations) Regulations 1989) to provide independent sources of supply to permit the safe evacuation of passengers from sub-surface stations ('Section 12' stations) in the event of a power supply failure.

Thus 25% (with a few exceptions) of lighting in Section 12 stations are supplied from the appropriate local REC street supply and 75% is supplied from SPL's System. These two sources provide power to two separate distribution systems within the stations but these systems are not electrically connected.

These two sources of supply are not strictly independent, as they both ultimately originate from the same National Grid Transco supply network in the UK. Section 12 stations are therefore provided with Local Emergency Power Supplies (LEPS) which derive their power from Off-Line Battery Inverters (OLBIs).

OLBIs are designed to come on line in 0.25 seconds following failure of both the REC street supply and the SPL supply within a station and provide a local emergency lighting supply. Each OLBI is required to have a minimum 30 minute capacity at all times during traffic hours. However, each unit is likely to have sufficient capacity for one hour of operation.

The LEPS system at each station comprises one or more OLBIs, according to the emergency power supply demand at each specific location. Larger stations have up to 7 OLBIs installed, with each supporting a discrete part of the total emergency power requirements. The OLBIs are only required to provide battery power in the event of a station power supply failure that results in a loss of both REC and (BSP fed) SPL power supplies.

On loss of the SPL supply and the REC street supply on the evening of the 28th August, the OLBIs operated as intended, providing 25% emergency lighting in those locations where they are fitted.

These OLBI units are provided and monitored by SPL under the Power Service Contract.

A1.9 Low Voltage AC Supplies – Jubilee Line Extension (JLE)

The exception to the above supply arrangement is the Jubilee Line Extension where stations are fitted with 3-hour uninterruptable power supply (UPS) units and no local REC street supplies. These UPS's are provided by Tubelines Ltd under its PPP Contract and provide emergency lighting supplies should the main SPL supplies to the station fail.

The SPL high voltage supplies to the Jubilee Line Extension are different to other high voltage supplies on the Underground Network in that substations and transformer rooms which feed the line are fed simultaneously from two different BSPs. Should one of these BSPs fail, the high voltage supplies to the Line automatically re-configures onto the other BSP supply.

A1.10 Electrical and Air Signalling Supplies

Power supplies for signalling equipment are in two forms, namely, electrical and air. Electrical supplies are used to operate interlocking and control systems, most signals and to provide heating, lighting and ventilation in signal equipment rooms. Signalling supplies are provided either as interconnected cable main supplies as or as direct low voltage AC supplies.

The interconnected signal mains are supplied from frequency changers in SPL substations. As the name implies, the supply to these mains takes place at a non-standard frequency and voltage. This is the historic method for ensuring that traction and other low voltage electrical supplies do not interfere with the signalling systems.

An air main runs throughout the Underground Network providing a compressed air supply. This main is fed with compressed air from compressors located at various substations. These compressors are operated remotely to keep the air main at an adequate pressure.

Air is used to operate points and train stops (devices that apply train brakes if a train passes a signal at danger). It also operates some shunting signals. In addition to signalling equipment, the compressed air network still supplies some ticket gates. An exception to this arrangement is the air supply on the Jubilee Line Extension where air supplies are provided by Tubelines Ltd. separately from the SPL fed air main network.

A1.11 Infraco Distribution Systems

Infracos are responsible for the distribution of power supplies within the Underground network from the point where power supplies leave SPL substations and transformer rooms.

The formal boundaries between the two systems are:

- the termination of the (Infraco owned) outgoing cable (for electrical power supplies) onto the SPL owned switchgear within substation and transformer rooms; and

- the termination of the (Infraco owned) compressed air main onto the SPL owned reduction valve within substations.

Infracos are responsible for the arrangement of supplies to equipment within the station and track environment. An exception to this arrangement is the provision of local emergency power supply systems for Section 12 Station lighting that is provided by SPL (excluding the Jubilee Line Extension stations where it is the responsibility of Tubelines Ltd).

