Executive summary
This was one of the most complex multidisciplinary engineering and tunnelling projects in Europe, being delivered against a challenging deadline, in unique environs, with a series of obstacles and risks encountered along the way. To deliver this project in half the time of the industry norm, on budget and with an impressive health and safety record was a considerable achievement. The careful planning, collaborative working and innovation used by the project team set a benchmark for world-class delivery, not only for the wider Olympic Park construction projects, but for the whole industry. The project is considered to be groundbreaking and was the first Olympic Park preparation project for the London 2012 Games.

The significance of the Powerlines Undergrounding project (PLUG) on the wider Olympic Park cannot be underestimated. This tunnelling and overhead line and pylon removal project was the key to unlocking the Olympic Park landscape for long-term regeneration, allowing the skyline of east London to be permanently transformed.

“PLUG is probably the highest risk and toughest project we’ll do on the Olympics and sets a fantastic benchmark to every other project that follows. A great start.” David Higgins,
chief executive, Olympic Delivery Authority (ODA). “The completion – on time and on budget – of the work on the powerlines tunnelling is a tremendous achievement. It is important not just for the creation of the Olympic Park, but also as a crucial part of our ambitious regeneration plans. It demonstrates clearly the excellent progress being made to deliver a fantastic Olympics.”

Tessa Jowell, Olympics Minister

Quick facts:
- Project cost: £250 million
- More than 1.5 million man hours on the tunnelling alone
- 420 workers on site (2 main sites and 6 satellite sites)
- PLUG tunnelling accounted for 85% of the UK’s tunnelling in 2007
- Tunnelling completed in 424 days
- 4 x 40 tonne tunnel boring machines working simultaneously
- 13km of tunnels
- 175,000m³ of spoil produced – enough to fill Wembley Stadium – 90% of which has been re-used in the earthworks for the Olympic Park
- Tunnels lined with 11,000 concrete rings
- Construction (and modifications) of four large electricity substations
- 200km of power cables – enough to stretch from London to Nottingham
- 52 electricity transmission pylons removed and recycled
- 80km of conductors removed – all recycled
- 8 tonnes of porcelain insulators removed – all recycled
- Early upfront fast track international procurement of plant and materials
- Period from start on site to cable energisation was half the industry norm

Brief project background
Following the award of the London 2012 Olympic and Paralympic Games in July 2005, a long-term regeneration plan to relocate 52 electricity pylons that dominated the landscape in and around the Olympic Park in the Lower Lea Valley needed to be fast tracked to clear the area ready for construction. After consideration of a range of options, it was decided to create two 6km long deep bored tunnels (typically 20-30m below ground) and a 850m long spur tunnel to carry the powerlines underneath the Olympic Park, together with a number of large electricity substations and associated infrastructure.

The tunnels, power cables and substations form part of the strategic infrastructure of EDF Energy and National Grid. In addition, the project was conducted in the face of intense public scrutiny, governance and engineering assurance. PLUG was the first major construction project for the Olympics and, as part of its commitment to transparency, the ODA published a detailed set of milestones at the outset. Consequently, any deviation from the original timetable had the potential to dent public confidence not only in the ODA but in the delivery of 2012 itself.
The key project objectives/priorities were to:

- meet the exacting programme;
- deliver a quality project;
- remove, mitigate and manage risk;
- ensure the safety and well being of all personnel and workers engaged on or affected by the project;
- demonstrate value for money;
- keep London and customer supplies ‘switched on’.

**Project management activity**

The project was developed to be executed in six distinct phases:

1) Concept and feasibility.
2) Definition.
3) Implementation – tunnelling, substation construction, cabling and equipping, pylon removal.
4) Handover of the assets and close out.
5) Operational testing and handover to the end user.
6) Termination/completion.

From the word go, teamwork and trust were absolutely key. All parties worked as one, focusing on the challenges in hand and buy-in to the common goal rather than on protecting contractual positions. The fact that individual success would only happen if everyone was successful was understood and drove positive behaviours (there were no contractual incentives to link these parties).

a) Organisation and governance were recognised as key aspects to the successful delivery of the project. Initially, the project office was set up in a hierarchical way with the project management team on the top floor, the contractor on the middle and the sub-contractors in separate site offices which led to fractured and incoherent project governance and organisation. Following the formation of the integrated management team, behavioural and team attitude workshops were held as well as coaching for the project team via an external facilitator. This led to dynamic change to create a more interactive, cohesive team where different disciplines (e.g. engineers, commercial managers etc.) sat together regardless of company affiliation. This enabled the future challenges and possible areas of conflict to be discussed at a very early stage.

