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Ingénierie et projets de modernisation des lignes Central et Nord du Métro de Londres - une approche pragmatique.

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The Institution of Railway Signal Engineers

ADVANCE PAPER ONLY

Paper to be read in London, on 13th November 1995, and not to be published until it has been read

System Engineering on the Central Line and Northern Line Projects - A Practical Approach

*Andy Doherty**

1 INTRODUCTION

This paper sets out to describe the practical and pragmatic approach to system engineering developed during the mega project to modernise LUL Central Line. It goes on to described the combined practical and theoretical methodology now being used on the Northern Line modernisation project. The paper will concentrate on the new Central Line control centre as a microcosm of the whole railway engineering system describing in some detail the equipment (including communications and signal control), its functionality, the engineering management and diagnosis facilities. The paper will use the control centre as an example to describe the process developed and used to ensure good systems integration.

The paper will also describe the rapid development of the Northern Line project through the use of the UK Government's Private Finance Initiative (PFI), the scope of the project and the system engineering approach being used as a result of the experience gained on the Central Line project. It is hoped that some insight can be gained into the vision of the engineering system planned for the Northern Line in the year 2002 in terms of the interpretation of the overall business objectives into hard equipment and process.

The paper will conclude and summarise with lessons learnt, the successful and unsuccessful techniques employed on the Central Line project using the first real time experience of system engineering on a mega project now in its final stages. The paper will propose areas where further development into as yet untapped areas may bring even greater benefits for the system engineer and the processes or work being undertaken.

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2 THE CENTRAL LINE

2.1 BACKGROUND TO THE CENTRAL LINE PROJECT

The Central Line is 55km long of which 26km is underground in small bore tube tunnels. With 49 stations spread along the 55km route the line has one of the most heavily used sections of the Underground, between Bank and Stratford, and yet provides a very suburban service at the ends of the line. This reflects the different types of area served by the line - suburban at the West End, high density mass transit in the central area and in rural urban Essex. The line is served by three depots at Hainault, White City and West Ruislip.

In 1988 much of the existing equipment on the Central Line had reached the end of its economic life and needed to be replaced to ensure the continued safe and efficient operation of the line. Rolling stock was 30 years old, and the signalling had already exceeded its nominal design life of 40 years. It was therefore essential to plan the renewal of this equipment so that the safety and reliability could be assured.

The power supply equipment in 15 of the 21 substations on the Central Line was now more than 40 years old and due for renewal. There was also a need to renew high voltage and traction feeder cables, again to ensure that the reliability of the system was maintained to support the needs of providing a demanding train service.

The tunnels and other basic infrastructure were generally in good condition and formed the major asset of the line. However, there were places where remedial work was needed to restore the tunnel to its original specification for clearance and alignment and changes to the permanent way to significantly increase the maximum train speeds achievable in many locations.

Customers will benefit from the new design of train which will be airy, bright and well lit, with large windows including end windows to aid security. More people will be able to travel in these trains in greater comfort than in the existing trains. Automatic Train Control (ATC) means that trains will run more regularly and frequently. This will help the Central Line to cope with the higher number of customers expected.

2.2 MISSION

The mission of the Central Line project was to provide a faster, more reliable, more regular and more comfortable service with:

- improved peak service and off peak service;
- ATC giving better regularity;
- 12% reduction in journey times;
- 16% increase in capacity;
- on board information systems;
- higher levels of comfort.

2.3 MODERNISATION OF LIFE EXPIRED SYSTEM

With the need for the replacement of so much of the life expired equipment the Company saw the opportunity to set up a modernisation programme that could provide the following benefits:

a) Corporate Image - achieving the Company's vision of a modern metro suitable for providing a service to customers well into the 21st century. This would be achieved by exploiting the latest technology to provide a safe, efficient, more reliable and intensive service with reduced travelling times. Such a service would offer competition and should attract customers away from other transportation systems and thereby provide real benefit to the whole of London.

b) Productivity Improvements - new technology can allow improved productivity by reduced maintenance and operating costs. New signalling systems can provide improved headway that allow more train operations within a fixed period of time. Increased line speeds will allow greater utilisation of existing rolling stock. New technology will provide better use of resources. Two major areas being:

   - all new trains will be operated by one person instead of the present arrangement of a driver and guard on the old trains;
   - the use of centralised control for all communications, signalling control and power control will remove the need for the 19 signalling cabins spread along the entire length of the line.

Maintenance costs will be reduced by higher reliability of all the subsystems, modernisation of depot facilities, full downloading capability of train health status to a control maintenance computer and central fault recording/management from an engineer's desk within the central control room.

2.4 FIRST TIME FOR THE COMPLETE TURNKEY REPLACEMENT OF WHOLE LINE

Traditionally, London Underground would have replaced the individual elements separately, as they become life expired, on a 'like for like' basis. It was realised that significant additional benefits, both technical and commercial, could be derived from renewing the elements simultaneously as an integrated project. The proposal therefore consisted of replacing rolling stock, signalling, communications, power supply equipment and infrastructure renewal as necessary in order to maximise the safety, reliability, capacity, efficiency and quality of service against defined present and projected future service requirements.

2.5 SYSTEM ENGINEERING WAS NOT RECOGNISED IN LUL IN 1989

While the project plan sought synergistic benefits from simultaneous renewal there was no methodology or process planned to achieve it, indeed system engineering as a discipline was not yet recognised within LUL or industry generally.

It was clear that the project would not be successful without a 'systems' approach and an integration plan. This conclusion was based not only on the sheer size and complexity of the project but very much on the fact of installing new equipment on to a working railway without reducing the level of safety and service provided to our customers.

The project was structured with a project engineer, reporting to the project manager, responsible for all engineering on the project. Specialist rolling stock, signalling engineers, power engineers, civil/permanent way engineers and communications engineers were appointed with each group reporting to a discipline project engineer who in turn reported to the overall project engineer. In effect, although titles did not recognise it at the time, the project engineer was the project system engineer.

The system approach was then developed by the introduction of a number of process techniques and engineering skills, as described in section 2.12.

2.6 INDIVIDUAL SPECIFICATIONS AND INDIVIDUAL CONTRACTS PLACED FOR ROLLING STOCK, SIGNALLING, COMMUNICATIONS, POWER, CIVILS AND TRACK

The features of the subsystems in the business plan of the project scope was divided logically into contract packages as outlined below and specifications were developed against overall project objectives.

i) **Rolling Stock**

85 new eight-car trains, each capable of carrying up to 1,300 people. Car bodies are aluminium extrusions giving weight and energy savings whilst improving structural strength. Externally hung wider doors to allow improved customer flow and shorter station stops.

For the first time power electric controlled traction equipment was used on LUL. All axles are motored, fed by dc chopper controlled traction equipment allowing higher maximum speed, smooth acceleration and deceleration, and regenerative braking. New lifting and maintenance facilities in depots being provided.