A1.12 Central Emergency Power Supply System

In the event that a complete failure of the National Grid Transco network in the London area occurs, Greenwich generating station provides Central Emergency Power Supplies (CEPS) within 15 minutes of the supply interruption. Five Rolls-Royce aero-derivative Avon gas turbine alternator sets, each with an output rating of 11/14MW, are dedicated to CEPS.

The designed minimum available capacity from Greenwich is 33MW, which allows one machine to be on maintenance and a start failure on another. This minimum capacity is adequate to meet the defined CEPS load, which includes lighting, supplies to deep lifts and escalators and other specified equipment.

A1.13 Connect Power Supplies

Connect (communications) power supplies are complicated by the split of responsibility between Infracos, Connect PFI and Power PFI. The following provisions are currently being made for critical connect communications power supplies:

- In ‘Section 12’ locations, equipment is provided with two supplies, one derived from a supply from SPL substations (BSP derived) and one from the local REC street supply. In addition, a minimum 4-hour battery back-up supports this supply arrangement via uninterruptible power supply units, and

- In non ‘Section 12’ locations, a single supply is provided, usually from the local REC street supply. In addition, a minimum 4-hour battery back-up supports this supply arrangement via uninterruptible power supply units. Each of these locations should be subject to concessions from the Chief Engineer’s Directorate (CED), as the CED standard requires dual supplies at all locations. In a few exceptions, a dual SPL and REC street supply is provided as per the Section 12 locations.

A1.14 Control of Power Supplies to the Underground Network

Control of the electrical power supply system generally follows the infrastructure ownership.

NGT control the switching and reconfiguration of their transmission network down to supplies into the public electricity supply company distribution networks, EdF, for the London area supplies.

EdF Energy's control room, controls the switching of the 132kV BSP circuits which feed the Underground Network.

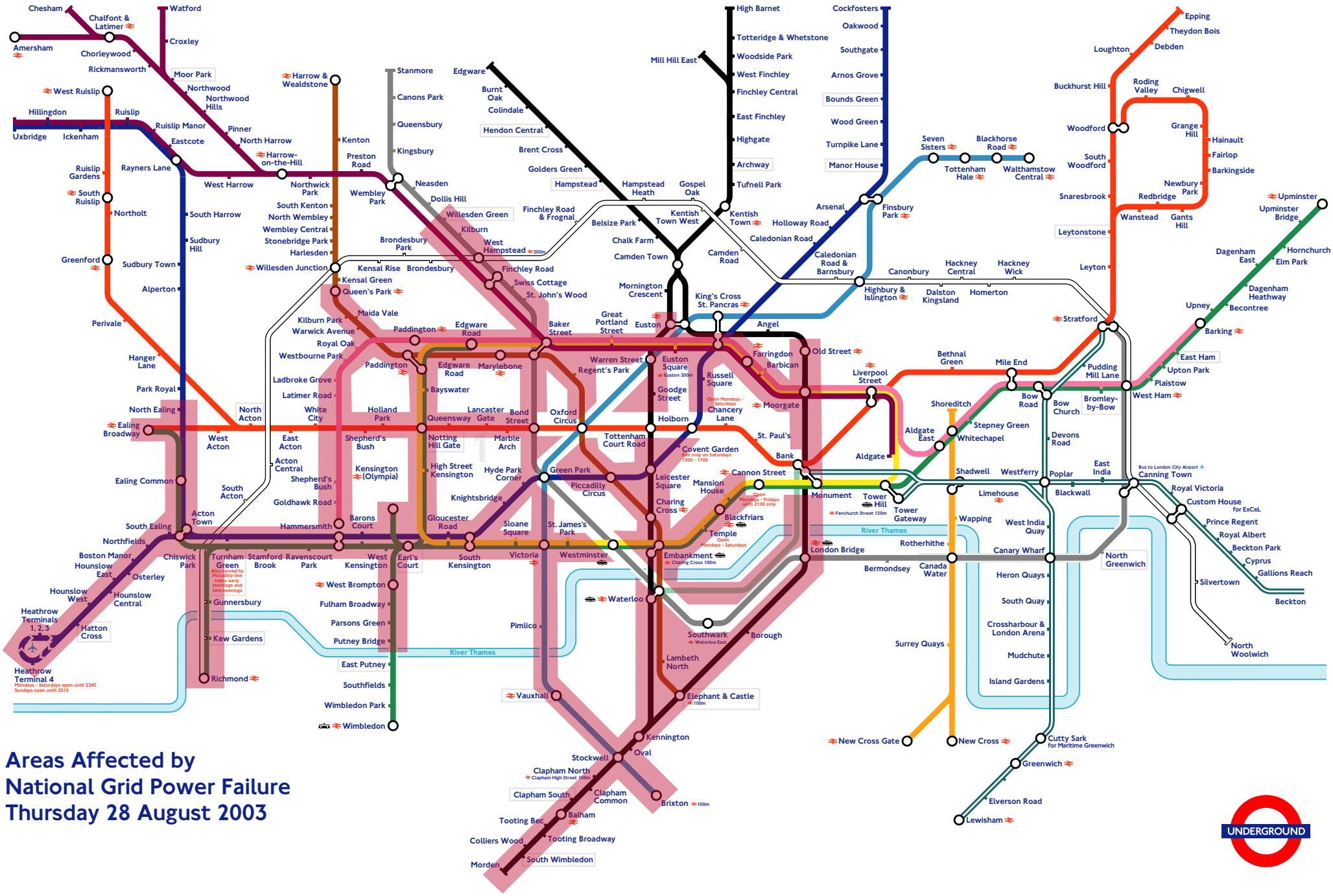
Control of SPL's system is the responsibility of the SPL's Shift Supply Engineer in the SPL control room. This responsibility covers the following:

