



INDEPENDENT CROSSRAIL SCHEDULE ASSURANCE REVIEW

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Author: John Boss

CLARIFICATION NOTE: The Independent Crossrail Schedule Assurance Review was carried out by John Boss Consulting B.V. between August 2018 and September 2018. The report was submitted on 1 October 2018 and subsequently re-issued on 21 November 2018 to correct a factual error.

Executive Summary

Background

John Boss Consulting B.V. has been asked to conduct an independent Schedule Assurance Review (SAR) and provide an opinion on the integrity of the revised schedule proposed by CRL for the Stage 3 opening, as well as plans for the commencement of Stages 4 and 5 services.

CRL has provided three scenarios for the revised schedule. The independent Schedule Peer Review (conducted by Ian Rannachan [16]) also provided a revised schedule. These are shown on the figure below. For the purpose of this review, these schedules shall be referred to collectively as the Revised Schedules, and individually as Scenario 1, Scenario 2, Scenario 3 and ISPR.

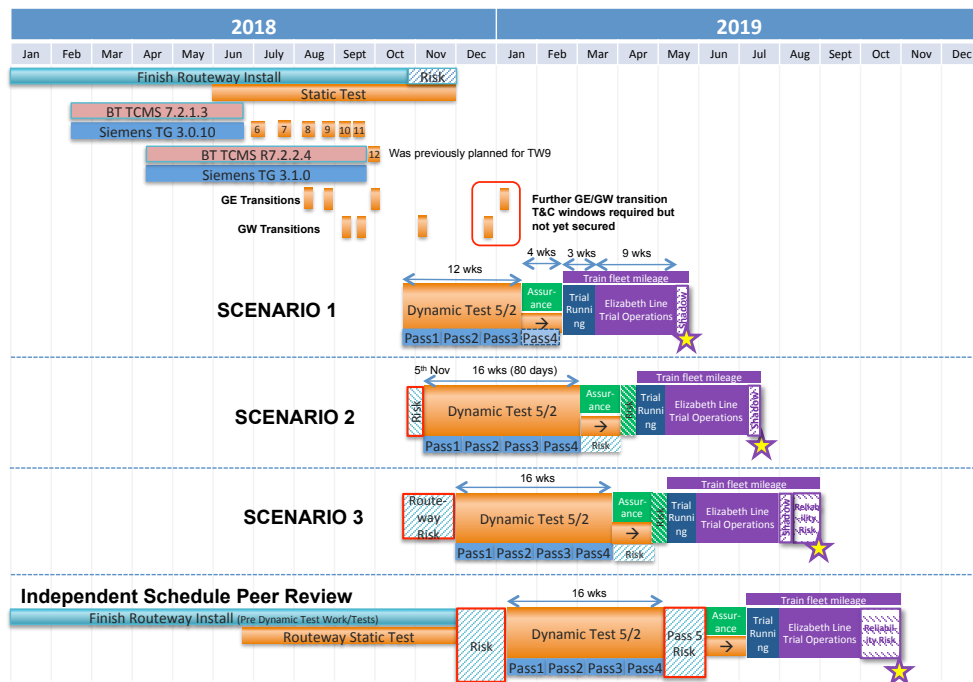


Figure 1: Revised Schedules for Stage 3 opening

This report will not comment on the causes of project delay to date, except to the extent that past performance of any particular contract may provide insight into the potential future delivery. The review was conducted from the point of view that “we are where we are” - and the must now look to determine the best path forward.

Headline Messages

- 1) There is confidence in the project organisations that an opening in the Autumn of 2019 is achievable, a view which is supported by this report.
- 2) It is not possible at this stage to determine exactly when Stage 3 can be opened, but that should become apparent two months into Dynamic Testing.
- 3) Scenario 2 is not realistically achievable, but remains a valid mechanism for the purpose of driving the project.
- 4) The Train should be put into COS as soon as possible.
- 5) Start of Dynamic Testing will be delayed due to need to grow functionality and reliability.
- 6) Opening of Stage 4 and Stage 5 will be predominantly driven by reliability.
- 7) Opening of stage 5 can be significantly de risked through operational mitigation measures.

Response to specific aspects of the review brief

The brief for the review noted 9 specific aspects.

Review Aspect 1:

Is the programme logic robust?

Response summary

The general strategy (clear the routeway and then get the train running on COS) proposed in each of the revised schedules is sound).

ISPR presents an additional logic constraint, being the completion of routeway install prior to commencement of Dynamic Testing. This is not appropriate from the perspective of operation commencement.

The Strategy should include starting testing of class 345 in the COS as soon as possible.

The Strategy should include running class 345 in COS as often as possible. (refer section 2).

Review Aspect 2:

Are the assumptions and durations realistic??

Response summary

The duration required by C660 for completion of radio and SCADA is a threat to achieving Stage Completion, and ultimately Stage 3 opening. Mitigation measures must be carried through. (refer section 3.1)

It should be possible to free the routeway for class 345 testing by the end of October or very soon thereafter. The duration for completion of routeway as presented in ISPR is realistic. However, the approach recommended in this report is to clear the routeway to allow for testing class 345s in the COS as soon as possible. The decision to commence clearing the routeway should be driven by the need for works trains, rather than by overall completion. Remaining routeway works will then need to be completed during engineering hours or on weekends. (refer section 3.2)

The assumption that Dynamic testing can begin immediately upon availability of the COS is not realistic. It is highly likely that a period of functional development and reliability growth will be required. The transition to start of Dynamic Testing will need to be pragmatically arranged to ensure Dynamic Testing (or test cases therein) can be started at the earliest opportunity. (refer section 4.1)

The four month duration allowed for the Dynamic Testing does not appear realistic. The available testing time itself is tight. There appears also to be a structural concern with technical back office turnaround time. It is not possible (at this stage) to confirm that all necessary testing will be completed within that four month period. No one knows exactly what will happen when the 345 is run in the COS. The actual duration will naturally depend on how successful the tests are first time and the complexity of the solutions required to fix problems. It should become clear how long the tests will take within two months of commencement of the Dynamic Testing. (refer section 4.3)

The duration for assurance completion appears realistic, but will need to ensure it has sufficient staff available when required. (refer section 3.4)

The duration for Trial Running is the bare minimum, but appears realistic. (refer section 3.5)

The duration for Trial Operations appears realistic. On-going monitoring of the Stage Completion dates is required to ensure dates remain staggered, or more time is allowed for Trial Operations. (refer section 3.6)

Review Aspect 3:

Are the dependencies and risks understood and plans for mitigation identified wherever appropriate?

Response summary

Dependencies are well understood.

Risks are well understood.

Mitigation plans have been identified and implemented where possible.

Review Aspect 4:

What is the overall level of confidence, current concerns and any opportunities to improve on current plan?

Response summary

The overall level of confidence could best be described as a cautious optimism. All persons interviewed considered Scenario 2 to be aggressive and overly optimistic. There was little confidence that the Dynamic Testing would be completed in 4 passes. There was a good level of confidence that an opening of Stage 3 could be achieved in the Autumn of 2019.

The most significant concerns were:

- Reliability of the rolling stock,
- Involvement of CRL in Systems Integration
- Completion of code for Signalling and Rolling Stock
- Completion of C660 (SCADA and Comms).

