



Crossrail project to Elizabeth line operations: Operational approach and lessons learned

Prologue

Authors:



Howard Smith

Elizabeth line
Director, Transport
for London



Martin Stuckey

Operations
Business Manager,
Crossrail

This paper has been written from the Elizabeth line/Crossrail Operations team perspective – the Operations team role is to act as the guiding mind and focus to bring into use and operate the Elizabeth line, liaising with the delivery teams and other operators (e.g. Network Rail, MTREL – the Crossrail train operating concessionaire, London Underground) for operation of the new line.

While the operator's involvement – and the main focus of this paper – particularly came to the fore in the final one to two years before opening of the line in May 2022, the paper also comments on the vital but less resource-intensive activities of the Operations team during the much earlier planning and delivery phases of the programme.

This paper starts by introducing the context for operating the Elizabeth line, then describes the strategic lessons that are considered the key operational learnings from the experience of bringing the Elizabeth line into use, and which are recommended to other operators and delivery organisations developing new rail schemes. The main section of the report is broken down into the key activities of the Operations team and explains the approach that was taken and what was done, linking this to one or more of the strategic learnings. The paper ends with a concluding note.

Introduction

The delivery of Elizabeth line operations from concept to passenger service has ultimately been very successful. The line is a new type of service in the UK, analogous to the French RER or German S-Bahn systems, and brings together (i) major new infrastructure, (ii) new rules and regulations (as it is a unique railway) and (iii) new teams, many of which are themselves new to the industry and/or are part of organisations that have not worked together in a similar formation before. This is almost unprecedented: most new railways involve one or two of these three elements, not all at once. The Elizabeth line was also delivered within the complex UK/EU-prescribed contractual framework, including separation of track and train.

Nevertheless, the Elizabeth line has (by the end of 2022) delivered almost exactly the train service envisaged in the original Sponsors Requirements and at the time of the Crossrail Bill receiving Royal Assent – with the final stage to follow in May 2023. Change to the proposed service has been carefully controlled throughout that period of nearly 15 years within an environment that could have seen significant and damaging ad-hoc adjustments, with the one significant change being the very worthwhile extension of the western terminus to Reading. Initial passenger operations in the Crossrail Central Operating Section (CCOS) from May 2022 were successful in terms of reliability and attracting ridership – the ‘stand-alone’ railway that was operated from May to November 2022 was among the UK’s most reliable – and while through running onto infrastructure managed by Network Rail (NR) is more technically challenging, there is every sign that this too will settle down into a reliable and very popular service, delivering the benefits intended.

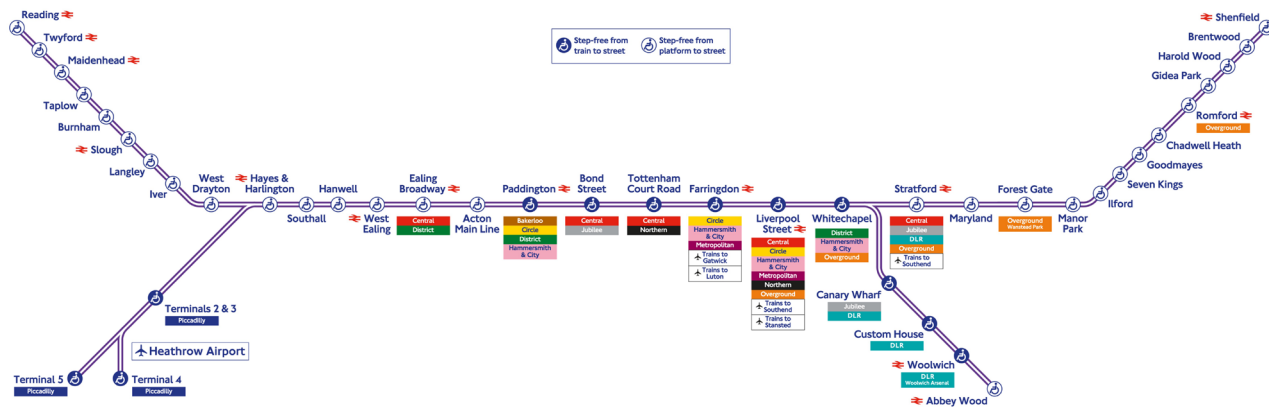


Figure 1

Summary

We have identified seven strategic lessons that have led to successful operations for the Elizabeth line. These are summarised below, with more detailed points set out under 12 workstream headings in the main body of this paper and referenced to the relevant strategic learning (SL1, SL2, etc.).

Strategic lesson 1. Establish and maintain a consistent and coherent vision and specification of requirements based on operational outcomes and customer needs.