- 22kV BSP feeds (following consultation with EdF)
- main 22kV system circuits
- secondary 22kV system circuits*
- operation of Greenwich standby facility (CEPS)
- 11kV system circuits*
- operation of the electrical and air signalling system supplies*
- provision of the DC power within the SPL substations*

At present the practical remote control of functions asterisked are undertaken by LU's Power Control Room (PCR) at the direct or standing instruction of SPL's Shift Supply Engineer. This is a temporary arrangement, which will cease once the new SPL power control system is complete and remote control for these functions will transfer to SPL's Shift Supply Engineer. This is currently programmed for 2005.

Remote control of DC and Direct Low Voltage AC supplies to the Underground Network is and will remain the responsibility of LU's Power Control Room. LU's Power Control Room consists of seven control desks, each staffed on a 24/7 basis.

Appendix B



Areas Affected by National Grid Power Failure Thursday 28 August 2003

Appendix C

Summaries of Line Reports

Bakerloo Line

Traction power loss:	*between Queen's Park and Elephant & Castle*
Control equipment loss:	*signalling diagram, signalling control, control room main lighting, platform CCTV and OPO (One Person Operation) monitors*
Trains stalled*:*	*5 between stations*
Method of detrainment:	*3 via track, 2 moved to platforms*
Stations without power:	*all stations between Queen's Park and Elephant & Castle*
Notable event:	*3 passengers trapped in a lift at Lambeth North station who were freed by 19:15*

The Bakerloo was the last Line to resume service when at 22.30 an 8 train shuttle was introduced.

From previous experience, key components of the signalling system are known to have problems restarting after power interruptions. This includes track circuits, interlocking machine rooms and the signal computer. Although this failure mode is well understood, it has never been addressed by an Uninterruptable Power Supply.

This knowledge helped with the decision to evacuate stalled trains via the track since it was realised that after initial attempts at restoration failed, a lengthy delay was probable.

The most heavily loaded of these trains had just left the Oxford Circus station northbound platform with 390 people on board. Evacuation began at 18.53 after the Train Operator – having tried and failed to contact the Control Room by radio – walked through the rear of the train back to Oxford Circus. He reasoned this was closer than the station ahead and more likely to have staff available.