CRL must more actively participate in systems integration. The role of Lead of Systems Integration should be end responsible for the delivery of a Crossrail as a working integrated transportation system. The Systems Integration Team acting under the Lead for Systems Integration, must have boots on the ground and be the beach master for tests that span systems (including rolling stock and Network Rail). (refer section 6)

See also recommendation.

Review Aspect 5:

Is there a credible plan and schedule from the start of Dynamic Testing (5 days per week planned from about 22nd October) to the opening of the railway to underpin the broad strategy under discussion?

Response summary

There does not appear to be a credible plan for delivery for the Dynamic Testing (refer section 4.3).

The process for Trial Running preparation needs to be restarted to develop the final test scripts and fine tune the acceptance criteria. (refer section 3.5)

Both RfL and LU had a clear agenda and series of activities that were to be undertaken during Trial Operations. Work is well progressed on the detailed planning. (refer section 3.6)

Review Aspect 6:

What is the current status of the Infrastructure Managers (IM's) in terms of their readiness?

Response summary

IMs are well prepared. RfLi have sufficient trained staff and are being involved with project delivery to ensure familiarity with the equipment.

Contract changes have been arranged with the existing LU maintenance contractors to address maintenance on the LU stations. The execution of these contract changes has been put on hold awaiting a confirmation of final opening date. (refer section 5)

Review Aspect 7:

Is there a credible plan to deliver the necessary documents to all the IM's to allow them to accept Staged Completion and Handover?

Response summary

There is a credible plan for the delivery of all necessary documentation. The delivery is running behind schedule (as a consequence of the overall delay). (refer section 5.3)

Review Aspect 8:

Is there an appropriate level of schedule risk allowed in the current plans?

Response summary

There are significant uncertainties surrounding the signalling and train software. There are also a significant number of issues to be addressed in the signalling and rolling stock. Significant risk provisions should be allocated against these activities. The revised Schedules do not allocate risk in this manner.

Review Aspect 9:

The report shall set out an assessment of the risks to the revised opening dates for Stage 3, 4 and 5 and the potential for any acceleration.

Response summary

The decision on commencement dates for Stage 4 and Stage 5 should be driven by the reliability of the Crossrail Transportation System as it is operating after each successive Stage. If the Crossrail Transportation System is working with a high degree of reliability, then making commencing Stage 4 in November 2019 and Stage 5 in December 2019 would not be a problem.

Planning to do so would not be prudent for a number of reasons, namely:

- it is highly unlikely that the CrossRail Transportation System will have achieved a suitable level of Reliability by that time;
- Any problems with commencement of Stage 4 would need to be addressed in within one month, before they would be compounded by Stage 5 commencement;
- Things during railway commissioning's rarely "all go well"; and
- Timetable changes (would this even be possible?).

In essence, making a decision at this point in time For a Nov / Dec start of service would be a huge gamble based on insufficient information. A more appropriate strategy would be to delay the decision on commencement dates until the last possible moment in order to have more insight into the Crossrail Transportation System reliability growth.

If the decision cannot be delayed, then the most appropriate decision would be to aim to commence Stage 4 in Dec 2019 and Stage 5 thereafter. (refer section 8).

Scenario x

Scenario x, (below) is provided to illustrate the implementation of the recommendations from this report (and one possible outcome for start of Stage 3). The scenario shows:

- Making the route way available as early as possible;
- Pushing remaining routeway work to weekends and engineering hours;
- Commencing with functional and reliability growth;
- A gradual commencement of Dynamic Testing; and
- Selecting the Stage 3 opening date during the Dynamic test period.

The date of start of October for completion of trial operations shown in scenario x is illustrative and should be seen as only one possibility. It is expected that the actual data for completion of trial operations, can not be accurately fixed until Dynamic Testing has been progressed. A milestone is provided during Dynamic testing to define when the expected end of Trial Operations will be achieved (refer section 4.4).

Similarly, the completion of routeway during weekends has been indicatively shown to be complete towards the end of June, but this is not based on any concrete analysis. The completion of the routeway would be the subject of further analysis leading up to the decision to clear the routeway. This is further discussed in section 3.3.

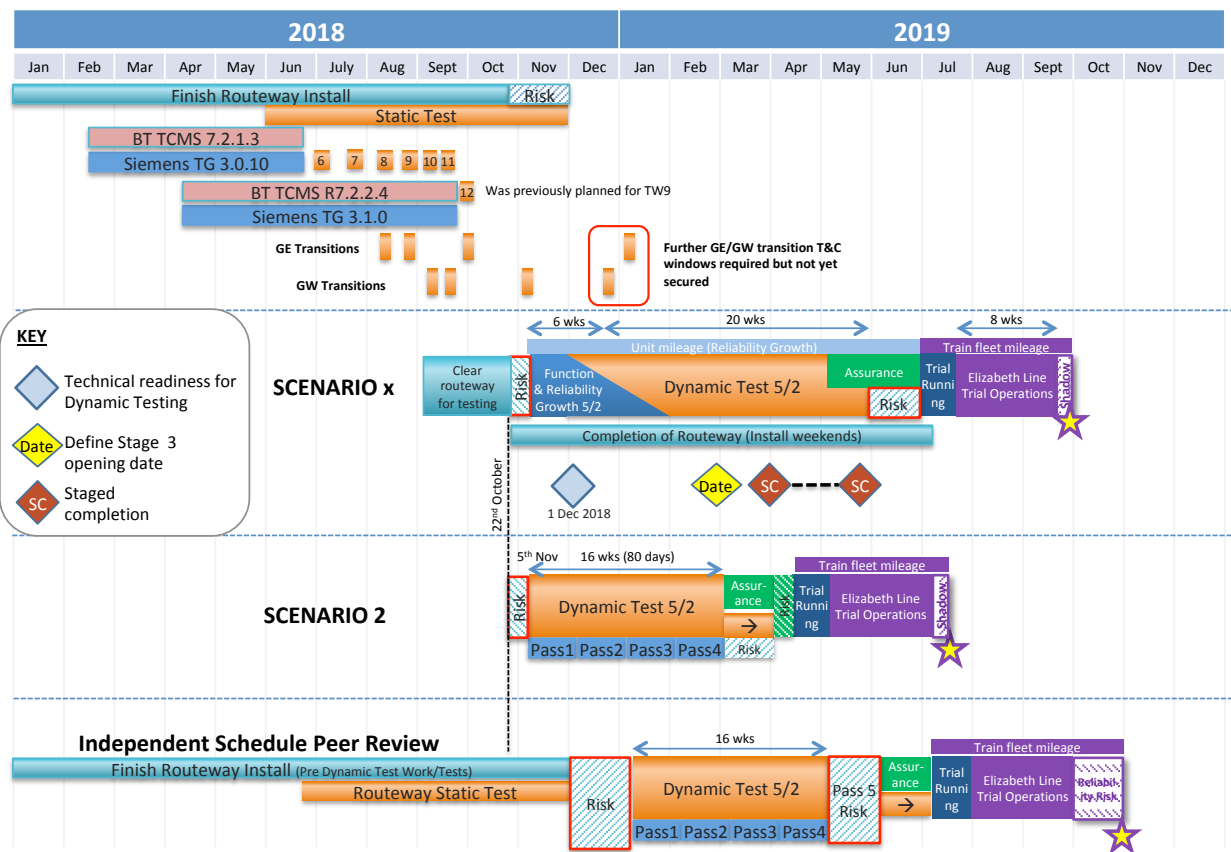


Figure 2: Scenario x demonstrating conclusions from this report

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1 Introduction

Stage 3 will see Elizabeth Line trains running through the COS. Crossrail announced on 31 August 2018 that the stage 3 opening would be delayed from December 2018 to Autumn of 2019.