The requirements for the operating railway were set out in various formal documents (the Crossrail Act, Sponsors Requirements, Crossrail Programme Functional Requirements and Track Access Option) that applied to the delivery of the project and secured the timetable for operation. Changes to these were rigorously controlled.

Strategic lesson 2. Relentlessly focus on the most important factors for customers and operational staff – ensuring the ‘product’ is safe and reliable.

Long experience and TfL’s own research shows that without safety and reliability you will never achieve high customer satisfaction. With it, you are most of the way there and you can focus more easily on the other elements that really help hit the heights. Ensuring that the product was safe and reliable was consistently repeated throughout all delivery phases over the many years to the various personnel in the delivery organisation and its suppliers.

Strategic lesson 3. Learn from best practice.

The Operations team drew on a range of resources, networks and knowledge to inform the requirements (referred to in point 1 above), the specification of the Crossrail Train Operating Concession (CTOC) and the implementation phase. Many aspects were informed by Transport for London’s (TfL’s) significant operational experience, including the introduction of London Overground services as well as TfL’s membership/formation of the suburban railway benchmarking group with Imperial College London. Independent advisors with expertise in various operational aspects were also drawn on throughout the delivery and implementation phases.

Strategic lesson 4. Have the right team.

The operational team was established to actually operate the railway rather than just ‘shadow operate’. This resulted in more continuity within the Operations team than almost any other part of the project – despite the delays to opening – as people joining the team had their eyes on operating the railway. The team members were appointed on their operational contracts under TfL, which mitigated transition risks in relation to a delivery organisation not having to transfer the Operations team to TfL at the end of the programme.

Strategic lesson 5. Ensure everyone has ‘skin in the game’ and can adapt – the Elizabeth line was a very complex project to bring into use.

As noted in the very first paragraph of this paper, the introduction of the Elizabeth line presented significant challenges and complexity, which were not, or could not be, fully mitigated for at the outset. The ability and capacity to respond to issues that arose was a key factor for operational activities in three areas in particular.

- For the two key operational contracts (CTOC and rolling stock and depot), long-term views were taken in their specification, which supported both suppliers being able to take a longer-term view to work with TfL to overcome issues that arose (e.g. in support of adapting the opening strategy to mitigate delays to customer and revenue benefits from the 2018 delays).

- Rail for London Infrastructure (RfLI) operations and maintenance resources were appointed in readiness for a 2018 opening. The delays then and afterwards, as well as the uncertainty over the actual opening date, resulted in loss of staff/competence due to a lack of flexible options to redeploy staff for the interim period until opening.
- Flexible resourcing contracts were in place and proved invaluable to supplement resources (and cover vacancies) to overcome the issues that arose and to provide resilience for opening.

Strategic lesson 6. Ensure there is sufficient time and capacity to learn and familiarise personnel prior to opening the railway to passenger use.

Trial Running and Trial Operations were always the planned final phases before opening the CCOS to customers, and these provided the opportunity to demonstrate that the railway would be reliable and for staff to undertake various exercises to ensure that passengers would be safe. It ultimately took 14 months from the start of Trial Running until passenger service (although this period was significantly disrupted by various blockades to complete work on the railway), which provided the opportunity to undertake tests, trials and exercises. There were very detailed plans about what would be done each day during this period, but the goal for the period ultimately was for operational (and maintenance) personnel to develop confidence in the assets, the railway system as a whole, the processes used and their colleagues. This was so that appropriate actions and responses to situations could be taken without prolonged consideration. As the period of Trial Operations evolved, it became increasingly apparent that the building of confidence could not be prescriptively scheduled, nor was it a linear process, and as such the focus increasingly turned to identifying learnings collectively and replanning accordingly.

Strategic lesson 7. Collaborate with delivery activities and personnel, and lead the bringing-into-use phase.

There was always an operational presence within the delivery organisation – which was essential from the start – and this creates a tension: “have built it / finished, I am now leaving” by delivery folk versus “but you haven’t given me everything I want” from operators. It became increasingly apparent after 2018 that there would be no success for any party unless the railway worked and would be safe and reliable. It was also then obvious that the ‘big bang’ approach to opening that had been pursued up to 2018 would lead to the highest cost and longest timescales to implement, and thus a pragmatic approach was required. This involved a change of mindset and collaboration between all parties and a clear understanding that we sank or swam together – ‘owning the whole’. This was not a quickly won change, and interestingly the pandemic – while creating a range of significant new challenges – proved a bit of a boost to achieving this change of mindset.

The final aspect of working within and with the delivery organisation is that at some point operations needs to take the lead – but not so soon that there is a ‘tail’ of delivery activity that operators are not suited to implement, or which requires significant access (and blockades/closures).