Here he telephoned the Line Controller and gained permission to evacuate, and received help from the station staff. This was one of only three instances where customers were left without immediate supervision, albeit temporarily. The Train Operator did explain his actions before he left the train.

The evacuation was complete by 19.40, 80 minutes after the power failure.

The second detrainment began at 19.00. Staff at Elephant and Castle station were directed to attend a train with 35 customers on board that was approaching the platform. This was completed by 19.25.

Also at 19.00, a Duty Manager at Queen's Park was asked to assist with the detrainment of 100 customers from a train approaching that station. The last person reached the platform at 19.30.

Central Line

Traction power loss:	*between White City and Bond Street*
Control equipment loss:	*signalling diagram, signalling control and OPO monitors*
Trains stalled:	*2 between stations*
Method of detrainment:	*both moved into platforms*
Stations without power:	*all stations between Shepherd's Bush and Liverpool Street*
Notable events:	*Two passengers at Queensway were distressed after being detrained via the platform after a thirty-minute wait and required the attention of stand-by ambulance staff.*

The Central Line resumed at 19.05, before most Lines, reflecting the relatively smaller area affected. However, the Line Control function was initially overwhelmed with calls from stations and Train Operators, and took time to establish train locations.

Early contact with the NCC and Power Control Room established that the failure would not be long term. Once trains started to run, co-ordination was a problem since the status of individual stations could not be established. It was also difficult for the Line to contact the NCC.

Circle Line

Traction Power Loss:	*from Moorgate to Mansion House (via Paddington)*
Control Equipment loss:	*signalling diagram, signalling control, OPO monitors, control room main lighting*
Trains stalled:	*none*
Stations without power:	*see other line reports*

Train radio held up, although it was of poor quality. No trains were stalled. The service was not restarted after power was available as resources were channelled into providing trains on the Hammersmith and City line instead.

It is standard practice for Circle Line services to be sacrificed in this way. The trains and their Operators are shared with the Hammersmith and City, and this Line serves stations west of Paddington that cannot be reached any other way. In theory, customers can reach Circle Line services by using Metropolitan or District trains instead.

In this instance the District Line was badly disrupted itself and did not offer a very robust service to these stations.

District Line

Traction power loss:	*between Acton Town, Gunnersbury, Putney Bridge and Embankment*
Control equipment loss:	*signalling diagram, signalling control, control room main lighting, networked computers, platform CCTV, OPO monitors and degradation of train radio*
Trains stalled:	*16 between stations*
Method of detrainment:	*All moved into platforms*
Stations without power:	*All stations in area affected by loss of traction current*
Notable events:	*Fire reported between Bromley by Bow and Bow Road at 19:06 and signalling not restored until 19:40*

The District Line relies on some of the oldest technology on London Underground and many functions require manual operation. With 5 branches in the west, signal boxes in the east and a very busy trunk section, the Line is difficult to regulate during any disruption.

On 28th August, the District Line Control Room experienced extensive loss of functions, including knowledge of train location. Train radio was degraded rather than lost, but it was rendered ineffective by severe congestion. The Line was the last to complete evacuations with the final customers clear at 20.19, almost two hours after power was lost.

There were also a number of problems with the power restoration process. When the signalling system was first re-livened, it repeatedly dropped out. When restoration was finally achieved, a number of routes over junctions at Earl's Court became locked. A track-side fire between Bromley-by-Bow and Bow Road, lengthened service restoration.

There were weaknesses in how the Line understood why power had been lost and the processes to manage the re-introduction of train services once it was restored. The intermittent return of the signalling system influenced the perception that there would not be a secure power supply for some time. This inclined thinking towards a managed run-down rather than to maximise the use of resources to restore a service.

East London Line:

Traction power loss:	*none*
Control equipment loss:	*signalling diagram and signalling control lost*
Trains stalled:	*1 between New Cross Gate and Surrey Quays*
Method of detrainment:	*moved into platform*
Stations without power:	*none*

The East London Line was the least affected by the power failure although as signalling power supplies are fed from the affected Bulk Supply Point, the service came to a halt at 18.20. Surrey Quays was the only station evacuated in consequence of stalled train nearby. Services were resumed from 19.05.