A revised Stage 3 Opening Plan has been presented to the Sponsors on 3 September 2018[1]. CRL has provided three scenarios for the revised schedule. The independent Schedule Peer Review (conducted by Ian Rannachan [16]) also provided a revised schedule. These are shown on the figure below. For the purpose of this review, these schedules shall be referred to collectively as the Revised Schedules, and individually as Scenario 1, Scenario 2, Scenario 3 and ISPR.

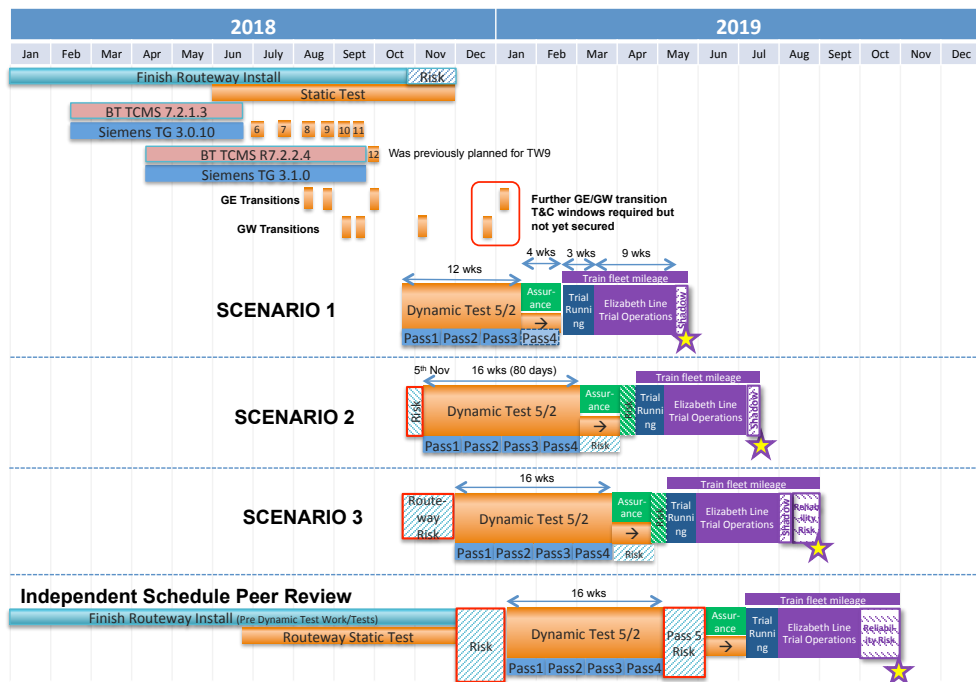


Figure 3: Revised Schedules for Stage 3 opening

John Boss Consulting B.V. has been asked to conduct an independent Schedule Assurance Review (SAR) and provide an opinion on the integrity of the revised schedule proposed by CRL for the Stage 3 opening, as well as plans for the commencement of Stages 4 and 5 services.

This report is the conclusion of this Schedule Assurance review. This report will not comment on the causes of project delay to date, except to the extent that past performance of any particular contract may provide insight into the potential future delivery. The review was conducted from the point of view that “we are where we are” and the must now look forward to determine the best path forward.

1.1 Scope of the Review

The review laid a particular focus to the periods for Dynamic Testing (starting about 22/10/18), Assurance Close Out, Trial Running and Trial Operations. The questions posed for the review were:

1. Are the assumptions and durations realistic?
2. Is the programme logic robust?
3. Are the dependencies and risks understood and plans for mitigation identified wherever appropriate?
4. What is the overall level of confidence, current concerns and any opportunities to improve on current plan?
5. Is there a credible plan and schedule from the start of Dynamic Testing (5 days per week planned from about 22nd October) to the opening of the railway to underpin the broad strategy under discussion.
6. What is the current status of the Infrastructure Managers (IM's) in terms of their readiness?
7. Is there a credible plan to deliver the necessary documents to all the IM's to allow them to accept Staged Completion and Handover?
8. Is there an appropriate level of schedule risk allowed in the current plans?

1.2 Approach to the Review

The approach to the review was to identify and interview key individuals within CRL, RfL, BT and MTR-C. Documents were reviewed to provide background and substantiation of information provided during the interviews.

- A list of those interviews included in Annex A
- A list of documents referenced is included in Annex B

Any issues that were raised during interviews or from document reviews were verified during subsequent discussions (to the extent possible, whilst preserving the anonymity of the interviewee). There remains, however, a degree of subjectivity with every discussion. The challenge is in understanding what part of a story represents a systemic issue within the delivery mechanism, and what is an incidental anomaly.

All interviewees were very open and helpful. The active participation and assistance of CTL, MTR-C, BT and CRL during the execution of this review was greatly appreciated.

1.3 Report Structure

The remainder of the report is structured to focus on the key areas of concern. This is not in line with the eight questions posed in the brief, however, the responses to the questions are highlighted in the text. The complete answers to the eight questions can be found in the executive summary with references to the specific section in the report where it has been addressed,

The structure of the report is as follows:

- Section 2 The Strategy: presents the programme logic and discusses the choice of perspectives: “Construction completion” verses “operational commencement”
- Section Examines the assumptions and durations of key tasks in the Revised Schedules.
- Section 4 Discusses testing of the class 345s in the COS, presenting the need for different types of testing that can be expected (not just Dynamic Testing)
- Section 5 Presents operational and Maintenance readiness
- Section 6 Examines the need for an integrated delivery of the Crossrail transportation System, and recommends the creation of an Integration Team within CRL with mandate over RfL and NR for delivery integration
- Section 7 Presents a view on metrics and how they are used to measure progress, in particular in the development of computer code and rectification of bugs.
- Section 8 Provides a discussion on the risks to opening of Stage 4 and Stage 5 due to delays in opening Stage 3.
- Section 9 Makes the link between the recommendations from the Ian Rannachan report [16] to the conclusions reached in this report so as to provide continuity of thought throughout the overall review process.

Recommendations have made throughout the report. Where appropriate, additional explanation has been provided for the specific recommendation. A summary of recommendations is included as Annex C.

