CTRL London Tunnels: an alternative approach to delivering a major tunnelling project

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ABSTRACT: The Channel Tunnel Rail Link (CTRL) London Tunnels involved construction of 19 km of underground railway. The capital value was around €780 million with an allowance of approximately 12% to cover risks including geotechnical uncertainties.

Early problems caused the contingency fund to be spent before tunnelling commenced. Clearly the project risked major overspend. To overcome this risk a commercial alliance was established between the parties to share the remaining funds and work together to complete the project.

This alliance changed the way the geotechnical engineering challenges were met. The team focussed on identifying the risks and selecting the best placed group within the combined team to manage each risk. No benefit could be derived from transferring risks unless it was to another part of the team with better skills to manage them.

The immediate result of the London Tunnels experience has been the successful delivery of the scheme well within the original programme and at the tender budget. The wider impact of this outturn may be in the planned adoption of similar models to deliver future major underground projects.

1 CTRL LONDON TUNNELS

1.1 *The project works*

The recently completed Channel Tunnel Rail Link London Tunnels account for 19 km of the route of the new high speed railway from the Channel Tunnel to central London.

The works involved the construction of approximately 36 km of 7.15 m internal diameter running tunnels driven through a range of soft ground conditions. Also included is the 1.1 km long station box at Stratford, 500 m of cut and cover tunnel in Dagenham, five ventilation shafts, 29 cross passages and various large sprayed concrete lined tunnels. The works are all within the London urban area and are largely under surface railways, highways or residential properties.

1.2 *The parties to the works*

The London Tunnels works have involved input from a large group of major civil engineering companies. At contract award three of the four main civil engineering contracts were awarded to joint ventures indicating the benefits of collaborative working for projects of this scale.

The client for the CTRL London Tunnels is Union Railways (North) Ltd a subsidiary of London and Continental Railways who won the concession to build the railway. The design and project management organisation, Rail Link Engineering (RLE), is itself a consortium composed of staff from Arup, Bechtel, Halcrow and Systra; these four companies being the civil engineering shareholders in London and Continental Railways.

The three London Tunnels tunnelling contracts (Table 1) were all awarded to joint ventures. The longest drive, C220, was awarded to Nishimatsu Cementation Skanska JV. C240, the drives east from Stratford, were awarded to Costain Skanska Bachy JV and C250 the easternmost tunnels were awarded to Nuttall Wayss & Freytag Kier JV.

C230, the station box in Stratford, was awarded to Skanska and the representation of Skanska in all three

Table 1. CTRL London Tunnels contracts.

Contract	Description	Approximate value
C220	Stratford to London West Portal	€230
C230	Stratford Box and landraise	€160
C240	Stratford to Barrington Road	€190
C250	Ripple Lane to Barrington Road	€200

of the contracts that were based at Stratford was clearly of benefit in developing collaborative working.

Thus, including the Client, the London Tunnels were to be undertaken by a group composed of twelve major civil engineering companies. Together these organisations assembled a team of over 300 staff.

The size and profile of the job also enabled the parties to assign senior directors to the project who were capable of looking beyond purely conventional solutions when the need arose.

1.3 *Contracts and partnering*

The contracts, which included the supply of the tunnel boring machines, were competitively tendered and the bids were subjected to a rigorous examination.

The NEC form of contract was used. This recognized the possibility that the price of the works might change and provided the fundamental flexibility that allowed later modifications to the arrangements. As awarded the contracts had a target cost and included pain and gain share arrangements.

It was made clear from the start that the Client expected the contractors to operate in a spirit of partnering to achieve a successful outcome. The tunnelling contracts included provision of a six month pre-construction period in which the contractor's management and the project manager could work together to develop the planning of the works.

During this period the contractors found themselves deliberately placed in shared open plan offices with their respective contract managers and administrators. While possibly coming as something of a surprise to some this did ensure that people got to know one another and got used to close working with one another from the start. Also, soon after the teams had been assembled, a series of residential partnering workshops were undertaken using external facilitators to encourage the teams to work together. The effect of techniques such as these can sometimes be difficult to assess but it is clear that these measures provided some of the building blocks towards mutual trust and respect that would later be essential to allow changes in the works.

1.4 *Cost, programme and contingencies*

These major soft ground works had a capital value of around €780 million.

The contracts were awarded in February 2001 with completion due in the spring of 2005. The need to procure the six tunnelling machines and to construct the deep excavations from which they would be launched gave a long lead in to tunnelling which would not commence until the autumn of 2002 and would run through well into 2004.