Hammersmith and City:

Traction Power loss:	*between Hammersmith and Moorgate*
Control Equipment loss:	*signalling diagram, signalling control, control room main lighting, platform CCTV and OPO monitors*
Trains Stalled:	*3*
Method of detrainment:	*moved into platform*
Stations without power:	*all stations between Hammersmith and Moorgate*

Train radio was preserved and this helped monitor train locations without signalling control. The signal computer crashed when power was restored and took several attempts for rebooting to be successful.

Services were restarted in concert with the Metropolitan Line and a twelve-train service between Hammersmith and Whitechapel was introduced from 20.45.

Jubilee Line

Traction power loss:	*between Finchley Road and Green Park/Charing Cross*
Control equipment loss:	*signalling diagram, signalling control, communications to signalling sites (from Baker Street) train radio, platform CCTV and OPO monitors*
Trains stalled:	*3 between stations*
Method of detrainment:	*1 detrained to track and 2 moved into platforms*
Stations without power:	*all stations in area affected by loss of traction current*
Notable event:	*2 detrained customers requested medical assistance*

Traction power was restored by 19.05 but problems with regaining signal site computers and signalling control from Baker Street delayed the start up until 20.45 when shuttle services were introduced outside the affected area as far as Finchley Road from the north and Waterloo from the east. This was not improved upon before the close of traffic.

One train was detrained via the tunnel walkway just outside Westminster station. This involved 250 people and the process was complete by 19.18. Two customers requested attention from the stand-by medical personnel. Taxis were found for them to complete their journeys.

Metropolitan Line

Traction power loss:	*between Finchley Road and Moorgate*
Control equipment loss:	*signalling diagram, signalling control, control room main lighting, platform CCTV and OPO monitors*
Trains stalled:	*4 between stations*
Method of detrainment:	*all moved into platforms*
Stations without power:	*all stations in area affected by loss of traction current*
Notable events:	*When power was restored the signalling computer at Baker Street needed rebooting*

The extent of the failure was not initially clear to the Line control team. Services are locally controlled from Harrow on the Hill northwards and there was no loss of power in this area of London. Train radio remained usable, albeit at reduced quality but persistent problems rebooting the signalling computers impeded reintroduction of services.

Of the stalled trains, 3 took longer than an hour to evacuate. 2 were in the long section between Finchley Road and Baker Street and the latest took until 19.32 for 100 passengers to reach the platform.

By 20.45, a special service had been introduced serving all branches.

Northern Line

Traction power loss:	*South of Camden Town*
Control equipment loss:	*signalling diagram, signalling control, tunnel telephone, train radio*
Trains stalled:	9 *between stations*
Method of detrainment:	*1 to track and 8 moved into platforms*
Stations without power:	*all stations south of Camden Town*
Notable event:	*1 customer suffered an asthma attack after detrainment and required medical assistance. Very late reopening of Morden group stations owing to need for Infraco assistance to reset escalators.*

Northern Line control staff were inundated with calls from stations and Train Operators outside the affected area, both reporting the fault and requesting information. There were almost 60 trains in the affected area. Tracing their last known location was problematic.

Following early consultation with the Power Control Room, the DOM and Line Controller took a conscious decision to await power restoration before moving trains forward for evacuation. Train Operators were advised as soon as radio was restored that this was the policy.

A train approaching Morden station was detrained after a Duty Manager secured the agreement of the Line Controller. There were 47 people on board and the train was only a short distance from the station where there were plenty of staff available to assist. This evacuation was achieved by 19.00.

Traction power was restored by 19.05. Trains ran empty until stations were ready to reopen. Balham, Tooting Bec, Tooting Broadway, Colliers Wood and South Wimbledon stations were not opened until after 23.00 since Tubelines staff were needed to reset escalators after attempts by local staff were not successful.