1.4 Abbreviations and terminology

Throughout the report, use has been made of abbreviations and specific terminology. Capitalised terms the specific meaning as defined below

BT	Bombardier Transport
Bug	A element, or elements, of computer code (or lack thereof) that cause an incorrect functionality to occur
COS	Central Operating Section
CPFR	Crossrail Program Functional Requirements
CRL	Crossrail Limited (the organisation)
Crossrail	Crossrail, (the project)
Crossrail Transportation System	The total of all systems and processes that are necessary to deliver a working transportation system to the public. This term is used to emphasis the need for an integrated approach to delivery (refer section .6).
DOO	Driver Only operation
Dynamic Testing	A series of (circa 320) tests conducted by the signalling contractors (both of which are Siemens) with the use of a calibrated class 345. This definition is provided to differentiate these specific tests from general discussions on dynamic testing (testing with the use of a train)
FLU	Full Length Unit (345 set with 10 cars)
FRACAS	Failure Recording Analysis Corrective Action System
ISPR	On of the Revised Schedules, being provided by the Independent Schedule Peer Reviewer (Ian Rannachan)
MTBSAF	Mean Time Between Service Affecting Failures
MTR-C	MTR Crossrail: Operator of Crossrail services.
NR	Network Rail (The organisation)
NRCR	Network Rail Client Requirements as referenced from the Protocol
ONFR	On Network Functional Requirements
QSRA	Quantitative Schedule Risk Assessment
RLU	Reduced Length Units (345 sets with 7 cars)
SAT	Site Acceptance test
Stage	Stage of opening as described in Annex []
TfL	Transport for London
tph	Trains per Hour

2 The Strategy - Programme logic

The general strategy (clear the routeway and then get the train running on COS) proposed in each of the revised schedules is sound. Scenarios 1, 2, and 3 differ in the amount of risk that has been included.

ISPR presents an additional logic constraint, being the *completion of routeway install* prior to commencement of Dynamic Testing. This constraint is entirely appropriate if the revised schedule is viewed from the perspective of “construction completion”, as it will allow for the most efficient working of the contractors (C610).

This report approaches the schedule review the perspective that operational commencement should weigh more heavily than construction completion. The consequence for choosing operational commencement over construction completion is that removing risk from the operational commencement (by starting train testing in COS at the earliest opportunity) will incur additional costs for construction completion (prolongation of routeway completion). This is further discussed in section 3.3.

The constraint *completion of routeway install* is not appropriate if viewed from the perspective of “operational commencement” for three reasons:

- When trying to start operations, it is critical that the rolling stock be allowed to accumulate as many miles as possible on the intended infrastructure to build reliability before opening service;
- It is highly probable that the class 345 will need a period of time on COS to ensure a sufficient level of functionality and reliability is attained before Dynamic Testing can begin (refer section 4.1). Compounding this, experience shows that running trains only on test tracks will never flush out all of the issues - there are always new challenges when the train is introduced onto the target infrastructure; and
- Siemens and BT will be confronted with the actual performance of their systems in the actual environment; a more pure allocation of system faults will be possible.

The logic presented in Scenarios 1, 2 and 3 (and supported by this report) requires that the routeway be cleared as a matter of priority. Any remaining works for completion of the routeway install would be concluded during engineering hours or at the weekend. This will necessarily extend the installation duration but provides necessary mitigation the time required to deliver functionality / build reliability of the transportation system.

Recommendation 1: Start testing the class 345 in the COS as soon as possible.

Reliability Growth is a critical challenge for the Crossrail Transportation System. This applies to both infrastructure as well as the train. On going reliability growth should be included into the program schedule logic. This will require that the class 345 continue to build up mileage in the environment in which it is to ultimately perform.

Response Summary:

The general strategy (clear the routeway and then get the train running on COS) proposed in each of the revised schedules is sound).

ISPR presents an additional logic constraint, being the completion of routeway install prior to commencement of Dynamic Testing. This is not appropriate from the perspective of operation commencement.

The Strategy should include starting testing of class 345 in the COS as soon as possible.

The Strategy should include running class 345 in COS as often as possible.

Recommendation 2: Accumulate miles as possible, as often as possible. If the class 345 is not being used for tested, then it should be out building up miles

ETCS poses a particular problem. The current approach has been to isolate ETCS from the overall delivery through obtaining derogations, and providing services with existing rolling stock. This approach should be continued to the extent possible to keep that risk outside of the Stage 3 delivery.

3 Assumptions and Durations

This section examines the assumptions and durations of key tasks in the Revised Schedules

The report by Ian Rannachan [16] makes some very valid and relevant recommendations for the inclusion of additional milestones to assist tracking delivery completion. These should be taken into account. A separate investigation was undertaken to add colour to the reporting being made available (refer annex B). The conclusion from this investigation corroborate the information being provided in the reporting. The summary of findings is in Annex F.

Whilst this section identifies a number of contracts, it must be noted that the path to completion remains a challenge for all parties. No one can afford to back off.

3.1 Completion of SCADA (C660)

The SCADA contract must make an incredible number of connections in order to bring the project to a completion. The SCADA system being installed on Crossrail is extensive. C660 is also responsible for installation of the radio. Delivery of their scope has been complicated due to a number of stations reaching completion at the same time. This can be clearly seen in the figure below.

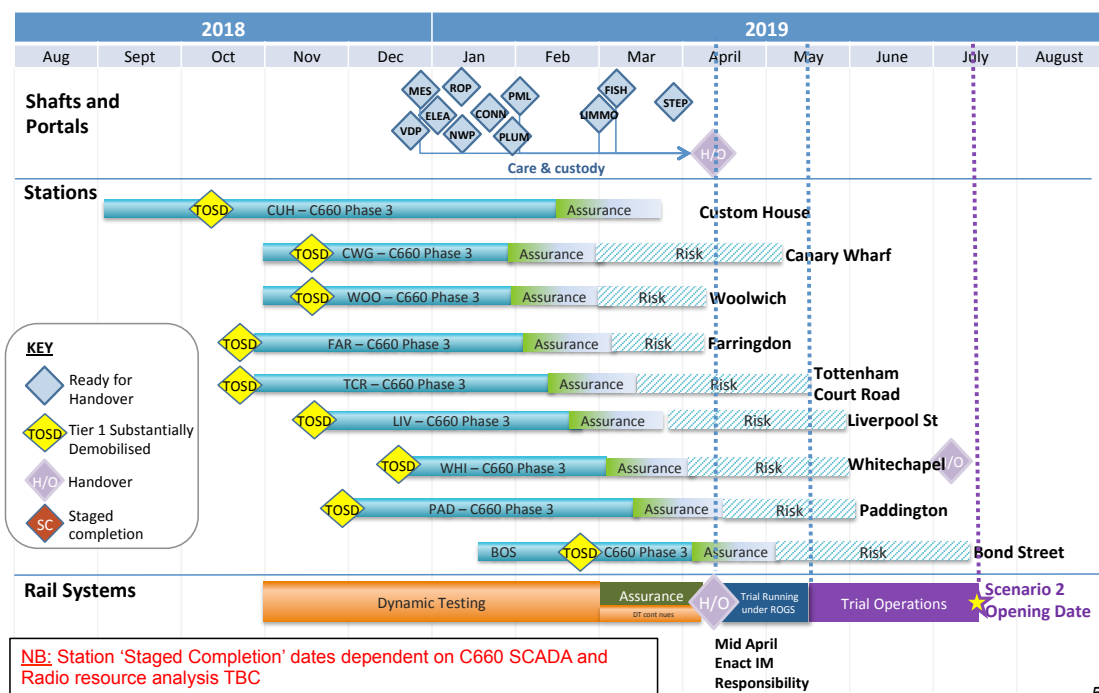


Figure 4: Schedule demonstrating concurrent working fronts of C660

Mitigation measures have been implemented including:

- Recruitment of additional radio testing staff
- Sheding of C660 scope to Tier 1 contractors where possible; and
- Prioritising of SCADA I/O, identifying those I/O that are necessary for the commencement of trial Operations, and those that can wait.