Cabs were egonomically designed for one person operation to include a CCTV monitor to view station platform, train radio equipment incorporating the latest digital radio technology and an information and diagnostic system to aid fault finding without delay to train services.

ii) **Signalling System**

Based on a coded track circuit system for full automatic control of trains. Jointless track circuits using Fast Fourier Transform decoders provide codes for automatic train protection and give immunity from traction generated interference. Automatic train operation up to 100 kph providing 33 trains per hour. Design ehanced to incorporate "WESTRACE" solid state system for significant proportion of the line. This was the first use of WESTRACE in a heavy mass transit system with ATP/ATO.

iii) **Control Centre**

Central computer based control system to provide automatic regulation for the train service via 16 local site computers. The performance of all systems being monitored via a centrally controlled communication facility.

iv) **Optical Fibre Communication System**

Wide area network includes loop protection 4 x 140 mbits/PCM communications network for speech and data transmission. Optical fibre cable system being dual routed throughout the Central Line to connect all operating sites: stations, depots, offices and control centre.

v) **CCTV System**

Platform view transmitted to train operator's cab to check passengers' safety as trains enter and leave stations. Pictures from platform and other surveillance cameras throughout stations being transmitted to central control to aid operation of the line.

vi) **Power Systems**

Modernised systems to provide 80 MW installed capacity via 21 substations. New systems include: substation and ac/dc rectifier plant, high voltage ac and traction dc power cables, and remote control and monitoring facilities for distribution system.

vii) **Civil Works**

120 new buildings/rooms to house new signalling, communications and power equipment - many at underground sites. Civil works at 15 substation sites and for jacking foundations at depots.

viii) **Tunnel and Track**

New track configurations and points and crossings at 15 locations primarily aimed at improving headway on an automatic railway as opposed to a manual layout, converging junction headway and improved ride comfort. Tunnel restoration work between Shepherds Bush and Holborn.

2.7 THE VISION WAS KEY

The vision of the whole system was key to the success of the project.

A clear vision to enable a definitive, strategic plan to be prepared for the project implementation which in turn enables the best selection of the technology for future requirements. The best example of this was the seemingly incongruous use of the optical fibre backbone, rather than the use of the traditional copper cable communications system. The clear vision of the future fully integrated system identified that savings and numerous future advantages could be had from such a decision.

The senior project engineers soon identified the advantages of contriving the environment for creative and forward thinking approaches for its staff. This all helped to evolve, in the early years, the original project scope into a system encompassing numerous improvements that led to signficiant numbers of variation orders being awarded.

2.8 CONTROL CENTRE

The Central Line project includes a new two storey control centre building at White City. Signalling, communications and power equipment rooms are situated on the ground floor with the control room on the first floor. This control room provides facilities for both the operating and engineering staff. This is the first time an LUL control room houses both operating and engineering staff. Figure 1 shows the layout of the desks in the control room. It was the result of the forward thinking of the system work being done by the project engineers.

The control room formed the focal point of the line. Extensive ergonomic studies were undertaken to engineer the equipment and plan its layout within the room. Operating staff clearly are responsible for the running of the service and the engineering staff for the availability of the equipment throughout the line.

The ergonomic studies concluded a single workstation for the operators should consist of a VDU and keyboard for all communications. This was to include telephones, radio calls, public address, selection of CCTV cameras, prerecorded announcements and tunnel telephones. All of these items were to be integrated via a communications switch supplied by Bosch.

Two further VDUs and a separate keyboard were to be included for signalling purposes. A further two monitors were installed in the bottom of the workstation for viewing CCTV on platforms.

These workstations were to be in groups of three to form a desk and above each desk a 5 x 2 matrix of VDUs showing a line diagram depicting the movement of trains. Again this type of diagram is a first for the Underground.

It is with this background we have in total three groups of three workstations contained in the control room for the operators. At any one time the operating staff consists of a line controller who is responsible overall for providng the service, a radio assistant and information assistant. A number of signalling assistants will also support the line controller when this central signalling system is fully commissioned.

2.9 ENGINEER'S DESK

A desk of three workstations is provided for the engineers overlooking the operators' workstations, in fact facing inwards. This is a new philosophy for the Company and was introduced as part of an operating

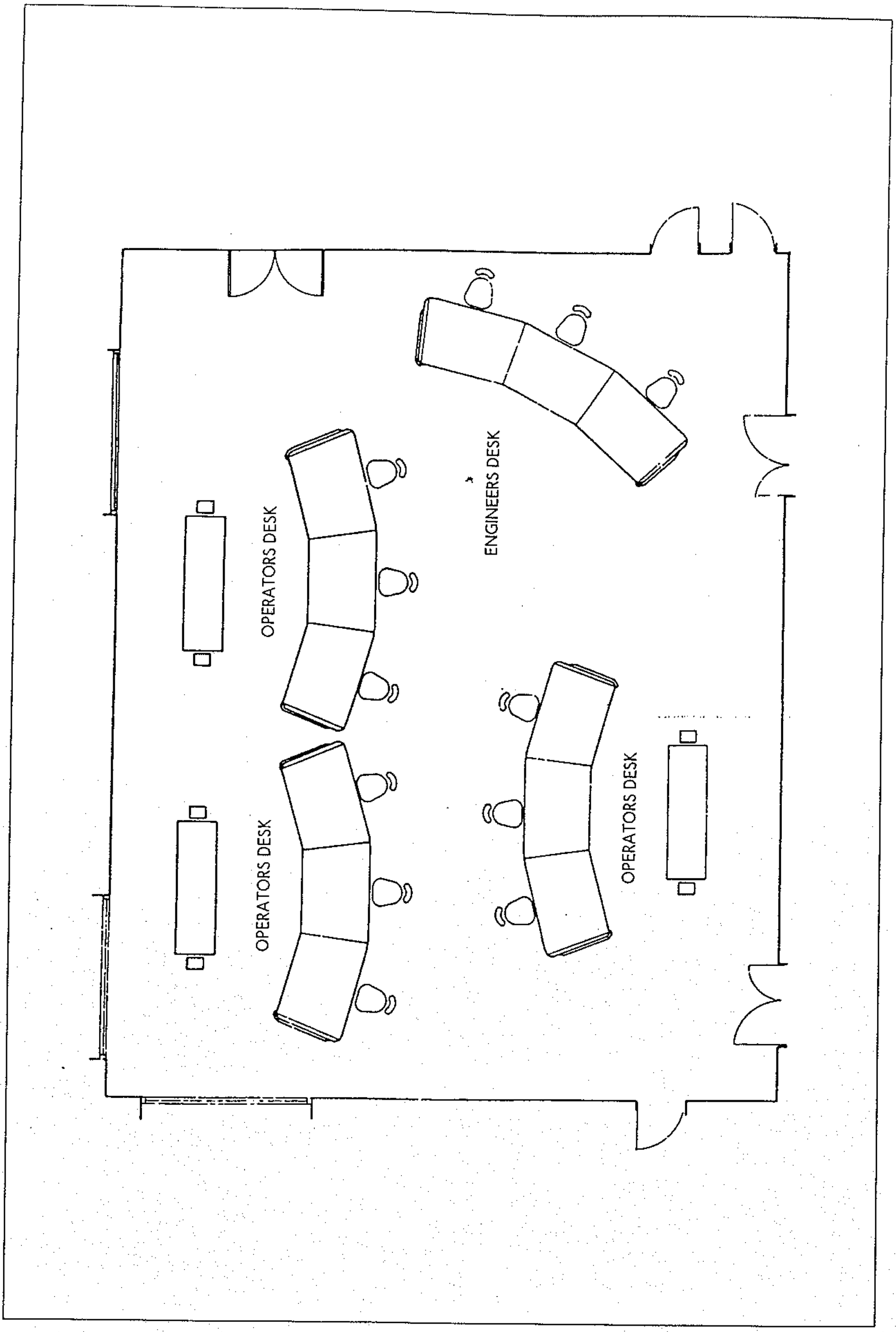


Figure 1 - Layout of Operators' and Engineer's Desks

strategy to minimise downtime resulting from equipment failures. To support this strategy a new role of duty engineer in the control room was introduced. The duty engineer is provided with this engineer's desk containing terminals for signalling control system, optical fibre network manager, SCADA for power supplies, customer information and central communications switch. The engineer, via these terminals, is able to interrogate the system, establishing faults down to remote card level in most cases.