Piccadilly Line

Traction power loss:	*between the Heathrow loop/North Ealing and Leicester Square*
Control equipment loss:	*signalling diagram, signalling control, control room main lighting, platform CCTV and network computers*
Trains stalled:	*14 between stations*
Method of detrainment:	*all moved into platform*
Stations without power:	*all stations in area affected by loss of traction current*
Notable event:	*Green Park station extended time to reopen following difficulties resetting equipment – complete by 21.13.*

The Piccadilly was the only Line that was already disrupted when power failed as it was recovering from a defective train that had been held at Green Park station between 16.48 and 17.20. It was the worst affected Line in terms of the physical extent of the failure. This explains the large number of trains stalled between stations.

At Barons Court and Acton Town stations, the number of stalled trains – 6 in total - meant delays in reaching platforms. The latest train was evacuated 85 minutes after the power had failed.

After stations reopened, train services were gradually restored from 20.10 between Cockfosters and Heathrow. This was at a much lower frequency than normal owing to the very reduced number of Train Operators available following the aggregated effects of both delays.

The Line team was cautious in planning service recovery as it believed there would be pent-up demand for services and over-crowding. This was not the case as commuters had already succeeded in getting home and evening traffic was very light. A better way of understanding likely demand would have strengthened this process.

Victoria Line

Traction Power loss:	*between Brixton and Victoria*
Control equipment loss:	*signalling diagram, signalling control, train radio south of Victoria only*
Trains stalled:	*4 between stations*
Method of detrainment:	*3 detrained to track and 1 moved into platform*
Stations without power:	*all stations were evacuated and closed except Highbury & Islington (where non LU services continued to run)*
Notable events:	*Traction current recharge was attempted before a Short Circuiting Device had been removed. Service resumption was severely delayed by difficulties resetting station supplies through local operation of switches.*

Trains south of Victoria were stalled and out of contact with the Line Controller and 3 were detrained via the track. In 2 cases customers were left without direct supervision for short periods whilst Train Operators sought assistance from station staff. Customers were informed of the reasons for these steps.

The first to be detrained was on approach to Brixton station. Under the control of a Duty Manager, 98 passengers had left the train by 19.10.

A second southbound train was stalled outside Stockwell station. This was detrained of 208 customers between 19.10 and 19.30, although by this time the Power Control Room operators were ready to recharge traction current.

Accordingly an attempt was made at 19.32 when these passengers were clear. This was unsuccessful and staff at Stockwell were asked to confirm that short circuiting devices had been removed from the track.

Whilst this was being resolved, because of the time elapsed a decision was taken to evacuate a third train. This had been detected (also on approach to Stockwell but from the opposite direction) when the signalling diagram had been restored at 19.21. However, it was discovered that the Train Operator had already contacted station staff and 54 people had been evacuated.

A short circuiting device had indeed been left to the rear of this train and traction power was finally restored at 20.38.

Service recovery was further delayed by difficulties resetting the electricity supply to Brixton station, the point where trains normally reverse. Victoria station – the next alternative reversing point - was very busy and since a regular Victoria Line service could not be guaranteed the Duty Manager there decided it was not safe to re-open until Brixton station was available.

From 20.38 Trains were run in service as far as Oxford Circus station, and then to Green Park by 21.13 when that station had solved problems resetting equipment.

Throughout this period, the changing status of stations and the extent of the train service meant customer information was fragmented. The Line repeatedly tried but was unable to contact the NCC. In common with other stations, staff at Victoria reported problems not only liaising with the Victoria Line Controller, but also the District Line Control office.

Brixton station opened at 22.38 when through services were resumed.

Waterloo and City:

Traction power loss:	*between Waterloo and Bank*
Control equipment loss:	*signalling diagram, signalling panel and train radio*
Trains stalled:	*1 between stations*
Method of detrainment:	*moved into platform*

Traction current for the Waterloo and City Line is provided from the Network Rail supply point at Raynes Park and this was unaffected by the power failure. However signalling supplies were lost along with train radio. The signal post telephone was used to authorise the one stalled train into the platform at Waterloo, where 800 customers detrained.