It is critical that these mitigation measures be followed through. Notwithstanding these mitigation actions, the progress of C660 will be a key driver in delivery of a working transportation system and will require increased attention.

Response Summary:

The duration required by C660 for completion of radio and SCADA is a threat to achieving Stage Completion, and ultimately Stage 3 opening. Mitigation measures must be carried through.

Recommendation 3: Perform a deep dive review on the C660 scope, planning and outstanding works. Confirm that there is a valid prioritisation of I/O and that scope sheading has been explored to the maximum. Confirm progress of recruitment of radio testers against the remaining work scope. Confirm the maximum has been achieved with all possible mitigation measures.

3.2 Romford Control Centre and control system.

The other end of SCADA is a control centre. The control centre at Romford has a particularly complex control system associated with the control of the Crossrail Transportation System. The interfaces on either end need to deal with different train describer technologies (using a method referred to as a ripple block). Some additional innovative functionality has also been provided, (including possessions management via a laptop on site).

Top end control systems have a history of proving problematic at the commencement of service. Despite not being safety critical (or perhaps because they are not safety critical), their development and functional delivery is often lost in a project. It would appear that the Signalling control system contract has already been busy with sheading functions. The interfaces between the signalling system and the NR train describers are “unsighted” on the NR side. Finally, the simulator has been delayed several times and has not yet been delivered with sufficient functionality to train the operators (who are said to be all new, as opposed to experiences signalling staff).

The integrated nature of the signalling control system makes it a prime subject of attention for the Systems Integrated Team (refer section 6).

Recommendation 4: Romford control system was conspicuously absent from most discussion. It is recommended that a deep dive be undertaken on the control system specification and delivery to understand where the critical issues are, and achieve a good sense of comfort that they are being adequately managed. This should be a matter of urgency for the Systems Integration team.

3.3 Completion of routeway installation (C610)

Completion of routeway is still a way off. The current outstanding work to complete (as reported in week 36) includes:

- Walkway: 6 km to go (all the hard bits),
- Fire mains: flow test of the fire main, remaining installations is the more difficult sections around the portals and station connections.
- Cabling: 38 km remaining (13 km at Connaught tunnel and 18 km around Farringdon and Whitechapel, Mainly lighting power)
- 2000 lights to go from 5,000. (installation rate of circa 400 per week).
- Glanding and Terminating (2000 to go)

It should be possible to free the routeway for class 345 testing by the end of October or very soon thereafter. The route way works will not be complete by that time. There will be works that will need to be completed during engineering hours or on the weekends.

The criteria for determining when sufficient work has been completed should relate to the number of work trains needed. There is at present a fleet of circa 15 works trains supporting works in the COS.

When the number of work trains can be significantly reduced, then the tunnels should be cleared to commence testing with the class 345. It should be noted that the works trains must be removed from Abby Wood to enable commencement of siding construction, necessary for Stage four.

Additional costs will be incurred due to the routeway contractor having to complete installation during weekends and engineering hours, rather than during normal working hours. There should not be any cost impact associated with construction completion at locations unaffected by the train running. No detailed costing analysis has been conducted during this schedule review.

The 660 contractor has a history of missing milestones and will require special supervision.

Response Summary:

It should be possible to free the routeway for class 345 testing by the end of October or very soon thereafter. The duration for completion of routeway as presented in ISPR is realistic. However, the approach recommended in this report is to clear the routeway to allow for testing class 345s in the COS as soon as possible. The decision to commence clearing the routeway should be driven by the need for works trains, rather than by overall completion. Remaining routeway works will then need to be completed during engineering hours or on weekends.

3.4 Assurance and Regulatory Approvals

Assurance remains a point of concern. The current progress on assurance is lagging significantly behind plan, however this is a reflection on the overall delay, as opposed to the assurance process in itself.

The assurance process remains well organised and structured. The oncoming bow wave of assurance documentation is well understood. There is a good degree of confidence that the volume of assurance can be managed in the time allowed. Notwithstanding this confidence, history shows that the “bow wave” can quite quickly turn into a “dam burst” one or two of the main deliveries are delayed. Consideration should be given now to beefing up the available staff to manage the flow of assurance documents when the eventually come.

Recommendation 5: *Review the staffing needs and arrange now for sufficient staff to be available when the rush of assurance documents begins.*

Delivery of assurance documents should be critically evaluated to identify where it is possible to start getting packages through the assurance process. Particular attention should be paid to station packages that can be processed (possibly after completion of design). Push the packages through, even if test evidence must follow when complete. The benefit is that the story is approved; it then becomes a matter of putting test results in the right “pigeon hole.”

Recommendation 6: *Start an action to push through assurance documentation that may not be entirely complete – but is in a state ready for the assurance process.*

Regulatory approval will dovetail with the assurance process. The regulatory approvals needed for Stage 3 are as follows:

- ATC to apply for a new exemption from ROGS (Railway and other guided transport systems).
- Crossrail to get Authority to Place into Service (APIS) for the Central Operating Section for the start of passenger service under RIR (Railway Interoperability Regulations).
- NR to get APIS for the assets they built by the start of passenger service.
- RFLI already have authorization under ROGS to operate the service. They will “stand up “ as Infrastructure Manager and operator at the start of trial running. They will get approval from their safety panel (in their case RABC) before they go into Trial Running.
- MTRC already have authorization under ROGS to operate the service. They will get approval from their safety panel before they go into Trial Running.
- LU have confirmed that they do not need additional authorization from the ORR to run the system.

Response Summary:

The duration for assurance completion appears realistic, but will need to ensure it has sufficient staff available when required.

3.5 Trial Running

The purpose and scope of Trial Running, as defined in the Trial Running Strategy [28] is as follows:

“In accordance with the Project Development Agreement: by the end of Trial Running CRL shall have demonstrated that the railway is capable of reliably meeting the capacity and other requirements of the Crossrail Programme Functional Requirements and the Sponsors’ Requirements; which will include any relevant Undertakings and Assurances.....

The scope of Trial Running will involve appropriate integrated testing with multiple trains to demonstrate that the Central Operating Section Railway system is capable of reliably meeting the capacity and other requirements of the Crossrail Programme Functional Requirements and the Sponsors' Requirements. “

There has been a significant amount of work invested in preparation or Trial Running. The entry criteria for Trial Running are captured in the Trial Running Strategy [28] as follows:

The key criteria to enable the commencement of Trial Running are:

1. Dynamic Testing successfully completed and Stage Gate IM1 (Ready to start Trial Running) passed, with particular emphasis on the safety, reliability and operability of the rail systems.
2. Handover of the Rail Systems element to the Infrastructure Managers has been achieved in accordance with the PDA. This will comprise all necessary and sufficient deliverables including, but not limited to, Health & Safety Files, asset databases, special tools and equipment, Operations and Maintenance Manuals, and necessary training.
3. Authorisation under ROGS by ORR for the Infrastructure Manager’s Safety Management System.
4. Authorisation under ROGS by ORR for the Train Operator’s Safety Management System.
5. Availability of 22 number Rolling Stock units, including daily train paths into and out of the Central Section from Old Oak Common Depot and other Stabling locations for the duration.