Once the failed equipment and the fault condition is identified, the relevant maintenance contractor can be briefed before attending the fault so that he can take the correct tools and equipment. Additionally, this asset failure information is logged in the line service centre database, which is used to interrogate failure rates and to generally monitor the long term performance of asset.

Hence, this engineering monitoring facility allows rapid response to failures, an accurate record of asset performance and the efficient and cost effective management of maintenance contracts. It will be possible in future to use optical disk imaging systems to provide to the engineer instantaneous access to all drawings, specifications, data sheets and manuals and to transmit them to the front line maintenance staff as necessary. Development of the line system model using Yourdon techniques and interactive software is ongoing at this time.

2.10 COMMUNICATIONS SYSTEMS

The vision of an excellent set of communications facilities was achieved by installing and integrating into one VDU display the following major elements:

Optical Fibre System

This system was introduced into the modernisation project in place of the original copper cable based network. A description of the system and its functionality is contained in the paper titled "Communications on the Central Line" which was presented to the IEE in December 1992.

Train Radio

New train mobile radios are fitted into each cab of the new trains. They operate in the VHF, 170 MHz band frequency range, in a Full-Duplex mode. These mobile radios have a telephone type of handset for two-way communication. The system includes a new train radio central control rack and 19 new base stations spread along the line. Each base station being connected by the optical fibre backbone.

Facilities provided by this system include:

- One Person Operation (OPO) radio alarm whereby if a train operator collapses then hand pressure is realised from the controller and an alarm is immediately sent to the main control centre. The alarm is registered on the communications workstation of the line controller and the radio assistant. Information regarding actual train number and its position is displayed on the VDU.
- Each train can be selectively called from the control centre.
- Cab to cab communication can take place by 'patching' through the control centre to the trains.
- May day calls can be made from the cabs.
- Public address announcements can be made from the control centre to the customers in a selected train.

Whilst the new radio system is FSK it has also been designed to operate with the original five tone sequential signalling system to enable the first new trains into service to continue operating on the original system.

Track to Train CCTV

Earlier safety studies have shown that a track to train CCTV system significantly enhances the safety of customers entering and exiting a train in a platform area. The train operator views a monitor in the cab and closes the doors when safe to do so. The operator continues to view the monitor as the train leaves the platform and thereby ensures no person has been trapped in the doors.

The provision of this type of system for the Central Line was again a first for the Underground.

Trackside elements of this system comprises of platform cameras, usually two cameras for a straight platform and multiple cameras for a curved platform. Camera information is fed into a picture combiner/transmitter whereby the picture is transmitted to a train antennae via a leaky feeder cable installed between the running rails and operating at 50.3 MHz.

The signal from the train antennae is decoded and displayed as a split picture on a 12 inch monitor mounted in the driving console. Where multiple cameras are used for a curved platform the picture is displayed in a matrix on the VDU.

Security for the customers is also enhanced by transmitting the camera pictures over the optical fibre (in analogue format) to the central control room. These pictures can be viewed by the operators on the small monitors fitted in the desks. Video recordings can be made of any selected platforms.

Other Systems

The communications facility also provides control of tunnel telephone direct lines, video and voice recorders and full PABX access.

Communications Switch

All communications facilities are provided to the desks and processed around the line by a proprietary crossbar switch configured to meet the needs of the line. As a result there is a large dual redundant switch at the centre able to process 450 CCTV feeds from all stations, PA, PABX, direct lines, tunnel telephones, traction earth detection etc. The system has 19 sub-switches (DIKOS) provided in a spoked wheel format around the line as shown in Figure 2. The system is based on ARCOM industrial PCs containing a duplicated data log in facility that logs each transaction. This arrangement gives additional security to the system by allowing rerouting of services around the failed area. The system also provides the recording facilities for all control room audio and selected CCTV pictures.

Major Achievements in Communications

- Track to train CCTV fully operational since May 1993.

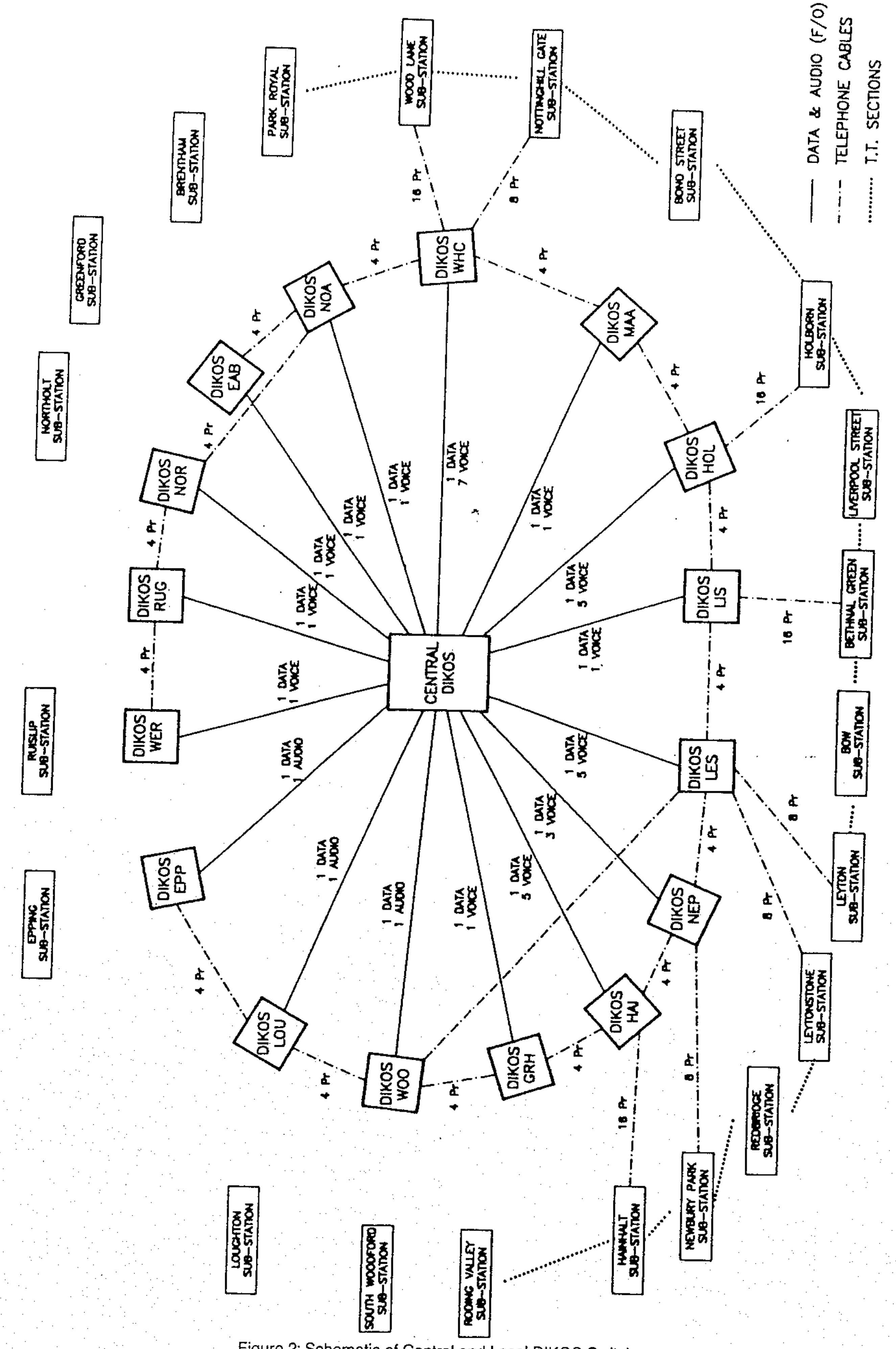


Figure 2: Schematic of Central and Local DIKOS Switches

- Optical fibre system fully operational since September 1993.
- Train radio fully operational since November 1993.
- Centralised communication switch fully operational since November 1993.
- Centralised control of communications operational since January 1994.
- Full upgrade of station public address completed in February 1994.
- New tunnel telephone equipment commissioned and operational in January 1994.
- Structure of the communications systems incorporates dual redundancy and there have been no failures causing a delay to service since the introduction of the communications systems in January 1994.