Operational workstreams

1 Establishing clear operational requirements that deliver to the needs of sponsors and customers

Sponsor requirements were written by an operator, who then played a progressively more important role in the implementation of the project. The requirements were written as outcome based and were formally set for the project. They stood the test of time, although interpretation as to how they could be delivered required strong operational influence in the design/delivery phase. (SL1)

The service pattern, with a limited number of branches and a defined geographical extent, was set (with operator input) before the bill stage. This was a vital foundation and meant that timetables and the customer proposition could be developed on a coherent basis. It's worth noting the Elizabeth line closely resembles French RER or German S-Bahn systems in mixing suburban and core metro operations, and this philosophy – and geography – has been maintained throughout, from design to passenger service. (SL1, SL2, SL3)

To ensure that the huge investment in the Central Operating Section (CCOS) could be used as anticipated, TfL worked with DfT and was granted 30-year rights (the 'Track Access Option') for operating the Elizabeth line and transfer of parts of the Greater Anglia (GA) and Great Western franchises. This not only provided certainty but also had the benefit of defining early and very clearly the service pattern that would be provided, and thus a sound basis for planning the remaining elements of the project and also other operators' services complementing the Elizabeth line. (SL1, SL2)

The Operations team, working within the delivery organisation, defined the customer proposition and successfully brought forward (albeit a relatively small number of) initiatives to cover key gaps from a customer perspective that were identified after the Crossrail Act was approved and which were not in the original Sponsors Requirements. Delivering these outside the Crossrail (CRL) delivery organisation avoided the difficulties of increasing the scope of a programme in delivery, but required additional capability and funding that was progressed by the Operations team. (SL1, SL2, SL3, SL5)

- On-Network Station Improvement Programme, which delivered consistent minimum standards end to end and a line-wide TfL identity, as well as delivering step-free access at the seven stations that would otherwise have not been step free.
- Liverpool Street mainline station platform extensions, without which there would have been little or no ability to operate at all with the CCOS closed, and which also enabled the flexibility required for revising the opening phasing to support introduction of through running into the CCOS outside of a timetable change.
- Additional rolling stock to support extensions to Reading, operation of a uniform fleet, and 'hot spares' to support operational reliability (although pre-priced options were included in the rolling stock procurement contract for this eventuality).
- Plumstead maintenance sidings and maintenance depot (which were not included in the original plans, where it was assumed that infrastructure maintenance would be provided from NR depots away from the CCOS).
- Ticket gating to support use of integrated ticketing/Oyster card on stations operated/maintained by other operators.
- 'Red Thread' design activity and application. The establishment of the Crossrail Design Panel, chaired by the Chief Operating Officer (COO) and attended by the Head of Architecture, TfL Head of Design and CRL Board members, provided a valuable focus and coherence to what could have been a fragmented identity.

2 Defining and implementing a strategy for opening and then following it in the light of issues arising, risk and uncertainty