By the time the signalling system was successfully reset at 21.20, the scheduled closure time for the Line had been reached.

Appendix D

People Consulted by the Investigation Team

Date	Name (s)	Areas Covered
10/9	Nigel Holness, Service Delivery Manager	Role on 28/8 plus stations perspective on event
11/9	Ian Buchanan, Energy Contract Manager	Power supply arrangements
11/9	Mike Stevens and Mike Jerome NCC Duty Managers	Roles on 28/8 plus NCC perspective on network wide events and command and control arrangements
11/9	Ron French and Chris Western, Operational Support	Operating procedures and dissemination
16/9	John Payne, Line Controller, Northern Line	Role on 28/8 plus perspective on command and control under failure conditions, emergency preparedness and contingency
17/9	Iain Rose, NCC Manager	Overview of NCC staffing structure and work flows plus development options
17/9	John Porter, Power Control Centre Manager	Chronology of 28/8, structure and work flows in the PCC
17/9	Nick Shaw, District Line Service Control Manager and John Doyle, Trains Team Leader	Chronology of 28/8, District Line service recovery problems and perspectives on command and control issues
19/9	Paul Naylor, Account Manager, Information Management	Potential contributions to underlying causes from IM projects such as Tracker
22/9	Jeff Ellis, Train Operations Standards Manager	Overview of competence assurance process in context of operational management of large scale incidents, plus RDO perspective on relevant issues
22/9	Nick Agnew, TfL Safety and Contingency Planning Manager	Role on 28/8 and perspective on command control and communication issues
23/9	Daniel Howarth, Iain Rose, Bob Thorogood, Andy Barr – Operational Support	Concept and objectives of NCC, options for developing command, control, co-ordination and communication
25/9	Simon Pitt, Director of Information Management and Phil O'Hare, Team Leader Quality Service Information Team	Views on improving information capability
26/9	Diane Kwarteng, Tricia Madge, Duty Station Managers, Oxford Circus Group	Role on 28/8 and perspective on detrainment, service restoration, command, control and communication
29/9	Ian Hart, Communications Engineer, CED	Progress with CED investigations
30/9	Mike Brown, Chief Operating Officer	Role on 28/8 and perspective on relevant issues
30/9	Phil Carmichael, Mark Easterby, Power Engineer, CED	Overview
6/10	Andy Bourne, System Engineer and Eddie Goddard Train System and Integration Engineer, CED	Assurance process for key systems and future plans for robustness

The above formal sessions have been supplemented by a continuous level of contact with key personnel, specifically Daniel Howarth, Andy Barr, Bob Thorogood and Mark Higgs, Access and Control Manager (accountable for the Power Control Room and the NCC).

Appendix E

	KEY RECOMMENDATIONS	Supporting Parties	LUL Action Owner	Completion Date
1.	LU acknowledges that the means of communicating system outages and network risks between NGT, EdF, SPL and LU leading up to the events on the 28th August could have been better and recommends that all parties should continue to work together to build on the commendable improvements that have already been made.	LU CED Phil Carmichael LU ECMT Mike Harrington LU PCRM John Porter SPL Rowland Wills EdF Pat Brooks NGT Gavin Brown	Richard Jones Energy Contracts Manager	December 03
2.	LU recommends that SPL and LU need to assess the technical and commercial implications of 'pre-emptive' reconfigurations of the Underground's HV power network where this mitigates risk from single feeder situations.	LU CED Phil Carmichael LU ECMT Mike Harrington SPL Rowland Wills LU PCRM John Porter	Richard Jones Energy Contracts Manager	December 04
3.	LU recommends that SPL and LU need to investigate what changes could be made to the current network to facilitate short-term paralleling of BSP's to allow uninterrupted power changeovers and thus limit disruption to the operation of the Underground network.	LU CED Phil Carmichael LU ECMT Mike Harrington SPL Rowland Wills EdF Pat Brooks	Phil Carmichael Power Engineer CED	December 04
4.	LU recommends that SPL and LU need to review the respective control system alarm management protocols to highlight key alarms in similar situations to avoid 'alarm swamp'.	LU CED Phil Carmichael LU ECMT Mike Harrington SPL Rowland Wills LU PCRM John Porter	Mark Higgs Access & Control Manager	December 04
5.	LU recommends that a review of the SCADA implementation programme and scope is completed and a cost / benefit study undertaken in respect of reducing switching time on the Underground's power network.	LU CED Phil Carmichael LU ECMT Dave Rushton SPL Andrew Pallet LU PCRM John Porter	Richard Jones Energy Contracts Manager	December 04