2.11 SIGNALLING AND CONTROL

The need to modernise the whole system was immense but never more apparent than with the 40 year old signalling system. The signalling had to be introduced on a piecemeal basis which required new signalling being tied into adjacent sites with old signalling; but probably worse was the need for the new signalling to function similarly to the old signalling with train stops and lineside signals in order to allow the old trains to continue running. To achieve these requirements the new signalling was designed, installed and commissioned with two operating modes, ie interim mode and final mode for ATP/ATO.

The signalling contract was placed with Westinghouse Signals Limited (WSL) in 1989. This contract included the provision of signalling and a signalling control system. Although these can be considered as two separate subsystems they do rely on extensive interfacing to achieve a satisfactory overall system. It was therefore appropriate to put both subsystems together with one contractor.

Signalling

Major signalling components include:

- Interlockings, originally relay based at every station, later solid state.
- Jointless track circuits for the purpose of detection of train position and passing maximum allowable safe speed information to this train. This jointless track circuit was chosen for its high immunity to electrical interference and its suitability for supporting the ATP system. Approximately 1,200 of these circuits are installed along the line.
- ATP for the purpose of ensuring all trains never exceed the maximum allowance speed for the section of line being traversed.
- ATO which effectively carries out the functions of a driver.
- A new type of cable route in the outside section used for the first time on the Underground. The design is based on a galvanised post arrangement with horizontal galvanised metal straps. Cables are placed in the hangers attached to the structure.

The opportunity was taken to change from relay based interlockings to a solid state interlocking. Relay technology was replaced by that of solid state WESTRACE interlocking.

A paper explaining the Central Line resignalling was presented to the IRSE in November 1994.

Major Achievements in Signalling

The Central Line's major signalling achievements are as follows:

- 22 relay interlockings have been commissioned.
- 10 solid state (WESTRACE) interlockings have been commissioned.
- Control centre (Phase 1) overview diagram operational.
- Platform ATO Communicator (PAC) system operational on all platforms.
- ATP commissioning at West End in its final stages.

Signalling Control System

A key feature is the provision of a centralised signalling system which is operated by means of workstations situated in the control room. All of the control and monitoring data is gathered from the local interlockings and conveyed to the central site by means of the optical fibre backbone. This centralised control removes the need for 19 existing signal cabins which are spread along the line.

Both central control and the local site equipment are based on Multibus II using Intel processors. All workstations are of the Sun-Sparc type integrated over a Local Area Network (LAN) based on Ethernet LAN to IEEE 802.3 using CSMA/CD (collision sensing multiple access with collision detection).

The centralised signalling computers, as shown in Figure 3, evaluate the train positions on the line and convey this information to the overview line diagram in the control room. Fresh updates of train positions are made every three seconds and predictions of train movements are calculated every 30 seconds. With this information the computers automatically route each train according to the timetable. Trains are released from platforms by countdown clocks driven by the timetable requirements. The clock is transmitted to the team and presented in the driver's console infant of the operator. If a perturbation to the normal operation occurs then an automatic regulation of the trains takes place.

Automatic routing can be overridden by the operators if so desired, for example there may be a need to change the route or put a train into a depot out of the normal sequence of timetable events.

Clearly another function of this system is to provide train arrival information for displays on the platforms of each station. This information is derived from the prediction calculations.

An offline performance monitoring system is also integrated to provide key management performance indicators.

A further feature of this system is to gather diagnostic information from the local sites and display this information on the workstations contained in the engineer's desk.

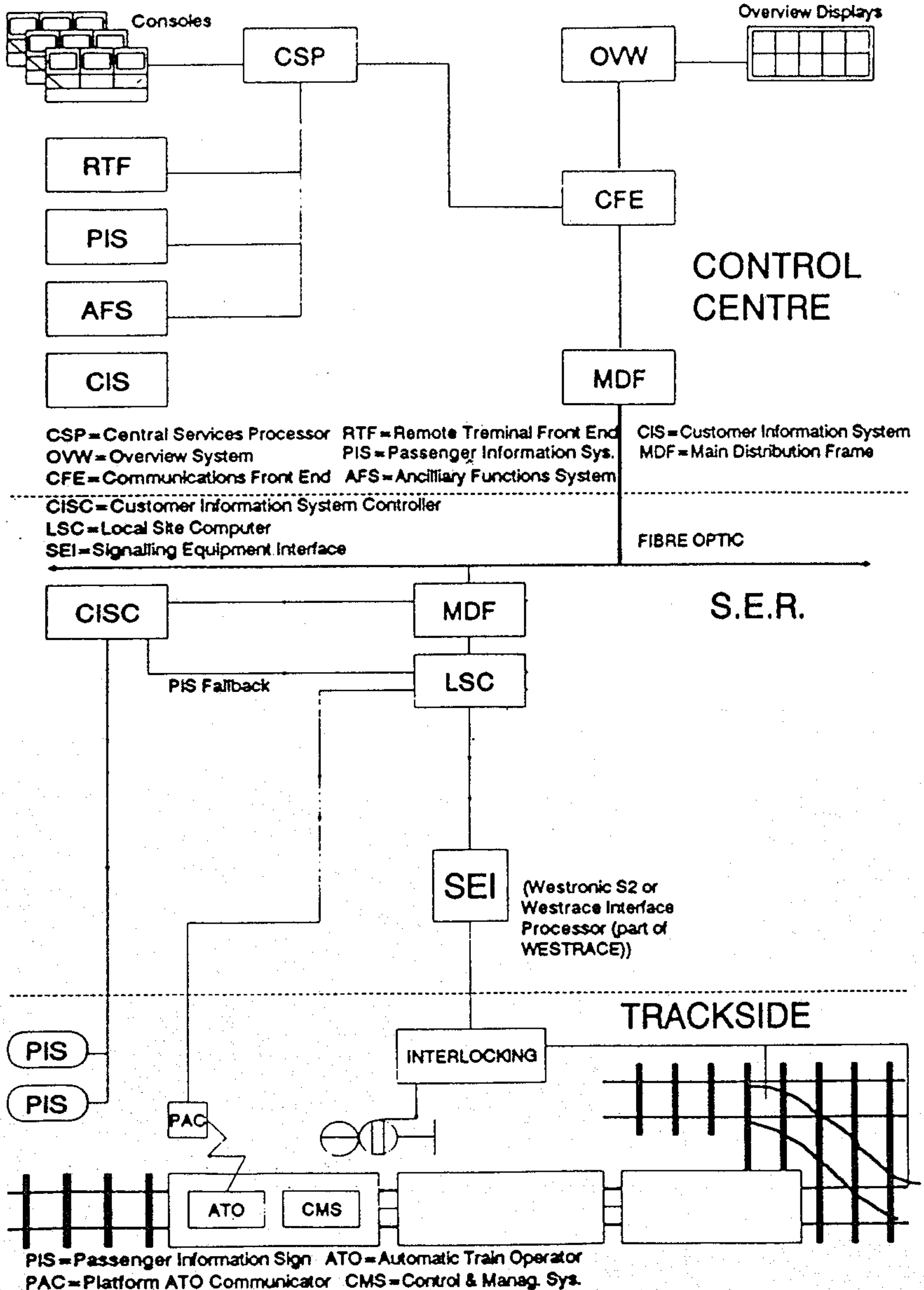


Figure 3: Schematic of Signalling Control Equipment

Automatic Train Regulation (ATR)

An ATR subsystem is being supplied as an integrated package within the signalling control equipment. Historically the purpose of ATR was to provide a regular service to customers or compliance to timetable.