6. Availability of sufficient numbers of suitably trained and competent train operators to support the trials.
7. Availability of sufficient numbers of suitably trained and competent signal controllers and electrical controllers to support the trials.
8. Availability of sufficient numbers of suitably trained and competent infrastructure maintenance staff.
9. Provision of adequate facilities including offices, stores, sidings, rail access, rail plant, equipment, and maintenance systems to enable maintenance of the Central Section sufficient for Trial Running. This may be through the delivery of the Plumstead Maintenance Management Centre.
10. Provision of Engineering Trains, Yellow Plant and other Mobile Operating Plant sufficiently tested to enable maintenance of the Central Section sufficient for Trial Running.
11. Reliability of the Rolling Stock units proven through running in service during Stages 1 and 2 of the Crossrail Staged Opening Plan.

(extract from "Trial Running Strategy [28])

Figure 5: Entry criteria for Trial Running

A more detailed tracking of start criteria is detailed in the readiness review [29]. Criteria for the successful completion of the Test Running are detailed in the Trial Running Strategy [28] at a high level. Particular attention must be paid to being able to end the Dynamic Testing – at a certain point, enough testing has been done, despite the protestations of the testing teams. Clarity on the conditions to start Trial Running will be critical in this regard.

Trial Running has a duration of three weeks in the Revised Schedules. The original scheme had 5 weeks of trial running. Three weeks should be considered as a minimum.

Response Summary:

The duration for Trial Running is the bare minimum, but appears realistic.

The process for Trial Running preparation needs to be restarted to develop the final test scripts and fine tune the acceptance criteria.

Preparation of the test scripts and detailed planning for Trial Running appeared to have been “parked” at a certain point in time. There are no test scripts developed for Trial Running, it was proposed that there would be some synergy from the Trial Operations Script and there may have been a thought to wait until they matured before starting on the Trial Running scripts.

Recommendation 7: *The process for Trial Running preparation needs to be “un-parked” to develop the final test scripts and fine-tune the acceptance criteria. The work stream should look to identify synergies with the Trial Operations preparations, keeping always in mind that Trial Operations and Trial Running have different goals.*

3.6 Trial Operations

The key objectives of trial operations are:

- Validate the rule book;
- Build confidence in the operators, (so not just on a simulator);
- Perform all of the operational readiness testing

Trial Operations ideally require at least 12 weeks. It may be possible to squeeze this down to 8 weeks but only if station access is staggered. There are prerequisites for the commencement of Trial Operations that have been agreed between CRL and LU.

The Revised Schedules allow 8 weeks for Trial Operations. Commencement dates of Trial Operations vary across each of the Revised Schedules, starting from Mid March in Scenario 1 to start of August in ISPR. Scheduled handover of staged completion is scheduled to be staggered across March and April 2019.

The suggestion was made that bringing the operational staff in on the Dynamic Testing could shorten Trial Operations. It must be clearly stated that Trial Operations needs to have time to conclude operational testing, and this is not compatible with a Dynamic Test regime. Operator involvement during Dynamic testing will assist in familiarisation and should be pursued as such, however, it should not be used as an excuse to shave an already reduced Trial Operation period.

Response Summary:

The duration for Trial Operations appears realistic. On-going monitoring of the Stage Completion dates is required to ensure dates remain staggered, or more time is allowed for Trial Operations.

Both RfL and LU had a clear agenda and series of activities that were to be undertaken during Trial Operations. Work is well progressed on the detailed planning.

4 Testing with FLU class 345 on COS

Dynamic Testing is a signalling contract activity. It consists of circa 315 tests. The tests are required to test and calibrate the CBTC system. A period of functional and reliability growth is expected to be necessary prior to the commencement of Dynamic Testing

4.1 Function & Reliability growth

It is expected that the train (and possibly some track side systems as well) will not be able to achieve all of the essential conditions on the first day of testing in the COS. In this case, a period of “functional development and reliability” growth will be required before Dynamic Testing can be begun.

In line with the philosophy of getting the train into COS for testing as soon as possible, the successful completion of all 29 train CBTC tests at Melton should not be defined as a prerequisite for commencement of testing in COS. The test list (refer annex F) details a number of tests for functionality that does not need to be present for the commencement of testing in COS.

For the avoidance of doubt, this is not to say that the 29 tests do not need to be passed, but rather it is more important to get the c345 onto the COS and continue testing there, than it is to try to secure successful completion of testing at Melton. A clear differentiation must be made between Dynamic Testing (being the tests required by Siemens) and function and reliability growth (being the process of getting a train and infrastructure into a state where the Dynamic Testing can begin).

Passing tests need also to be viewed in the context of reliability. Passing a test once is not necessarily confirmation that the function works. Tests must be repeatable - passing that test 20 times without failure gives a more reliable indication that all is well. Transition testing to the Great Eastern or Great Western could be expected to pass 800 times without incident before it could be considered stable (and that would only be a couple of days running). Care must be taken not to proclaim victory too early in completion of tests.

4.2 Entry conditions for Dynamic Testing

A document has been developed to define entry conditions to Dynamic Testing. The conditions are not unreasonable and are reproduced below:

Essential:

1. Trains operating with final braking and propulsion characteristics;
2. Successful completion of all 29 train CBTC tests at Melton specified by Siemens (i.e. all of the 37 tests, excluding the 6 relating to transitions into ETCS and the 2 that need to be undertaken in the COS);
3. Assurance in place to support multi-train operation (with safe separate provided by the signalling system);
4. 4 trains available in COS for all dynamic testing periods;
5. Units used for testing in the COS to have successfully passed static testing to the latest configuration;
6. Trains sufficiently reliable so as not to impede the productivity of dynamic testing;
7. Support arrangements in place to maintain trains (including from critical sub-contractors);
8. Constraints regarding resourcing communicated and agreed.

Desirable:

1. No Driver Machine Interface issues outstanding that significantly affect operability;
2. All issues affecting Stage 3 operational functionality closed;
3. Train achieving reliability level required for Stage 3 operation.

(extract from "Entry into Main Dynamic Testing Regime" [11])

Figure 6: Entry criteria for Rolling Stock to commence Dynamic Testing

Whilst the entry criteria for commencement of Dynamic Testing [11] is an excellent starting point, a more pragmatic approach will be required. Emphasis must be given to commencing Dynamic Testing as soon as possible, albeit with controllable hindrance. In short – the sooner problems are identified, the sooner they can be fixed. A pragmatic approach will be required arranged to ensure Dynamic Testing (or test cases therein) can be started at the earliest opportunity.

A case in point are the 29 train CBTC tests – The challenge will be to identify what is necessary in order to start clearing Dynamic Test cases and which can wait till later.

Recommendation 8: Critically evaluate the list of "29 tests", identify those that can be completed after the commencement of Dynamic testing. Prioritize activities to ensure the key tests from the 29 are passed before Dynamic Testing begins.

The transition from "functional development and reliability growth" to Dynamic Tests should therefore be seen more as a gradual transition than a hard point in time (refer also section 6.3). A milestone should be created to check technical progress on functional development and reliability growth. The purpose of the milestone would be to provide a target for completing functional delivery and mark a change in focus towards Dynamic Testing.