At the contract award stage the project manager also held a contingency of approximately €94 million to cover the risks associated with the work. At about 12% of the tender value this was fairly small for such major underground works. This was planned to cover design development, management of third party interfaces, interfaces between contracts, unforeseen or omitted scope and crucially the geotechnical uncertainties including in particular the risk of tunnelling induced settlement and its consequences.

2 EARLY CONSTRUCTION DIFFICULTIES

2.1 *Problems in Stratford*

When construction commenced problems were encountered at the station site at Stratford. Issues including soil contamination, problems working around live railways, the need for further design development and the management of National Grid electricity transmission lines all gave rise to increased cost.

By mid 2001, when the tunnels contracts started to set up on site, the forecast was that the budget for the London Tunnels would be broken because the contingency funds would have all been spent resolving problems on the station box itself. Thus there was effectively no contingency fund available for tunnelling, yet the outstanding risks included:

- tunnelling in ground largely not tunnelled before,
- tunnelling under thousands of properties,
- tunnelling under many sensitive structures,
- tunnelling beneath live, busy, old railways,
- tunnelling under various metro tunnels,
- tunnelling beneath rivers,
- tunnelling under hundreds of sensitive utilities.

It was immediately apparent that the project was at risk of a similar major overspend to that seen previously on many other urban tunnelling schemes around the world.

The problem was compounded by some newly recognised problems. Many of these related to the geotechnical and structural assessment work which was required to determine the scope of the settlement mitigation needed. The initial assessments were leading to settlement mitigation designs which were proving very expensive and were tending to suggest requirements for greater than expected advance works. In some cases the designers were struggling to resolve issues in time to support the tunnelling programme. Thus there was a danger of the engineering process delaying the works and a strong suspicion that it was not achieving optimum results.

In a number of cases, such as tunnel crossings close under metro tunnels and major piled bridges, the problems were in part due to the lack of previous experience of similar works. Tunnelling settlement assessment is an area of geotechnical work that is not greatly codified and therefore solutions often have to be developed from analysis from first principles tempered by experience. It became apparent that it was sometimes difficult for the contractor's sub-contract designers to optimize this work as they did not have the same financial priorities as the contractors, nor the close relationship with the construction teams that was needed to optimize control of the machines as part of the settlement mitigation.

On top of these problems it was realised that the delays to the station box would result in tunnelling commencing 4 months late.

2.2 *Recognising the need for change*

Given the above and the record of similar situations that have occurred on other large projects things did not look good. There was potential for the project to become a financial disaster. It was recognised that something had to be done which would achieve a step change in the financial performance of the London Tunnels enterprise. All the parties recognised that a fundamental change to the process was needed to recover the situation.

The formation of the London Tunnels Alliance was the response to this.

3 LONDON TUNNELS ALLIANCE (T2A)

3.1 *The Alliance agreement*

The London Tunnels Alliance was established as a commercial alliance of the parties to the CTRL Area 200 (London Tunnels) contracts. It was formed with the simple objective of delivering the works within the available budget and within the programme.

The Alliance had a single budget which became known as "the Pot". This budget was established by pooling the budgets of the four main contracts, together with the contingency fund held by RLE and also the RLE Field Engineering budget. No new funding was available to the team for this work.

The Alliance was governed by a new set of rules enshrined in a formal signed agreement between all the parties to the contracts. This supplemental agreement aimed to remove the need for narrow focus by individual parties. One party could no longer make profit at the expense of another. The key features of the agreement were:

– Removal of contract Compensation Events,
– Removal of the Pain Share arrangement,
– Establishment of a unified budget (the Pot),
– Retention of all other aspects of the Contracts.

The agreement did not convert the contracts into a cost plus arrangement. If the Pot was exceeded there would be no further fee.

Thus the contractors gave up the right to recover additional expenditure needed to complete the works.

Figure 1. An example of the constraints: a shaft site located between two railway lines.

In return they received an enhanced reward for successes achieved. Success was measured through the timely achievement of a series of milestone events through the course of the works. The incentive to work to generate a traditional profit margin on individual elements of work was effectively removed.

The Alliance became commonly known as "T2A", which stands for "Team 200 Alliance" and worked to establish this unified identity through methods such as the use of a common logo.

3.2 *The Alliance methods*

The Alliance team endeavoured to meet its objectives through two main measures.

The first of these was rigorous and positive management of the risks between the parties. The intention was to distribute the risks between the parties so that the most appropriate person or group deals with any given problem regardless of whether they were contractor, designer or project management staff. Nobody gained from attempting to transfer risk to other parties who were less well placed to manage it.

Secondly the Alliance actively sought out opportunities for savings and costs minimisation through cooperation. This resulted in various shared facilities such as the tunnel segment factory at Stratford.