The ATR being supplied is a pro-active subsystem rather than the historic re-active type used elsewhere. It seeks to identify trains which would potentially run late and within reasonable limits, to take action to negate the potential perturbation.

Inputs to the ATR include timetable, service demand, passenger loading, train performance, route information and station dwell time.

A complex algorithm to operate on these impacts has been developed by LUL working in conjunction with others, including Birmingham University. It is believed this development will admirably meet the demands of regularity and minimise waiting time. Benefits of ATR will be achieved when it becomes operational for all trains between White City and Leytonstone, ie the central area. As a result the Central Line ATR seeks to achieve the minimum waiting time for the maximum number of customers.

Diagnostics

The diagnostic subsystems have been installed as part of larger systems ensuring that correct and intelligent status information is provided to the user. This aids fault finding and improves the time taken to respond to failures, reducing the overall delay to customers. Diagnostic systems are provided on the trains, in the signalling system, in the communications system and in the control centre.

The control room is staffed by qualified engineers as well as control signal staff. These engineers, using the monitoring and diagnostic facilities provided, are able to contribute to the reliability and safety performance of the railway.

On the trains, a diagnostic computer based system is provided to the driver to allow him to quickly diagnose train faults without delay to train services. The on-board Control and Monitoring System (CMS) records both fault and status changes. Some of the status information is passed to the line controller at stations and all records are downloaded to the depot based Maintenance Support System (MSS) automatically when the train is stabled.

The WESTRACE system has a remote diagnostic facility whereby a failure of any WESTRACE is alarmed at the engineer's desk. By means of an inquiry routine the failure can be diagnosed to module level. This has the benefit of significantly reducing the time to repair the fault.

All of the control and monitoring data is gathered from the local interlockings and conveyed to the central site by means of the optical fibre backbone. A further feature of this system is to gather diagnostic information from the local sites and display this information on the workstations contained in the engineer's desk.

2.12 SYSTEM ENGINEERING PROCESS AND MANAGEMENT

System techniques were introduced and developed throughout the project and include the following.

Identification of High Level Requirements

One of the first processes was to identify the 'operating' facilities and 'technical' functionality required of the completed system. This process and resulting high level specification was achieved by 'brainstorming' the facilities and functionality with representatives from the operating staff, chief engineer's standards group and selected members of the project team. The project engineer, assisted by the project staff then decomposed the high level requirements into specifications for each major subsystem.

The project engineer prepared a summary of the scope of work and generated the Project Plan of Engineering and Implementation. This document known as the Project Plan was the first of the project procedures. Although this documentation has been updated a number of times to reflect the changes it has formed a key document for engineers throughout the life of the project.

System Diagrams

The project developed a system diagram for the Central Line, an example is shown in Figure 4. Prior to this there has been no overall system drawings for individual lines on the Underground. The task of producing the drawings required a wide overall knowledge and understanding to be gained. A number of techniques were used to produce these diagrams including block schematics and the Yourdon methodology. These system diagrams have been maintained throughout the life of the project to show all equipment and their interface arrangements. This process has identified and allowed examination of interconnectivity of systems being used resulting in a number of minor shortcomings being identified. Review and update of these drawings adds discipline to the system engineering process.

System Reviews

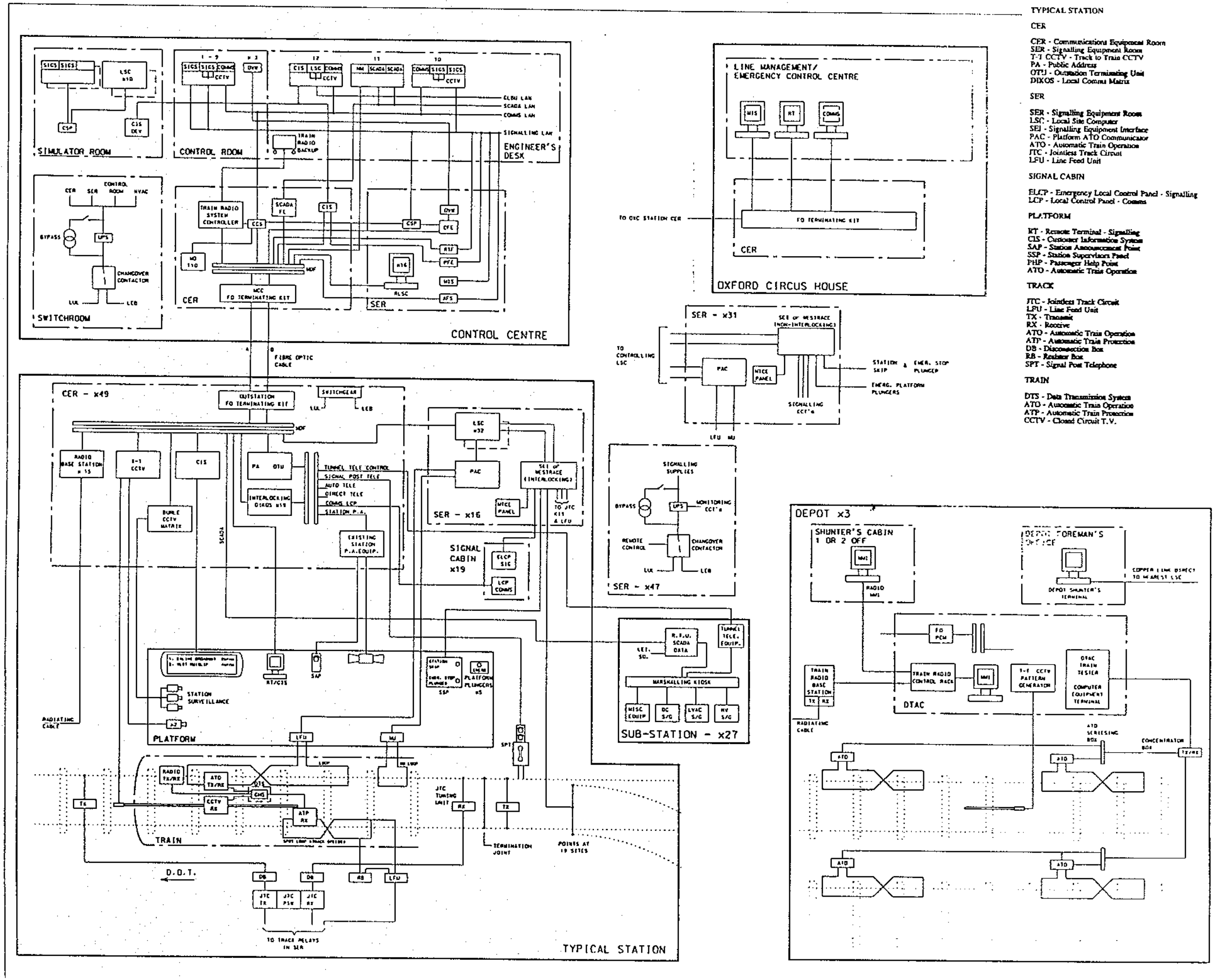
The project engineer arranged and led regular system reviews. These review meetings brought together the coordination engineers and discipline engineers from the project alongside the chief engineer and operating staff.