6.	LU recommends that EdF, LU, SPL and the Infraco's need to jointly assess the impact of 1.5s auto-reclose schemes across the Underground's HV power network and the effect it may have on other operational equipment on the Underground.	LU CED LU ECMT SPL EdF	Phil Carmichael Mike Harrington Rowland Wills Pat Brooks	Phil Carmichael Power Engineer CED	December 04
7.	LU recommends that SPL, LU and the Infraco's need to review and assess the current configuration of the lighting main and its resilience to network reconfigurations and power supply interruptions.	LU CED LU ECMT LU PCRM SPL MRBCV MRSSL JNP	Phil Carmichael Mike Harrington John Porter Rowland Wills David Ogden Geoff Virrels Andy Mitchell	Phil Carmichael Power Engineer CED	December 04
8.	LU recommends that SPL and LU need to investigate and review the robustness of the lines of communications between the EdF Control Centre, the NCC and the power control room from the perspective of the technical adequacy of the equipment installed and the management interface procedures in place..	LU CED LU A&C LU ECMT LU PCR SPL EdF	Phil Carmichael Mark Higgs Mike Harrington John Porter Rowland Wills Pat Brooks	Mark Higgs Access & Control Manager	December 04
9.	LU recommends that it should work jointly with all other network operators in the London area and specifically with the London Resilience Team to identify any improvements in co-ordination to enhance the overall security of electricity supplies to the Underground.	LU CED LU Ops Lu A&C LU ECMT EdF NGT	Phil Carmichael Andy Barr Mark Higgs Mike Harrington Pat Brooks Gavin Brown	Andy Barr Operational Response Manager	December 04
10.	LU recommends that EdF should be supported in its review of its equipment at Wimbledon and it be encouraged to accelerate its programme of asset replacement both here and at Wandsworth such that the current switchgear fault level limitations can be removed.	LU CED ECMT SPL EdF	Phil Carmichael Mike Harrington Rowland Wills Pat Brooks	Phil Carmichael Power Engineer CED	December 04

11.	LU recommends that all the relevant stakeholders within the Underground, likely to be affected by power interruptions, investigate and establish the true cost / risk balance of (i) *Bismark* testing; (ii) other options to full *Bismark* testing and (iii) other such operational switching in their respective areas of accountability. These investigations should cover both the planned changeover scenarios and also unexpected interruptions similar to the events on the 28th August. It is also proposed that a business model is developed to accept such data and facilitate better decision-making in this respect going forward and to use to define, for once and for all, the appropriate frequency and scope of *Bismark* testing.	LU CED LU Ops LU A&C LU ECMT MRBCV MRSSL JNP	Phil Carmichael Andy Barr Mark Higgs Mike Harrington David Ogden Geoff Virrels Andy Mitchell	Phil Carmichael Power Engineer CED	June 04
12.	LU recommends that its technical standards, particularly those pertaining or relevant to the design, installation, operation and testing of the Underground's power network should be the subject of a detailed reviewed, led by CED and supported by ECMT. This detailed review should be mandated to identify any elements that would benefit from updating - the objective being to better facilitate improvements to the resilience of the power network.	LU CED LU ECMT	Phil Carmichael Mike Harrington	Phil Carmichael Power Engineer CED	December 04