The whole process was steered through disciplined weekly meetings plus ad-hoc meetings when required.

Throughout the whole process a fundamental rule was established that no party within the Alliance should be disadvantaged by anything the Alliance as a whole did. Given that the financial success or failure of all the parties depended on the same Pot this became quite achievable.

4 WORKING WITHIN THE ALLIANCE

4.1 *The Alliance impact on engineering*

The Alliance arrangement had a profound effect on the day to day work of the project engineering teams. The fact that everyone became very focused on optimum delivery of the project raised the profile of the engineering input. With purely contractual mechanisms for making profit removed optimized engineering and production was the best way for everyone to benefit from the project. This was important because many of the outstanding risks to the project related to fundamental engineering problems including in particular the assessment and mitigation of settlement effects.

The design group within the Alliance was able to work very closely with the construction teams to find the right blend of modifications to the construction process and advance works to at-risk structures to minimize the impacts. For example, the close working also made it contractually easy for the design team to direct trial tunnel sections and demonstrations to prove the extent to which the TBMs could be carefully controlled to minimize movement in key areas. This sometimes incurred initial delay to production but as all parties had the same overall objectives for delivery of the works it was not a contractual problem. In the course of the work a great deal was learnt about the optimal control of the machines – to an extent far beyond that envisaged or expected at the planning stage. This learning process resulted in successively better control through the length of the drives and justified a substantial reduction in advance mitigation works in the later parts of the route.

Similarly in critical areas, such as the crossings under other railway tunnels, the non-adversarial contract environment made it easy to form a single team of skilled and motivated staff jointly from RLE and the contractors to supervise and direct the works.

5 THE OUTTURN

At the time of writing the civil works are substantially complete but the London Tunnels Alliance has not yet reached financial completion. This is expected to be achieved in late 2004. However, the overall results are already apparent. The work has been finished early, with the final agreed milestone reached six months early. Production rates have been fast, sometimes reaching as high as 30 m of tunnel in a 12 hour shift. Settlement has been limited to around 0.5% volume loss on average through the drives. The safety record has also been very good. All the works have lower accidents rates than the UK construction industry average while the best tunnel drives have been well under a tenth of the industry average. These results have all been achieved within the original budget. Overall this is a strikingly successful outcome compared with many other major tunnelling projects.

Since the signing of the Alliance agreement in early 2002 there has been no further incursion into the contingency funds. Thus 36 km of large diameter tunnel have been driven in areas not previously tunnelled and entirely under the existing city without exceeding the tender costs. This is a most unusual result and a very positive reflection on the procurement method that was developed for the work. Had the original arrangements been followed it seems certain that the management of settlement risks alone would have incurred a substantial cost overrun.

It is also worth noting another side to the Alliance outturn. The arrangement fostered a distinctive working environment free of many of the pressures often associated with traditional civil engineering contract practices. The engineering team had the refreshing experience of being able to seek the best engineering solutions to problems without being overly influenced by commercial pressures. On balance the participants enjoyed working under the performance pressures of T2A and therefore probably performed to a higher level than might otherwise have been the case. At times it even became fun!

6 LESSONS LEARNT

6.1 *Lessons from the London Tunnels*

"Can be repeated?" is the obvious follow on question to the London Tunnels Alliance experience. The answer is probably not exactly as every project is different and in any case the Alliance was not planned from the start but rather was developed as a response to a particular set of circumstances.

Nonetheless, the Alliance system obviously had benefits and yielded an unusually good result. These arose because all the parties shared the objectives and therefore the risks and were rewarded according to the same measure of achievement. To repeat the close working would require a situation where the parties had complete confidence and trust in one another's capabilities. It would also require everyone to be focused on the risks to the job. Inevitably this is hard to achieve when a team of pre-existing organizations is first brought together (remember; the London Tunnels team had worked closely together for over a year before entering into the Alliance).

There are, however, wider lessons that can be learnt and which could be developed in the procurement of future works. Central to these is the benefit of positive management of risk for major underground construction projects. Under a more conventional contract approach with each party trying to avoid bearing the risk it is likely that the engineering would not have been pushed to the level that was needed to achieve this result.

6.2 *Risk transfer: the traditional approach for underground works*

It is interesting to reflect on other comparable underground construction projects and their outturns. Historically, major underground works construction projects often substantially over run their budgets and timetables. Recent estimated examples include the Channel Tunnel 85% over budget, Jubilee Line extension 65%, Storebelt 55% and Boston Central Artery 200%. Yet these were all jobs with high calibre people, who tried their best. History would suggest that the London Tunnels result could well have been similar.