The reviews were usually to focus on a specification or subsystem to resolve what technology to use, the opportunities for integration, the side benefits, problems, etc. These reviews generally took the form of open discussions, brainstorming and input/output analyses. They have been extremely useful in giving the project 'vision' on the way forward.

Engineering Coordination/Integration

Systems integration was enhanced with the introduction of an engineering coordination group led by the project engineer and with a remit to:

- review engineering interfaces across the project;
- hold regular coordination meetings;
- to review the overall need for data communication and management.



TYPICAL STATION

CER

CER - Communications Equipment Room
SER - Signalling Equipment Room
T-T CCTV - Track to Train CCTV
PA - Public Address
OTU - Outstation Terminating Unit
DIXOS - Local Comms Matrix

SER

SER - Signalling Equipment Room
LSC - Local Site Computer
SEI - Signalling Equipment Interface
PAC - Platform ATO Communicator
ATO - Automatic Train Operation
JTC - Jointless Track Circuit
LFU - Line Feed Unit

SIGNAL CABIN

ELCP - Emergency Local Control Panel - Signalling
LCP - Local Control Panel - Comms

PLATFORM

RT - Remote Terminal - Signalling
CIS - Customer Information System
SAP - Station Announcement Point
SSP - Station Supervisors Panel
PHP - Passenger Help Point
ATO - Automatic Train Operation

TRACK

JTC - Jointless Track Circuit
LFU - Line Feed Unit
TX - Transmit
RX - Receive
ATO - Automatic Train Operation
ATP - Automatic Train Protection
DB - Disconnection Box
RB - Resistor Box
SPT - Signal Post Telephone

TRAIN

DTS - Data Transmission System
ATO - Automatic Train Operation
ATP - Automatic Train Protection
CCTV - Closed Circuit T.V.

CONTROL CENTRE

CONTROL ROOM

WSL - WESTINGHOUSE Signalling
ANT - BOSCH ANT Communications
CIS - Customer Information System - EDS-SCICO…
LSC - Line Service Centre Terminal - Siemens (…
NM - Fibre Optic Network Manager - Pilkington
SCADA - POWER (Supervisory Control and Data …
OVW - Overview Monitors
LAN - Local Area Network
CCTV - Closed Circuit T.V.

SIMULATOR ROOM

CSP - Central Services Processor - Signalling
LSC - Local Site Computer

SWITCHROOM

CER - Communications Equipment Room
SER - Signalling Equipment Room
UPS - Un-interruptable Power Supply
HVAC - Heating, Ventilation and Airflow Control
LEB - London Electricity Board
LUL - London Underground Ltd

CER

CER - Communications Equipment Room
MDF - Main Distribution Frame - Fibre Optic
MCC - Main Control Centre - Wood Lane
CCS - Communications Control Switch/System - A…
SCADA - POWER (Supervisory Control and Data …
FE - Front End
CIS - Customer Information System - EDS-SCICO…
MD110 - Ericsson Telephone Exchange

SER

SER - Signalling Equipment Room
CSP - Central Services Processor
OVW - Overview Processor
CFE - Communications Front End Processor
RTF - Remote Terminal Front End Processor
PFE - Passenger Information Front End Processor
MIS - Management Information System Processor
RLSC - Remote Local Site Computers

SUB- STATION

RTU - Remote Terminating Unit
DC - Direct Current
LVAC - Low Voltage Alternating Current
HV - High Voltage
S/G - Switchgear

OXFORD CIRCUS HOUSE

MIS - Management Information System - Signalling
RT - Remote Terminal - Signalling
ANT - ANT -BOSCH Communications
SUP1 - Supervisory PC - Fibre Optic
CER - Communications Equipment Room

DEPOT

MMI - Man Machine Interface
T-T CCTV - Track to Train Closed Circuit T.V
DTAC - Depot Test of ATC Equipment
ATC - Automatic Train Control
ATO - Automatic Train Operation
LSC - Local Site Computer

REV	DESCRIPTION	DRN	CHECKD	APPVD	DATE
B	SUP1, SUP2 DACK REMOVED. WESTRACE, CLDU LAN, LFU, MJ, SER POWER. RTF TO MDF. CIS DEV. CER SWITCHGEAR ADDED	ADP	DP		[illegible]
A	MDF REVISED. MIS, CMS & PLATFORM PLUNGERS ADDED.	ADP			[illegible]

CENTRAL LINE PROJECT

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Drawn	ADP	Date	SEPT. '91
Checked	DP	Date	22-10-91
Approved	AMD	Date	25-10-91

Title

SYSTEMS DIAGRAM

Scale

Drawing No 90-1001 Rev. B

This group comprised of six engineers (including the project engineer) but in reality was larger due to the inclusion of the specialist engineers. The first task of this group was to conduct a review of the planned scope of the project to identify omissions and enable the production of a detailed project implementation plan. Although this was not done against any formalised technique of process an implementation plan was produced and has been updated during the project.

Hazard and Operability Studies (HAZOPS)

Safety of the railway is of paramount importance. New techniques of formal analysis were investigated early in the project and a technique widely used in the oil and gas industry was adapted for use on railway projects. This being the first time a formal method of safety assessment had been used in LUL.

The process calls for all the specialist engineers, operators and maintainers to sit down under the chairmanship of an independent facilitator and review selected key events against a set of pre identified key words. This process, although principally to identify safety issues from specification, design and installation, is actually a system review, identifying shortcomings and omissions from the discrete and overall systems. These outputs were used as important inputs to the monthly engineering coordination meetings.

The objective of the hazard identification procedure is to produce a comprehensive list of potential threats to the safety of passengers and the scope of the hazard identification extends to all sources of hazard within the defined system boundary of the study. Essentially the boundaries of the system can be broadly considered as including the station platform areas, the running rails and immediate trackside area and the rolling stock.

From a review of the identified hazards it is possible to identify a subset of hazards considered to be significant which are then carried forward for detailed analysis within the Quantified Risk Assessment (QRA). The QRA allows estimated risks to passengers to be evaluated and the risks judged for acceptability or otherwise.

Electro Magnetic Compatibility (EMC) Studies

Extensive theoretical EMC studies were carried out to examine the compatibility of new trains operating with the old signalling. This was to ensure suitable arrangements could be made to allow the introduction of new trains to safely operate on the existing signalling prior to the completion of the new signalling programme. The existing track circuits were considered to be vulnerable and these were covered by the studies.

The existing track circuits were predominantly of the 125 Hz double vane type, with a few 33⅓ Hz and a few Delta track circuits.

Studies therefore covered the following:

- Compatibility of the new trains with the existing 33⅓ Hz track circuits. These studies concluded that a potential unsafe situation could occur and it was recommended these track circuits be changed. Approximately 40 such track circuits were changed in the Stratford area prior to the first new trains entering service.
- Compatibility of the new trains with the existing 125 Hz track circuits was found to be acceptable under normal conditions. However, under certain failure modes of the traction equipment it was possible to generate an interfering signal which had the potential for an unsafe condition of this track circuit. The probability of this occurring was small but nevertheless the risk was unacceptable. On the basis of large numbers of these track circuits being in existence it was decided to fit a monitoring system around each traction package such that any failure of the equipment which could generate unwanted levels of 125 Hz would cause the offending package to close down.
- Compatibility studies of the new train with existing Delta track circuits identified unsafe conditions. Approximately 25 such circuits were changed for the axle detector system prior to the new trains entering service.