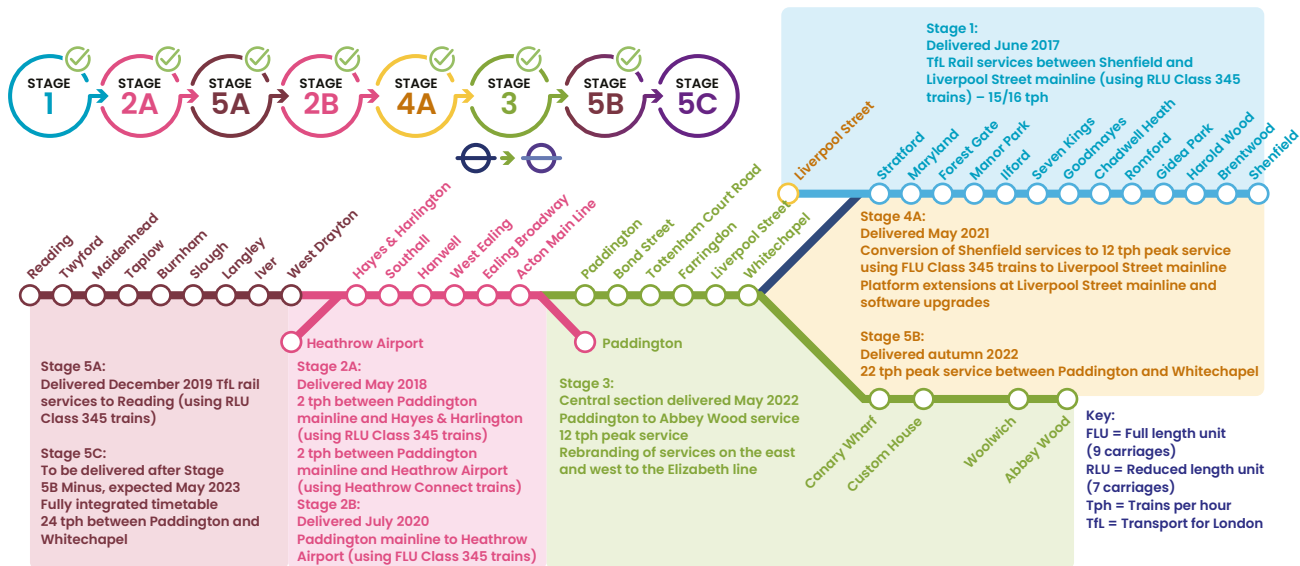


Figure 2

The very significant risks in adopting a ‘big bang’ approach to opening were avoided by defining a staged opening (which introduced a contracted train operating company early together with phased introduction of rolling stock, initially on the surface railway, and a phased connecting-up of east, central and west routes). (SL2, SL3, SL5)

Customer/revenue-driven focus was key in light of delays that emerged in 2018 to introduce revised phasing with new phases introduced that enabled: (SL1, SL4, SL5)

- extension of operation to Reading, known as Stage 5A, in 2019
- operational resilience and flexibility for future opening stages through platform extensions at Liverpool Street mainline station and timetable reconfigurations, known as Stage 4A, in May 2021
- end-to-end operation (known as Stage 5B Minus) within six months of opening Stage 3 while also achieving flexibility over its precise date outside of national timetable changes (noting that additional considerations were introduced to revising timetables as a result of serious issues with the Thameslink and Northern timetable changes introduced in 2018)

An ‘Earliest Opening Programme’ was considered following on from the delays announced in 2018 (see also lessons-learned paper on recovery for the delivery perspective). This identified and considered various combinations for opening the CCOS – including how many and which stations would be required as a minimum – and also (briefly) considered passenger operation on only a part of the CCOS. The complexities of the systems in the CCOS ultimately led to the conclusion that these needed prioritising, and the strategy followed was to introduce testing/Trial Running over the whole CCOS, with the stations progressively achieving readiness states that would support through running first. (SL2, SL4, SL5, SL7)

3 Agreeing the organisational structure and responsibilities for operations and establishing them

As part of the agreement between government and TfL, it was decided a concession contract would be let for operation of the trains and management of (some) stations using the model successfully established for Overground. It was also agreed that NR would be the Infrastructure Manager (IM) for the CCOS and London Underground (LU) the IM for the five stations that are (very significant) expansions of stations it already operates. (SL3, SL4, SL5).

CRL recommended, and sponsors agreed, to change the IM for the CCOS from NR to RfLI (a new TfL subsidiary organisation) in 2013, to reduce risks associated with acceptance of the CCOS, as NR did not have specialism or focus on metro tunnel operation and maintenance. This required establishment of RfLI as a new organisation with opportunities to set up an organisation from scratch that supported a strong customer focus with its own culture but equally presented challenges to overcome in terms of building expertise and knowledge in parallel with a new set of assets that have no operational/maintenance record (with more details covered under various issues below). (SL2, SL5, SL7)

4 Defining the rules and processes for operation

Elizabeth line CCOS operations combines elements of both National Rail (through services mainly on NR tracks, mainline railway trains, 25kV electrification, conventional signalling) and LU (21km of central tunnels, 24 trains per hour (tph), Communications Based Trains Control (CBTC) signalling and platform screen door operation). The philosophy that was adopted was to take the National Rail Rule Book as a base, and the Operations team then worked, very successfully, with the Rail Safety and Standards Board to write the new Rule Book and procedures and manage their acceptance. A similar 'line-wide' approach was taken to the Driver Only Operation (DOO) systems, notably DOO CCTV, where an in-cab leaky feeder-fed system from platform-mounted DOO cameras was needed for the CCOS (because of the use of platform screen doors (PSDs)) but also adopted for the surface stations. (SL2, SL3)

5 Specifying, procuring and bringing the rolling stock into use, including its maintenance and depot construction

As the rolling stock contract is a 30-year design, manufacture, maintain arrangement, it made sense for it to be contracted within TfL – the party that would have the long-term relationship. Nevertheless, it had to be closely managed as part of the overall Crossrail delivery project and was therefore integrated into CRL's programme reporting and controls. (SL4, SL5, SL7)

The specification of the train was a complex process but again has very largely stood the test of time. A key challenge was making the train equally suitable for medium-distance suburban/surface 90mph running and metro-style high-capacity/high-frequency running in the CCOS. This has been a challenge to RER/S-Bahn systems, and was achieved in the case of the Elizabeth line by the specification of a regular three double doors per carriage (different to standard UK practice of two sets of doors at 1/3 and 2/3) and also careful design of the interior layout, with wide circulating areas round the doors, a careful mix of longitudinal and 'bay' seating, and physical and visual 'cues' designed to move people away from the door areas. (SL3)