It was decided that the project would comprise framework agreements between the LDA, NG and EDF Energy, which would be based upon the following principles:

- The design of the tunnels would comply with both NG and EDF Energy requirements (including operational, maintenance and health and safety).
- The LDA would procure the tunnels and might novate the contract to the ODA once it was established.
- NG and EDF Energy would procure the cabling, its installation and the removal of existing OHLs. The agreements would include detailed estimated costs of these elements. The LDA (or the ODA following any novation of the contracts), with appropriate agreements from funders, would meet the actual costs incurred by both NG and EDF Energy. Where costs were likely to exceed the cost estimate, NG and EDF Energy would need to notify and justify such increases.
- Costs incurred by NG and EDF Energy had to demonstrate value for money and an open book policy was to be adopted.
- Contractors (and where appropriate subcontractors) and consultants employed by the LDA/ODA had to provide warranties to NG, EDF Energy and the LDA/ODA.
- NG and EDF Energy would pay for any betterment.
- NG and EDF Energy would own, operate and maintain the tunnels and cables once completed. A Project Governance Plan (PGP) would be put in place to give guidance to the working relationships between the LDA, NG and EDF Energy, and facilitate the development and maintenance of collaborative, productive and effective working arrangements. In order to ensure the project ran in accordance with the scope of the PGP, a project steering group would be set up to act as a forum for high level communication and to oversee the project. It would be the forum within which all key project decisions would be discussed prior to a decision by the LDA and implementation by the project team.

A significant effort was put into engaging with the workforce so that they felt a sense of ownership and pride. Celebratory events were organised to mark key milestones and DVDs were produced for the families of the workforce to see what work they were doing.

b) Clear and effective communication was absolutely vital. Structure processes were put in place and implemented to manage change and communicate its effects. Formal communication channels were agreed from the start and identified within the project execution plan and project governance plans. These included daily third party structure and tunnelling reviews, weekly meetings with the principals of each party through the IMT, detailed
weekly design coordination and interface meetings, risk review and mitigation meetings, and monthly reporting. In addition, all ODA PLUG project board meetings (including stakeholders) were held on site, which ensured clear communication of key issues at a high level, rapid decision making and influencing, and that everyone was able to see progress for themselves.

On the Olympic Park the effect of change, both on the scope and programme, was magnified as there were so many teams working simultaneously in a constrained space. A key component of effective communication was therefore mediation. The project manager (Arup) acted as a mediator between parties and helped find solutions that benefited the programme as a whole.

The need from the outset was to have structured processes in place to engender as flexible an approach to decision making and works execution as possible, and to allow for change, given the unique scale and complexity of the project. The achievement of this can be demonstrated in a number of ways, e.g. the contract changing from a target cost contract (September 2005) supplemented by incentives (December 2006) to a lump sum contract (December 2007). These changes allowed the commercial consequences of the challenges that were encountered to be addressed in a timely manner and gave timely financial redress to the contractor where necessary.

With the change of project manager five months into the contract, a lot of opportunities to put in place the necessary ‘framework’ for collaborative working had passed. However, the project manager implemented a number of partnering sessions with the project team, including the cable installer/substation works contractor.

One seemingly small change, but with a major beneficial impact, was to re-arrange occupancy of the site accommodation. From day one the contractor had occupied the ground floor with the project manager on the first floor. This arrangement meant the team was not truly co-located and reinforced the divide between the two roles. Despite some initial resistance, the ‘construction’ team was relocated to the ground floor and the contractor’s document control and quality teams were moved to the first floor.

All project team members freely admitted this was a beneficial move, creating a working environment for rapid problem solving between team members, regardless of which company they were employed by. It became the PLUG team rather than the individual parties.

c) Risk management and mitigation were vital aspects of the project. The IMT and the ODA provided an important role in managing this risk through continuous risk review and mitigation workshops, on some occasions on a weekly and daily basis. This ensured continual communication and fostered a good working relationship between all parties.

The comprehensive risk management process used throughout the project was a key factor in its success. Where possible the risks were removed, such as the implementation of a £5m temporary diversion of the NG overhead lines to protect the construction programme for the Olympic Village. Where this was not possible a risk mitigation strategy was defined and closely monitored through its implementation, with modification to the strategy if required in response to a changing assessment of the risk.
A key goal for the IMT and the ODA was the achievement of specific health and safety targets. The IMT worked closely with the contractor to strengthen the safety culture on the project and ensure that these targets were met. This included highlighting health and safety issues to the ODA project board on a monthly basis and, at the height of construction, coordinating regular site safety inspections. Examples of specific actions taken included making eyewear mandatory on site, instigating incentivisation for good health and safety practice (donations to local hospitals for the incident-free achievement of milestones, monthly safety awards), and setting up safety suggestion boxes in the canteen.