Cable Records

The traditional method of recording the route of signalling, communication and power cables has been by paper copies. Unfortunately the main contracts were let on the same basis. This method suffers from the difficulty of imposing a rigorous discipline to keep these records up-to-date over a 40 year plus period of time. Experience shows this does not work. In fact, any changes to existing wiring for interim purposes always required a hand trace and wire count before any work could be undertaken.

Recognising this problem, the project engineer reviewed the market for a suitable CAD tool and gained the necessary authority to purchase the tool and resource for the electronic means of storing this information. This work entailed taking the hard copies of the newly installed cables and transferring this to the CAD machine. Whilst this work was somewhat of a reverse engineering nature it did assist in fully understanding any omissions from cable runs and of course provides the Company with an arrangement for easily recording all changes through the life of the system.

2.13 ENGINEERING LESSONS LEARNT FROM THE CENTRAL LINE PROJECT

The key areas where engineering lessons have been learnt and improvements can be made in future projects include:

i) Originally individual subsystems specifications were prepared and contracts placed without real definition of the overall systems and operational/user requirements.

The process of engineering the system evolved throughout the project to meet the operational/user requirements and ultimately achieve an acceptable system.

Consequently, this evolutionary approach resulted in large number of variations to the original contracts which in turn has cost money and time.

ii) As the project progressed a number of inconsistencies, ambiguities, omissions and incorrect interfaces were uncovered in the original specifications. Corrections had to be made and again a number of variations to the original contract were required. Cost of these variations often depended on how quickly the deficiencies were identified.

iii) Lack of a formal system engineering methodology has resulted in data being somewhat distributed and very difficult to reference. An attempt was made at a late stage in the project to bring the design and maintenance data, together on to a single workstation. This has been reasonably successful but again unforeseen expenditure was required.

iv) The effect of working on an operating railway was significantly underestimated in the early days. The amount of enabling work, interim work and stagework throughout the various implementation phases was immense. A structured system engineering methodology would have been most beneficial to ensure the work was planned and executed by the most efficient means.

2.14 BENEFITS ALREADY DELIVERING FROM THE CENTRAL LINE PROJECT (already gained by October 1995)

Whilst the project is not yet complete and the full benefits still to be gained, many of the systems and processes are now operational and delivering improvements to the Central Line service. The improvements already quantified are as follows:

- The final new train was delivered on 14th March 1995. Since 17th February 1995 all Central Line services have been provided by new trains. Operating on an OPO basis, they bring cost reduction through the elimination of around 375 guards.
- Overall train reliability has continued to improve and is now below two failures per 25,000 train kilometres - making it already the most reliable on the network. The project target of no more than one failure per 25,000 train kilometres (which would make it the most reliable train in the world) appears fully achievable on the basis of present trends.
- The reduced marginal cost of operation has allowed off-peak services to be increased. A new timetable was introduced in June 1995 increasing line mileage by over 10%. Further improvements to the service will be implemented once the signalling is completed. It is currently planned to increase the service to 30 trains per hour in August 1996 and to 33 trains per hour in January 1997.
- Customer reaction to the new trains has continued to be very positive. Recent independent quality assessments (Mystery Shopper Scores January to March 1995 wave) ascribed to the Central Line best performance of any LUL line, at 88% (next best 79%; worst 65%). The Central Line's scores for train public address, brightness and external graffiti levels were 86%, 87% and 90% respectively.
- Customer perception scores placed the Central Line as the best line for train information at 76.8% (next best 76.2%; worst 68.2%); best also for train cleanliness at 71.1% (next best 70.5%; worst 49.9%); and equal third best for train safety and security at 85.8% (best 86.5%; worst 81.2%).
- The optical fibre network, train radio and CCTV systems continue to meet contractual and service availability requirements.

3 THE NORTHERN LINE

3.1 BACKGROUND TO THE NORTHERN LINE PROJECT

After the authorisation of the Central Line project in 1988 LUL planning processes turned to the next line that was in need of modernisation, the Northern Line. The Northern Line did in fact have older trains than the Central Line but the other major assets such as signalling and power had undergone some modernisation in the late 50s and early 60s. Indeed the control system using its programme control machines was relatively sophisticated for its time if now somewhat older technology.

The Northern Line provides 108 million passenger journeys every year (in 1994/95 this will be 15% of all Underground journeys); it earns £109 million in revenue and costs roughly £90 million per annum to run. On the Northern Line there are 50 stations and two depots (at Morden and Golders Green), the line management employs 2,000 staff. The train fleet comprises 75 1959 tube stock, two-and-a-half 1962 tube stock and 25 1972 Mk 1 tube stock.

By the late 80s the Northern Line equipment was showing its age and the nickname of the 'Misery Line' was gained due to its continued poor performance. The need for a major modernisation of the line was now apparent. However, as a result of the topsy-turvy world of public finance, the Northern Line project was started and stopped twice in the period 1990 to 1993.

The problem with this type of project is that it consumes so much cash, a fleet of trains would cost £400 million and the whole Northern Line modernisation over £1 billion.

Ironically, the same financial constraints produced the UK Government's PFI proposals in November 1992 and after a fairly long gestation period enabled LUL to place a service provision contract for a new fleet of trains with GEC-Alsthom (GEC-A) in April 1995.

This initiative and the recognition that to get the new trains into service and get the most out of them when the rest of the Northern Line was modernised caused the Northern Line project to be rapidly authorised.

In the period from May 1994 to November 1994 a project team was established and outline project plans prepared. Most importantly, a vision of the Northern Line in the year 2002 was prepared, including system diagrams for the primary stages of the project. As a result, the scope of the GEC-A control was enlarged to include, for example, optical fibre cabling requirements for the whole project. Clearly it would be ideal to have plans prepared in advance and much of the systems thinking already done but it has to be recognised that opportunities may unexpectedly arise as a result of political issues and other opportunities.

As a result of the PFI and successful placing of the Northern Line service provision contract with GEC-A, LUL now has a Northern Line project proceedings with a six to seven year time span and a great opportunity for the system engineering to demonstrate its worth.

3.2 THE 'TRAIN SERVICE CONTRACT'

In April 1995, LUL placed a contract with GEC-Alsthom Northern Line Service Provision Limited to provide a 20 year leasing arrangement of a daily train service for the Northern Line. Within the train service contract there are other distinct groups of equipment and services that will be provided.

The total equipment to be provided is as follows:

i) 106 new six-car electric multiple unit trains;

ii) platform to train CCTV equipment for each Northern Line platform;

iii) an interim VHF train radio system;

iv) a new UHF trucked radio system for the whole Northern Line;

v) a track to train data transfer system at all stations and other locations to provide operational data prior to the signalling system being upgraded to ATO. This includes data for 'correct side door enable' operation;

vi) the provision of an optical fibre network, part of which will be utilised by the trunked radio system as its data transmission network;

vii) the upgrading of the depots and outstations on the Northern Line.

The services provided for 20 years include:

i) the maintenance and servicing of 106 trains to provide a 96 train service (including cleaning, graffiti removal, safety testing, heavy overhaul, etc);

ii) the maintenance and servicing of the trackside equipment, ie the CCTV and radio systems etc;

iii) the maintenance and operation of the two depots at Golders Green and Morden.

To allow the new trains to run a number of enabling works have to be undertaken and completed prior to any new train running on a particular portion of the Northern Line. The enabling works are varied and incorporate depot reworking, the upgrading of the power supply system, modifications to the signalling system and gauge restoration works in tunnels and at platforms to maximise kinematic and structure gauge clearances.

3.3 IMPLEMENTATION PLAN

The overall implementation plan for the Northern Line modernisation work falls in two phases, Phase 1B and Phase 2.