The interior design of the trains was led by TfL in collaboration with the train manufacturer, and with the support of a third-party design agency that helped to deliver a much more considered interior ambience than is traditionally applied to commuter/metro vehicles,

with colours ranging from darker shades at ground level to lighter ceilings, carefully diffused lighting, high-quality stainless steel fittings and careful colour contrasts, meeting the requirements of those with visual impairments but without the heavy use of orange and yellow, which gives many buses and trains a 'climbing frame' ambience. The rolling stock procurement contract included a 'permitted design change' principle that allowed TfL to develop the manufacturer's standard interior designs to deliver a train uniquely tailored to the Elizabeth line. (SL2, SL3)

Consideration was given at specification stage to whether toilets should be provided on trains or on stations. It was decided that on/near-station provision was the best answer, given that these were metro trains with a short average journey length and that toilets would take up significant space within the overall train. Toilets were therefore provided at 34 of the 41 Elizabeth line stations, including virtually all surface stations where longer journeys begin and end. (SL2)

The train is in many respects 'the integrator' of the various CCOS and surface systems, including the three signalling systems (European Train Control System (ETCS), CBTC and 'conventional' Automatic Warning System (TPWS)), the PSDs, radio (GSMR), Supervisory Control and Data Acquisition (SCADA) and power supply.

The procurement exercise was run by CRL to TfL's specification and five parties initially bid, reduced to four (with the withdrawal of Alstom) and then to three (with the withdrawal of Siemens). The competition was won by Bombardier (now Alstom) with the first production of its new 'Aventra' platform. Its train was the most 'track friendly' of the three bids and had the lowest long-term costs. The contractual basis and risk allocation have remained as originally envisaged. (SL7)

The rolling stock and depot build-and-maintain procurement was launched envisaging a PFI-style 'service provision' contract and with manufacturers obtaining financing. After the first round of bidding the sponsors changed to an outright purchase structure and the bid process was rerun. Notwithstanding, CRL delivered contract signature on time in 2014. The train itself was approximately one month late entering service for Stage 1 of the Elizabeth line (June 2017) using conventional signalling (due to train software and regulatory approval delays), and was 18 months late (to the original sponsor requirement) entering service to Heathrow using ETCS signalling. (SL2)

The technical complexity of integrating three signalling systems on the train, and the duration of testing and compatibility-proving needed between the trains and infrastructure systems, presented major challenges to train readiness. This led to the need to prioritise CBTC over ETCS to support the critical CCOS programme. The delays to the CCOS infrastructure and systems meant the train could not be tested in the CCOS in line with the original schedule.

The complexity of the train systems, especially the software controlling the three signalling systems and the overall train control software (TCMS), led to low reliability, which has been successfully mitigated to support entry into passenger service while defects are progressively fixed; although, with a high level of redundancy, most failures can be recovered fairly swiftly by a system 'reset' by the driver. This remains one of the key reliability drivers of the overall railway. (SL2)

A new fleet maintenance depot at Old Oak Common was bundled with the rolling stock procurement. The depot layout and principal features were specified by TfL based on depot operations experience, and the detailed design and construction was carried out by the rolling stock manufacturer and its civil engineering and depot systems subcontractors. The benefits of this process were using the TfL concept design to obtain planning consents in advance of the depot procurement, to de-risk the programme, and a depot design perfectly matched to the maintenance needs of the new trains.

Old Oak Common Depot was brought into use in stages starting in March 2018 and was fully operational by July 2018. This was two months later than the original programme due to sponsors agreeing to temporarily pass a parcel of depot land to NR in connection with the decommissioning of an adjacent railway facility. This required a substantial re-phasing of the new depot construction. (SL5)

6 Specifying, letting and managing a contract to manage train (and station) operations

We used the experience and knowledge from management of the London Overground concession, which was let around seven years in advance of the concession for the CTOC – which commenced operating inner GA services from May 2015 (providing a network to facilitate driver training and rolling stock introduction). Key points included: (SL3, SL5)

- No revenue risk. Service delivery-based payments that incentivise delivering reliability, recovering the service (whichever party caused the failure) and a basket of customer satisfaction/revenue indicators.
- Incentivisation to ensure that industrial relations risks are managed and that there are sufficient drivers. The CTOC 'inherited' drivers from previous TOC(s) but needed to build a significantly larger workforce to support the expansion of services for Elizabeth line operation.
- The duration of contract was set for full staged opening (assumed end 2019) of Crossrail plus three years, with further extension option.
- Some flexibility within the contract to vary for provision of minor works – noting that the core operational incentives/obligations in the contract should minimise adverse impacts to operations from doing any works.