There can be many factors behind these over runs but there is probably one common feature of this over run and that is that none of the parties gained greatly from the situation. Usually all suffer financially and the Client is particularly heavily exposed. There is another common and fundamental feature in that all these unsuccessful projects were probably procured using the same base model or rules. The basic premise being that all parties attempt to transfer risk throughout the supply chain. However, the statistics clearly suggest that this transfer of risk is an illusion, albeit an initially comforting illusion for the Financiers of projects.

For the vast majority of major construction projects, the quantification of the works (how much concrete, earthworks, metres of tunnel) is known to a high degree of accuracy before the project begins. Likewise, the scope of work is known (what is to be built, how and where and when). Usually, the major unknown is defined as Risk and it is the apportionment of this that often leads to over runs in budget. Very commonly for underground works a large part of this risk is intimately associated with the ground conditions.

Construction companies in the UK generate 2% to 3% profit on turnover, sometimes less, rarely more. This is their raison d'etre and this is what they fight to maintain on a project. This is their focus and yet Clients attempt to transfer financial risks to them far in excess of this. Inevitably the construction companies must respond by resisting this or attempting to transfer risk elsewhere (for example to subcontractors who may then behave excessively conservatively to reduce their own exposure). Responsibilities for dealing with issues become fragmented. The result is consistent cost overruns of the sort described above. Thus the clients' efforts to transfer risk away in these cases clearly brings false comfort.

6.3 *Alternative case histories*

There are many other types of major project where risk transfer has not been attempted (or certainly not to the degree that is traditional in underground construction). How does the outturn of these compare? Two examples are discussed below.

The huge Bluewater retail complex in southern England was built in a deep disused chalk quarry with no pre-existing infrastructure. It was completed exactly to programme in a period of only two years. This result was achieved despite around 200,000 significant variations (essentially changing the retailer's requirements) during the construction period. There was no main contractor for this work. Instead the Client opted to retain direct control and managed all the risks in house. In the absence of any other party to attempt to transfer risk to the focus was clearly on effective resolution of the issues.

Another major infrastructure development is the construction of Heathrow Airport's Terminal 5. Again the Client has opted to retain and manage the main risk issues. The Airport Terminal is predicted to be delivered to time and budget.

The CTRL London Tunnels can now be added to this list of alternative approaches. They represent the most ambitious tunnelling project ever attempted in London (36 km of 8 m diameter excavation under the city in one phase). They will complete 6 months ahead of programme and within budget. The Client retained and managed the risks, albeit through a subsidiary body.

6.4 *Future practice*

The fundamental difference between success and failure in the scenarios discussed above is not the quality of the engineering or the dedication of the engineers. Instead it is the approach to and management of Risk. Where this has been dealt with most positively an environment has been created in which the necessary engineering can flourish. This is a lesson that can be directly applied to the procurement of future works. It is especially relevant in fields such as underground construction where there are inevitably many unknowns and there will be a need to develop an engineering response to situations as they become apparent throughout the period of the works.

For future major projects the Financiers need confidence that the budgets and programme are robust and achievable. They will ask "Why will history not repeat itself?" It is the authors' view that it almost inevitably will if the usual approach of attempting to transfer risk is followed.

Another question that the Financiers should ask is: "Can it be constructed significantly below the present budgets?" The experience of the London Tunnels is that if we remove the illusion of risk transfer and think positively about the optimised management of the inevitable risks we should be in a position to change the business case for some future projects.

7 CONCLUSIONS

The immediate result of the London Tunnels experience has been the successful delivery of the scheme well within the original programme and at the original budget. The fact that the work has been done in ground not previously tunnelled and yet has been achieved with almost imperceptible disturbance at the surface over most of the route is a valuable bonus.

It is also very clear that this result is very much a product of the procurement method that allowed the engineering effort to be as productive as possible. The work was done within a commercial alliance that had a fundamental effect on the way the geotechnical engineering challenges were met. Under the new system the combined team was focussed on identifying the risks and selecting the best-placed group within the alliance to manage each risk. No benefit could be derived from trying to avoid or transfer key risks to others less able to manage them. This in turn allowed formation of a core team of specialist engineers to direct both client and contractor input into the project management of critical works such as tunnelling close under live railway tunnels.

The wider impact of this outturn may be in the planned adoption of similar models to deliver future major underground projects. This in turn should make it easier to promote the benefits of underground construction for major infrastructure works. It is believed that the use of procurement models that promote positive management of risk such as on the London Tunnels will prove to be a key tool in the successful delivery of future schemes. Ultimately it is an approach that has the power to change the business case for future urban tunnelling.

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