Phase 1B

This phase has three major activity groups:

- implementation of the train service contract;
- implementation of the enabling works identified in the preceding Phase 1A for the delivery and operation of the new rolling stock;
- complete the definition of the remaining elements of the work for the full modernisation of the Northern Line.

The above is fully authorised and is scheduled to complete in 1998.

Phase 2

As part of the total modernisation of the Northern Line, new signalling, control and communications systems will be required. The new signalling, control and communications system will allow a more regular and higher density train service to be achieved with reduced operating costs and are therefore an important requirement in the corporate aim to provide a decently modern metro.

Provision of new communications systems and upgrades to the existing communications systems will be carried out in this Phase 2 - these will be in addition to the Phase 1B activities included in the train service contract.

Phase 2 also includes modernisation of other systems such as power and infrastructure improvements such as permanent way and station modernisation.

In summary, the work includes the following:

- signalling system with ATP/ATO;
- signalling control system and backup facilities;
- optical fibre communications network;
- customer information system (platform indicators);
- public address;
- customer security - help points/CCTV;
- management information system;
- power system renewal - high voltage, low voltage and control systems;
- station upgrades including opening Mornington Crescent;
- track upgrade of running lines, sidings, points and crossings;
- lifts and escalators upgrade;
- civil infrastructure upgrade on assets such as ventilation, tunnels, bridges, drains, pumps/sumps etc as determined necessary.

3.4 PROJECT TEAM

A project team has been set up to manage the Northern Line project in accordance with authorised scope, budget, schedule, safety and quality objectives. This team is a multidisciplined team with an integrated structure composed of professional management and engineers.

The project team structure is not a fixed organisation but varies in composition and content to reflect the particular needs at particular times in the work. Many of the staff bring valuable experience to this team from their earlier work in the modernisation of the Central Line.

3.5 NORTHERN LINE - SYSTEM ENGINEERING PROCESS

Due to the rapid 'kick-off' to the project it was necessary to conduct the following activities in parallel:

- prepare a rolling stock specification with a sensible increase in its scope to include an interim radio, final radio, installation of optical fibre cable, track to train CCTV and correct side door enable sub-system;
- define the enabling work to be completed prior to the first new train in service;

- develop the vision for the completion of the work in 2002 ensuring maximum performance from the trains.

Running these activities was really only possible by using experience and knowledge of previous work on the Central Line project and Jubilee Line project. Once this work was 'up and running' and the train service contract awarded, the project committed itself to system engineering at all levels. The objectives being to:

a) minimise risk to project overrun;

b) minimise inconsistencies in specifications;

c) improve efficiency of the project;

d) minimise project scope development by understanding likely technology growth at the start;

e) build a complete asset database for handover and ongoing maintenance.

The methodology now in place in the Northern Line project team is:

- the appointment of the project system engineer reporting directly to the project manager;
- the continuation of the processes used on the Central Line project as outlined in 2.12, ie the practical and hard grind system engineering;
- the use of a formal system engineering tool, the project has selected the RD100 tool from Ascent Logic configured to provide six workstations spread throughout the project;
- a system team of four full-time engineers is in place to manage and run the systems tool.

To date, the system engineering has a vision for 2002, an implementation plan, a group of engineers to continue the processes used previously and a system engineering tool.

Currently all of the system engineers and a number of discipline engineers have been trained on the tool. Information is being captured on the tool and we are about to formalise the 'vision' and the operation/user requirements.

Clearly a considerable amount of specification work has already been accomplished, especially for the train service contract. Consideration was given to 'reverse' engineering the contract specifications already in place but with the amount of work facing the system engineers it was decided to treat the specifications of certain subsystems as 'constraining black boxes'. A pragmatic and practical view had to be taken to maximise the future benefits that could be obtained.

4 SUMMARY

The Central Line project has made good use of system engineering to deliver an effective engineering solution.

In each engineering area maximum use has been made of innovation and new technology and focused by a determined system integration target. This approach has been justified both in terms of project cost and performance achieved. For example, the new Central Line trains are already the most reliable in the London Underground fleet, even though they are significantly more complex than any other type of train.

The project has delivered a fully integrated and advanced railway engineering system supported by robust dual redundant subsystems able to identify, diagnose and switch to alternative routing or facilities. The whole concept of control has been changed by the use of a single line control room for the 55 route kilometres of the line. The control room provides normal operational control of the train service and additionally provides control of the vital engineering systems, power supples etc. The room is staffed for the first time by qualified engineers as well as operational staff. These engineers, using the monitoring and diagnostic facilities provided, are able to contribute to the reliability and safety performance of the railway. A secure optical fibre, dual redundant communication system is provided throughout the line for telephone communications, signalling and power control. A modern, automatic safety signalling system is used for the protection of the trains and passengers with automatic driving from station to station.

The system integration spreads throughout the project from the use of welded, aluminium, lightweight construction trains for energy efficiency and reduced track damage to the automatic download at stations and depots of its serviceability and passenger load.

The culmination of the system is the development of the proactive automatic train regulation package which will act in real time on passenger load information from trains. The package seeks to 'reduce station waiting time to a minimum for the maximum number of passengers' and not just achieve regular headways.

The use of system engineering does not preclude the possibility of contractual claims and variations but does dramatically reduce their size and impact. The practical processes used are effective and have their use in any system engineering approach. The Central Line project has successfully developed the use of a system model to assist in asset management and maintenance response. Whilst this is a reverse engineering process on the Central Line project it will be an essential deliverable on the Northern Line project.

The Northern Line project plan identifies the numerous stages that the line's engineering system will go through. This improves specification development, ITT production and project planning. The use of system engineering should minimise technology and/or scope growth on a long duration project by enabling the best judgement to be made on emerging technologies and providing a clear plan and understanding of equipment specification needs against the project brief. Due to the rapid recommencement of the Northern Line project some element of reverse engineering is being undertaken but it should be recognised that waiting for a full, complete system engineered plan may have resulted in no project at all.

5 CONCLUSION

1 The key to a successful and well integrated Central Line project has been a clear engineering vision, highlighting expected performance and interconnectivity.

2 The practical/hard grind system engineering approach has benefit and has its place in any system engineering process.

3 The use of system engineering does reduce project risk to contract claims for specification mismatch/error and does highlight opportunities to use under utilised facilities with discrete systems for new or improved business performance.

4 With the benefit of hindsight, the only truly missed opportunity for Central Line was the lack of integration of the engineer's desk into a small number of screens, whilst technically feasible the ongoing technology development of the project made this an almost impossible goal.

5 The Northern Line project will use a combination of pure theoretical and practical system engineering processes to maximise project delivery.

6 In view of the expected complexity and level of technology on the Northern Line it is essential that a master systems integrator role is established either within the project team or within the communications or signalling contracts.

7 The software tools now available offer the possibility of testing the capability and viability of an emerging technology or new equipment on an existing system. Hence allowing the technology strategy to be developed and honed against real engineering constraints.

8 The system engineering process has much in common with safety assessment techniques. The Northern Line project will investigate using its tools for HAZOP, FPTA, since these are system measurements by another name.

9 Ideally project plans should be fully system engineered sometime before project approval. However, political and financial constraints made this difficult in reality. The system engineer will have to accept that an element of reverse engineering will always be necessary and part of the job.

10 The very use of standards on the system engineering database would be very beneficial but for the Northern Line work time does not permit for this to be done, perhaps the next major project or venture could pick up this benefit.

11 The use of the system engineering tool alone or in parallel with the processes used on the Central Line cannot achieve the objective without the high technical vision of how to deliver the business aspirations.

6 ACKNOWLEDGEMENTS

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