7 Establishing the infrastructure maintenance and operations organisation (Rail for London Infrastructure, RfLI)

RfLI – a new infrastructure management organisation – was appointed to manage the CCOS, as described in workstream 3 above, which was established from scratch.

The opportunity was taken to try to radically update the operations and maintenance concept compared with existing systems. (SL1, SL3)

Multiskilling was the preferred approach wherever possible and has been more successful within operations than maintenance. (SL5)

In maintenance the approach has been condition-based rather than time-of-failure-based reactive maintenance, using the large amount of data and remote condition monitoring available. However, the asset data has, as on other projects, proved to be the most challenging part of the completion and handover process, and condition-based approaches require an understanding of wear and a maturity of the infrastructure that has not been fully realised to date. (SL3)

One of the most significant changes to maintenance practice compared with existing UK infrastructure managers has been the elimination of Red Zone working and the use of handheld devices that form part of the signalling system to lock out sections of track and take and hand back nightly possessions. (SL3)

Recruited with expectation to train and establish a 'new culture'. (SL3)

Lead time for competency and delays impacted skills retention. (SL5)

Because the CCOS (and RfLI) use a heavily adapted version of the National Rail Rule Book, many competencies differ from their NR or LU equivalents. This imposed a heavy burden in terms of bespoke training and assessment and a difficulty in keeping up competencies. A dedicated training facility was established by repurposing the former Tunnelling and Underground Construction Academy (TUCA). (SL5)

There were also challenges in training in advance of having infrastructure available, requiring the initial group of Traffic Managers (signallers and power controllers) to achieve competency largely on the basis of simulators, and familiarisation of maintainers was only possible quite late in the handover process. (SL5)

Because of slippage to the project timescales (notably the delay announced in 2018), a significant number of staff were taken on earlier than required, leading to skills fade and some leaving before starting their substantive roles. (SL5)

Specialist yellow plant was identified as necessary to enable the maintenance of the CCOS and milling machine, and infrastructure monitoring vehicles were procured that use leading technologies to provide very efficient maintenance and inspection. These are complex tools and required significant effort to integrate and test along with the Class 345 passenger trains. (SL3, SL7)

8 Working with(in) the delivery organisation – role of Operations team – and working with external operational parties

It was helpful that the COO, as the senior operational voice and guiding mind, was appointed reporting to the CRL Chief Executive Officer in 2013 and was a member of the Crossrail Executive team. (SL7)

There will always be tensions between the delivery organisation and the receiver/operator, but these were generally at an acceptable level – although with particular challenges in the period immediately before and after the announcement of the delay in 2018, when there were tensions in almost all relationships within the overall project. After the reset in 2018–2019, things were much more collaborative, and there was a clear focus on meeting the requirements of the Infrastructure Manager and operators and a recognition that the project could only be a success once it was integrated and delivered a high-quality operational railway. (SL7)

Collaborative working with the delivery team led to a number of benefits in terms of being able to take advantage of opportunities arising from its activities (e.g. TUCA was transferred and converted to a wider training facility, storage facilities were created for spares). (SL7)

Operations defined and led a countdown process to Stages 1, 2, 4A, 5A, 3 (from Trial Operations (TO)) and Stages 5B Minus and 5C. This included, for Stage 3, decisions to phase TO into two phases and adding a timetable demonstration phase. Countdown to Stage 3 Trial Running (TR) was led jointly by Delivery and Operations. (SL2, SL5, SL6, SL7)

There were various iterations of governance around the project and operations, but success was driven less by structure than by the relationships and experience of those involved. The senior leadership of the project post-2018 had much greater experience of the integration and commissioning phases of railway projects and the need to bring all parties to a joint success. (SL7)

A Systems and Operations Advisory Panel was established to challenge and advise on scope of operational activity. It was largely helpful and brought external perspectives and experience from other projects, but, like other aspects of Crossrail governance, could lead to repeated discussions of the same issues in a number of different forums and required quite an effort by the executive to provide information and briefings. (SL3, SL7)

Work with other Infrastructure Managers was relatively late to hit its stride, as the project organisation dealt with NR largely through the On-Network Works and RfLI was embryonic for the early part of the project delivery period. NR had many interfaces both in terms of adjoining IM (east and west) and also in terms of timetabling, and provision of national systems such as GSMR – and in its day-to-day relationship with CTOC, which was operating services on the surface sections from May 2015. The IM and operational activity and co-ordination came together from 2020–2021 as day-to-day involvement with NR and LU was increased through testing and then – successfully – through Trial Running and Trial Operations. The fully integrated T-minus countdowns (to commence the next phase) embedded more of a culture of joint endeavour and ownership. (SL4, SL7)