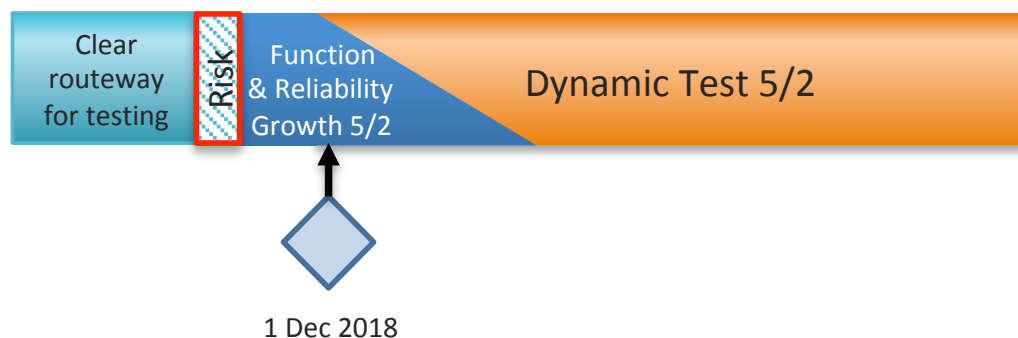


Figure 7: Transition to start of Dynamic Testing

Response Summary:

The assumption that Dynamic testing can begin immediately upon availability of the COS is not realistic. It is highly likely that a period of functional development and reliability growth will be required. The transition to start of Dynamic Testing will need to be pragmatically arranged to ensure Dynamic Testing (or test cases therein) can be started at the earliest opportunity.

Recommendation 9: Create a milestone to check technical progress on functional development and reliability growth. The milestone will mark change in focus towards Dynamic Testing

4.3 Dynamic Testing duration

The test list for Dynamic test was not available within CRL during the course of this report. Siemens (C620) was able to provide a list of the proposed tests, but advised that the test scripts were still being produced. What was required of many of the tests could be determined from the test name. Translating the name of a test into a resource loaded schedule detailing an exact series of events, locations, speeds, measurements and staffing actions is a significant step.

It can be expected that the tests planned for Dynamic Testing are defined as a part of the Siemens product delivery plans and specifications. Tailoring those tests to the COS will be a project specific task. There was no evidence that this task was in any way close to being completed. This statement should be qualified with the expectation that the production of the test scripts is expected to be a predominantly mechanical process. Unlike debugging software, the production planning for detailing test scripts should have should have very little uncertainty in terms of scope, resource and production duration.

The proposed 4 cycles is questionable. Whilst there will be a number of cycles of software production and testing, the exact number, definition and content will be a product of the test results and discussions between client, contractor and developers (see also section 7.2), Careful and precise management of the tests and software fixes will be required to ensure the multiple cycles do not evolve into an on-going churn.

Response Summary:

There does not appear to be a credible plan for delivery for the Dynamic Testing.

Recommendation 10: *A work group should be engaged to ensure all test scripts are detailed as a matter of urgency.*

Siemens were confident that the four month period would be sufficient to concluded the tests, but this seems to be more based on corporate wishes than engineering reality. Given the lack of test scripts, there was nothing material upon which to build confidence. The concern over the proposed four month period can be articulated as follows.

The two critical resources in completing the Dynamic Tests are:

- Available testing time; and
- Technical back office turnaround time.

4.3.1 Available testing time

Available testing time refers to the time that is actually available for conducting the tests. It requires a working train and working infrastructure, as well as appropriate arms and legs to support it. The proposed plan conducts 315 tests over four periods of four weeks, anticipating 16 hours per day for 5 days a week resulting in 1,280 hours. This allows, on average, 4 hours per test.

On face value, the nature of the tests would appear to indicate that whilst this is in some individual cases optimistic, the overall duration is by no means unrealistic. A number of factors however, will negatively influence available testing time.

- Equipment failures: Any failures in train or trackside that impact the test;
- Failed Tests: Tests, which fail to deliver the anticipated results, will need to be redone. The number of tests required is therefore higher than the 315 anticipated;

- Test material availability: If there is no updated releases, then there is nothing that can be tested;
- Operational matters: Getting trains out to the test site and in the correct positions (refer also section 6.3);
- Configuration: Setting up the train and trackside to the appropriate configuration for the execution of the tests (including loading new data sets after fixes);
- Staff availability: Including operational staff, technical testing staff and staff to maintain and prepare the train.

4.3.2 Technical back office turnaround time

Technical back office turnaround time is required for analysis of the test results, identification of the issues to be resolved and then implementation of solutions in new releases. If the technical back office is not given that time (or if it can not be interleaved with the on site activities), then it will not keep up with the site testing teams. There is a real chance that the site team will need to wait on delivery of the revised releases.

It is worth noting that the examples cited by Siemens in support of the 4 month duration of Dynamic testing (Copenhagen, Hong Kong...), were all spread over a year or more. There was indeed a similar number of testing hours, however, in each case there was also a significant amount of time available for the technical back office to process test findings – a situation that does not occur with the proposed revised schedules.

Response Summary:

The four month duration allowed for the Dynamic Testing does not appear realistic. The available testing time itself is tight. There appears also to be a structural concern with technical back office turnaround time. It is not possible (at this stage) to confirm that all necessary testing will be completed within that four month period. No one knows exactly what will happen when the 345 is run in the COS. The actual duration will naturally depend on how successful the tests are first time and the complexity of the solutions required to fix problems. It should become clear how long the tests will take within two months of commencement of the Dynamic Testing.

4.4 Defining the end of Trial Operations

Given the conclusion of the preceding section, that it is not possible to identify now how long Dynamic Testing will take, and consequently predict a date for the completion of trial Operations, it is necessary to try to define a point in time when such a prediction can reasonable be made.

It is expected that the process of Dynamic Testing, and associated reliability growth will lead to greater confidence in the delivery timetable. Particular attention should be paid to the predictability of obtaining positive test results, as metric for understanding when stability in the testing process is being approached.

Recommendation 11: Create a milestone during Dynamic Testing to trigger the definition of the Stage 3 commencement date.

Scenario x, (below) is provided to illustrate the implementation of the recommendations from this report (and one possible outcome for start of Stage 3). The scenario shows:

- Making the route way available as early as possible
- Pushing remaining routeway work to weekends and engineering hours
- Commencing with functional and reliability growth,
- A gradual commencement of Dynamic Testing and

- Selecting the Stage 3 opening date during the Dynamic test period.

The date of start of October for completion of trial operations shown in scenario x is illustrative and should be seen as only one possibility. It is expected that the actual data for completion of trial operations, can not be accurately fixed until Dynamic Testing has been progressed. A milestone is provided during Dynamic testing to define when the expected end of Trial Operations will be achieved.

Similarly, the completion of routeway during weekends has been shown to be complete towards the end of June, but this is not based on any concrete analysis. The completion of the routeway would be the subject of further analysis leading up to the decision to clear the routeway. This is further discussed in section 3.3.