Sustainability initiatives included:

- 90% of the tunnel spoil was stockpiled on the former Hackney dog track site for subsequent re-use in the earthworks for the Olympic Park. Only the most heavily contaminated spoil arising from the early shaft excavations had to be removed offsite.
- At a workforce level, as the site was difficult to access via public transport, a green travel plan was set up which encouraged car sharing.

Challenges

PLUG presented significant technical and management challenges:

a) Change of client
   The project was originally initiated by the LDA. Once London won the bid for the 2012 Games, ownership of the project was passed to the ODA. The project team planned for this client change from the project outset to ensure that the programme was not derailed and a swift and seamless transition and legal transfer of the project was achieved in November 2006 when the project was already well underway.

b) Technical challenges
   - The tunnels passed below the Channel Tunnel Rail Link (CTRL) twice, Network Rail lines six times and the London Underground (Central and District Line) and Docklands Light Railway twice. The tunnels had just 4m clearance below the CTRL Stratford box. There was just 2mm of movement in the box and the face loss was less then 1%.
   - The main tunnel/railway interface of the entire project was encountered almost immediately so there was no learning curve or room for error.
   - Shaft sinking and tunnelling occurred within and under large live electrical substations housing a highly sensitive 132000v switchgear which couldn’t sustain any movement without failing.

- Naphthalene and benzene were discovered at one point causing tunnelling on the National Grid tunnel to stop for over a month.
- There were tunnel boring machines in the ground (two for each tunnel) driving from two central drive shafts N & S which is very rare in tunnelling.
- Cable installation was re-configured to allow parallel working with ongoing tunnel ancillary works, requiring cables to be pulled in two directions from one central shaft.
- The 4m tunnel diameter and final location of the cable supports required a significant degree of working at height underground with some 1200 tonnes of scaffold required to be erected and removed for cable jointing procedures. The innovative design of cable rollers allowed up to three cable lengths totalling 2400m to be pulled through the tunnel at any one time.
- Overhead lines and pylons had to be removed from over busy rail lines, major A roads, residential and commercial areas – a special system was employed called a catenary self support system.
- All of this occurred with a backdrop of continually changing access arrangements, as the Olympic Park continued to evolve.

c) A local project
   PLUG took place in a highly residential area and it was therefore vital to ensure good community relations. Art by local school children was displayed on the site hoardings and local school children were shown around the site.

d) Large number of stakeholders
   There was a diverse range of third party stakeholders including private land owners, DLR, Tube Lines, Metronet, Network Rail, Port of London Authority, TfL, London Borough of Hackney, London Borough of Newham, Thames Water, the Environment Agency and British Waterways.

e) Large number of consents/approvals
   Consents and approvals were obtained from scratch including 20 rail, 6 river and 60+ utility consents. At no time did any third party approval issue impact on or stop work on the tunnels.

f) Tight timescales
   These required the constant refocusing of the team’s efforts on the critical activities and detailed coordination of construction methodologies and programme.
Success factors
Despite the considerable challenges faced and the fact that the initial programme had to be constantly reviewed and amended, the key project objectives were met and the project was delivered on time, to budget and with an excellent health and safety record. The testing and commissioning of the cables is complete and the power has been switched over.

The major success factors of the project were as follows:

- Commitment from each organisation’s principal for this project to be a success.
- Ability to calmly and quickly adapt to changing circumstances.
- Flexibility of workforce (being able to re-programme the job with everyone’s agreement, reshaping contracts so that the tunnelling and cabling phase could overlap and different sets of workers could go in at different times).
- Teamwork and hard work by a lot of dedicated people – tunnelling was relentless for 12 months and at its peak involved 4 TBM’s operating on 1 site with a workforce of 350 people.

“The project itself was extremely fast track and the programme was about half the duration of the industry norm in order to meet London 2012 Olympics deadlines. The project was completed on time and to budget.”
Terry McDonald, project director, PLUG Project

“I think it has been exceptional. The contamination and the unexpected gasworks has thrown everything at the team that you could have expected and they have managed to get around that, to innovate, to come up with solutions to ensure that we still hit our switchover date in mid 2008.”
David Higgins, chief executive, ODA (June 07 DVD)
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