9 Accepting CCOS infrastructure into use

The infrastructure handover approach broke the railway down into 27 elements, so that it was manageable and divisible but in coherent parts that could be integrated and tested. This approach generally worked well. (SL7)

Considerable tension occurred with the initial, precedent-setting, handovers. This was significantly exacerbated as a result of the delays to the programme – where operator personnel involved in acceptance had lost trust in the delivery team as a result of feeling let down and disappointed by cumulative delays in the programme and unmet ‘promises’ to complete the assets by certain dates. The result was that the bar set for Handover, which included provision of all the records (e.g. asset data, operational and maintenance manuals), meant communication was very transactional. This only changed when both the delivery and operator personnel started to trust each other, which occurred through changes of personnel and the personal drive and willingness to collaborate by some individuals in key positions, as well as the ‘reset point’ to ways of working, triggered by the pandemic, which catalysed the ‘we are all in this together’ spirit. Once this collaborative approach was established, it led to achieving ‘beneficial use’ for a number of the assets whereby operators could become familiar with the assets in practical terms while the records were finalised in parallel to achieve a Handover. (SL2, SL7)

Senior intervention, focused on the overall outcome for TfL, was employed, which also assisted with the possibility of ‘star chambers’ being used. This helped move things to a conclusion, which was good, as only a fraction of the potential issues could have been handled at that level. (SL7)

Ultimately the receiving parties (RfLI, LU and CTOC) had an effective veto on safety grounds, although the process of commenting on handover documents became very transactional and needed common-sense senior intervention focused on risks to bring it over the line. (SL2)

10 Testing and commissioning the railway

- Running test trains while construction continued.
- Placing a railway into use according to the Office of Rail and Road (ORR) requirements (the Railways and Other Guided Systems Regulations (ROGS)).
- A period of Trial Running including managing access for remaining construction work.
- A period of Trial Operations including operation and emergency exercises using volunteers.

Four months were assumed in the initial plan (firmed up between 2008 and 2010) for commissioning Stage 3 (three months TR and one month TO), which assumed a clean handover of the full railway. In fact, 14 months were required including significant effort to undertake trials, iterate and build reliability in parallel with managing works needed to enable passenger operation. (SL6, SL7)

The Trial Running railway was still very immature and subject to significant technical upgrading and change. A cautious safety-first approach was taken, building up from an initial 4 tph to the full pre-service levels. (SL2, SL6, SL7)

A dedicated team for Trial Operations was established by the Operations team, which paid major dividends, and this team took control of the plan for all activities that were to be undertaken once this phase had commenced. (SL4, SL7)

Trial Operations was, however, conceived of as taking place on a technically and operationally mature system; in practice there was much more learning during Trial Operations. The challenge wasn't so much to invent exercises and create opportunities for rehearsing responses to disruption – the disruption was there 'naturally' at that stage. So, the challenge was then how to avoid overwhelming and burning out new staff and how to share lessons learned effectively, especially with six or seven shifts of staff covering 24/7 operation and partners such as NR and CTOC learning too. (SL5, SL6)

For the countdown between stages, a high-level and high-profile T-minus approach was taken, involving all the key operational parties, at senior manager and director level, and chaired by the CRL Chief Operating Officer in TO. It was used to ensure the receivers were in charge of the process rather than those handing over the railway. This worked well. (SL6, SL7)

The other successful elements of T-minus were keeping it to a sufficiently high level to ensure all areas could be covered at each weekly meeting; clear thresholds, although with a common-sense rather than 'hair trigger' approach to their use; self-declaration by accountable directors rather than 'inquisition'; a 'red is good' approach, where a culture was developed where it was seen as laudable to highlight issues so that help could be offered and plans supported; and an 'own the whole' approach to the product, the 'safe and reliable railway'. (SL3, SL7)

11 Building reliability

The Elizabeth line is an unusual railway in the complexity of predicting and achieving reliability, as it spans significant new infrastructure and trains as well as long mileage on existing and upgraded existing infrastructure, and also has complex transitions between signalling systems. The overall reliability requirements for the CCOS were derived from end-to-end modelling used in supporting the grant of the track access option. (SL2)

These CCOS reliability, availability, maintainability and safety (RAMS) targets were in turn broken down by component systems to build overall reliability. However, elements of the systems were brought into service at different levels of maturity, and the train and signalling suffered particularly from software bugs that took time to resolve given the life cycle for changes to safety-critical 'SIL 2 and above' systems. (SL2)

In addition, the existing infrastructure and services interacting with the Elizabeth line performed differently from those modelled inputs from nearly 10 years before, so the reliability modelling and actions needed to continually be updated and revised. (SL5)

A Reliability Board was created involving all of the key parties involved in operations (CTOC, NR, LU and RfLI as well as the Crossrail project team) and chaired by the COO. The main train and systems suppliers either attended directly (Siemens and Bombardier/Alstom) or were represented by project managers or engineers. (SL4, SL7)

During Trial Running a weekly Reliability and Resilience Delivery Group was initiated, based on a weekly cycle and focused towards immediate actions to address current issues. (SL7)

A dedicated reliability team was established and was present on a shift basis in the Route Control Centre throughout the mobilisation and initial operating period, providing in-depth analysis, particularly of complex system-related issues such as train and signalling software and platform screen doors. (SL5, SL6)

12 Governance and transition/management into full operation and business as usual

The principle employed was to appoint all business-as-usual (BAU) personnel to their 'home' department/organisation (rather than to a team within the delivery organisation) and promote a collaborative approach with the delivery organisation to collectively bring the railway into use. This established a business-as-usual function in good time for opening (many RfLI personnel were in post by the end of 2017 – some four or five years in advance of the CCOS actually opening, which, of course, created its own problems with staff and skills retention) and ensured no transition was necessary. (SL4)

Similarly, a systems programme was established in 2016 that built the various management systems (e.g. for asset management, competency management) on TfL's IT estate, which again meant no transition of IT systems was required – although the asset information developed by CRL did need to be transferred, which was done progressively as it became available and was finalised. (SL4)

The Operations team worked under the governance of CRL during the delivery phase of the programme, which operated under authority delegated by sponsors. The various directly contracted TfL resources (e.g. RfLI personnel and the contracts for the trains and operating concession) were approved and managed in accordance with TfL's 'business as usual' governance. Working under the delivery organisation provided benefits, as decisions could be made and implemented swiftly, as that is how CRL set itself up; but the interface with TfL-contracted resources did present challenges as pre-2018 CRL tended to perceive these resources as an external supplier rather than people who would actually be operating the railway. This also led to tensions as to what should be funded by CRL and what should be funded by TfL, and sponsors' opinion was sought on a number of occasions as to which was the responsible party. The change in governance in 2020 to TfL managing the programme brought both of these governance routes together and also provided the focus to bring the Elizabeth line into use. (SL7)

A budget was identified and secured for operations activities at the outset of establishing the function within CRL, which was not fully detailed initially but proved essential to enable the team to be built and be able to respond to emerging items and issues. Flexible resource contracts (for project or bringing-into-use purposes) were established to support response to emerging issues and accommodate the issues arising from delivery complexities and delays. Resource contracts and non-BAU personnel for the Operations team were sourced via both CRL and TfL. This added complexity but provided options. Resource management was a vital activity – in terms of mobilising teams as well as responding to issues and risks and adding resilience. It was given a dedicated focus within a business management function with knowledge of and links into both the delivery and operator BAU processes, organisations and personnel. (SL5)

Some contracts were let via TfL rather than CRL. This was the right approach for the major contracts for CTOC and the rolling stock and depot (RSD), as TfL is the owner of the key obligations, costs and revenues associated with them, but it was important that governance of those TfL contracts that had deliverables necessary for CRL's performance was managed day to day within CRL's programme controls (rolling stock being the obvious example for integration and commissioning of the CCOS). (SL4, SL7)

Transition and demobilisation activities were initially led by CRL. (SL4, SL5, SL6)

- In anticipation of a 2018 opening, the demobilisation of staff commenced as early as 2016 for some of the central support functions (e.g. Commercial, Programme Controls).
- During 2020 CRL established a transition workstream – the right thing to do, but principally with too many personnel involved (e.g. external consultants with no previous involvement in the programme) who lacked knowledge of or ownership/accountability within TfL. The transition worked better with fewer people involved, who had a good understanding of TfL and its organisation, and using simplified methods that promoted close interaction between ‘givers’ and ‘receivers’ of knowledge, activities or personnel.

It was recognised both that the opening of the Elizabeth line and evolving it to full end-to-end operation were significant changes to manage, and that it would take many months to establish operations truly as ‘business as usual’. Additional resources (particularly drawn from personnel already involved in some way within the programme) were deployed to provide a heightened level of resilience in the preparations for these phases, during them, and during their early bedding-in. This also considered the impacts of sickness (COVID-19 still provided a material risk) and more latterly industrial action, which also impacted operations and preparations for Stages 5B Minus and 5C. (SL5, SL6)

Conclusion

This paper has identified seven strategic lessons that are recommended to operators and delivery organisations that are developing, or wish to develop, new rail schemes. It is considered essential that the operational guiding mind is established at the outset. The operator’s role is to champion the customer and the operability of the project. The resource-intensive effort of operators is at the end of the project (and beyond for day-to-day operations), but this role is ultimately absolutely critical throughout the whole development and delivery phase of a project if its benefits are to be fully realised.