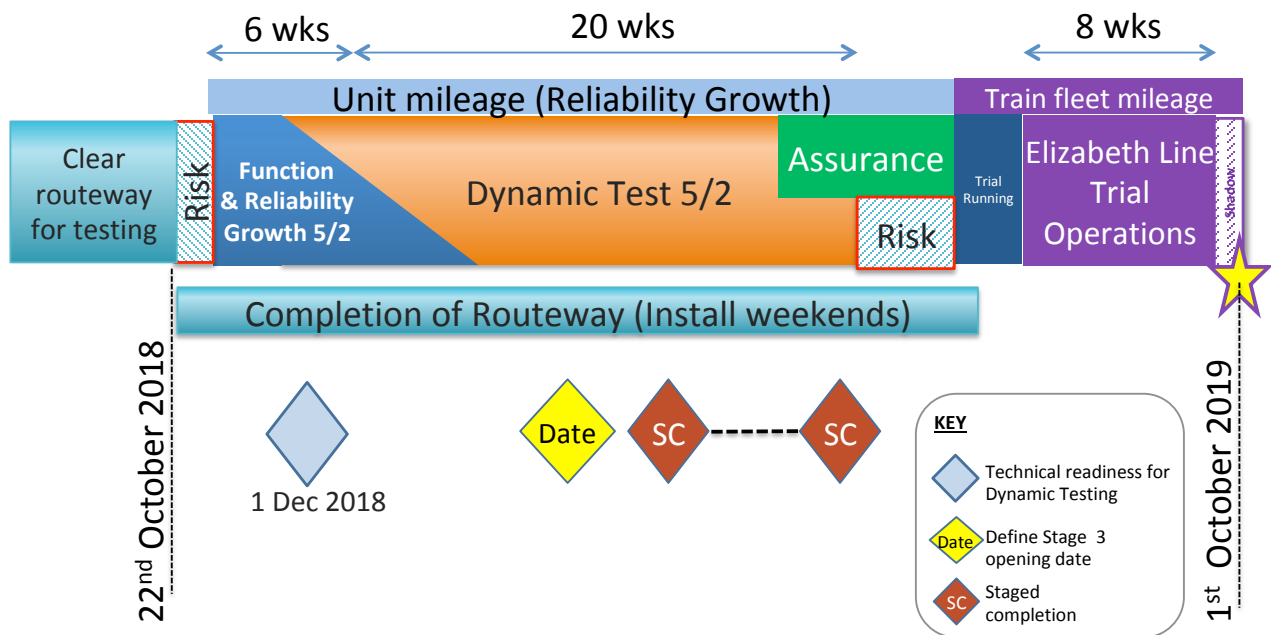


Figure 8: Scenario x

4.5 Safety Critical Issues.

The period of 4 months for Dynamic Testing comes with a caveat that no safety critical issues are found. Development time for implementing safety critical changes can stretch out to many months. Should an issue be found that necessitates a change to a safety critical component (software and/or hardware), then “all bets are off”. The risk that a safety critical issue will be found has been significantly mitigated:

- Demonstration of safety also tracks design and development processes. Testing is only the last step. The documentation supporting the design and development of the safety critical components for Crossrail has been sighted and found to be in good order.
- Changes to the safety critical components have been kept to a bare minimum. The majority of the safety critical components remain the same as those used in previous applications.

It is realistic to expect that no safety critical issues will arise during Dynamic Testing.

5 Operational & Maintenance readiness

Response Summary:

IMs are well prepared. RfLi have sufficient trained staff and are being involved with project delivery to ensure familiarity with the equipment.

Contracts changes a have been arranged with the existing LU maintenance contractors to address maintenance on the LU stations. The execution of these contract changes has been put on hold awaiting a confirmation of final opening date.

5.1 Operations staffing

Staffing appears to have been well progressed. LU has identified and engaged all staff necessary for running their station along the COS. The approach was to draw on experienced staff and then use the recruitment to back fill. The delay in Crossrail has means that around 60 LU staff are waiting to gain access to the stations. In many cases, it has not been possible to send them back to stations from which they came as their old position had already been filled.

MTR has 388 drivers trained, which is sufficient to address the operational needs.

Operators have been sourced for Romford and are undergoing training. The problem with the Romford team is the time between being trained and actually implementing their skills may be so long that additional training is necessary. There have been some staff that have resigned due to the inactivity.

5.2 Maintenance

RfLi maintenance (IM COS) has secured staffed and completed training. Staff are currently engaged on site to assist in developing familiarity as well as prevent boredom. Some staff have resigned citing inactivity as a reason. Lack of progress with installation of some equipment has been a source of frustration (turning up on site to inspect a piece of kit, only to discover an empty room).

Maintenance of LU stations will be arranged through changes to contracts of the existing station maintenance contractors. The execution of these contract changes has been put on hold pending confirmation of a date for stage completion. Arrangements have been made for maintenance contract staff to participate with station finalisation works to ensure familiarity with the installed systems.

5.3 Documentation

Provision of asset information and maintenance manuals remains a point of concern. The provision of as built documentation, as well as maintenance manuals is delayed. This seems to be related to the delay in overall delivery rather than a systemic break in the defined deliverables.

There is a credible plan identified for the delivery of necessary documents to all the IL's to allow them to accept Staged Completion and untimely Handover. Notwithstanding the existence of contractual obligations and a plan, it would be highly advisable to highlight this matter with the delivering contractors to ensure it does not slip from the radar.

Response Summary:

There is a credible plan for the delivery of all necessary documentation. The delivery of documentation is running behind schedule (as a consequence of the overall delay).

Recommendation 12: CRL should make a special action to chase though all maintenance and as built documentation – ensuring that the documentation maintains a significant priority in overall delivery.

6 Integrated Delivery

Response Summary:

CRL must more actively participate in systems integration. The role of Lead of Systems Integration should be end responsible for the delivery of a Crossrail as a working integrated transportation system. The Systems Integration Team acting under the Lead for Systems Integration, must have boots on the ground and be the beach master for tests that span systems (including rolling stock and Network Rail).

6.1 Systems Integration

CRL must more actively participate in the integration of Crossrail, and in particular the track and train. The existing system integration roles need to be strengthened. A dedicated systems integration team should be established in CRL with responsibility to oversee and implement the integrated delivery of the project. The systems integration team would be lead by the Lead of Systems Integration who should be end responsible for the delivery of a Crossrail as a working integrated transportation system.

The Lead of Systems integration would be the one who would define the path for the delivery of the Crossrail Transportation System. This role would be the owner of the integrated delivery including systems, rolling stock, NR interfaces, operations and timetables.

There is a strong need to bring systems people into the CRL, the number of peoples who have gone through the systems delivery and operational delivery phase of a railway is "lethally thin". This is not a task that can be asked of the existing PMs and technical Leads.

The implementation of the role of systems integration lead should be carefully balanced to ensure collaboration with the PMs (charged with ensuring delivery of specific contracts) whilst allowing the Systems Integration team to meet their responsibility. Systems Integration must work alongside the PMs, not through the PMs.

Lead Systems Integration and the Systems Integration team must have direct contact with the delivering contractors, whilst not compromising the PM's ability to manage the contract delivery

Having responsibility for delivery of a working Crossrail Transportation System necessarily means the Lead of Systems Integration must also have authority also over the integration of the rolling stock with rest of the Crossrail project. This must be explicitly defined between CRL and RfL. Lead systems integration must not be a role that functions through the Rolling Stock delivery team, but alongside. There is no time during the final period for any opaqueness between any contractor and delivery of a working transportation system.

The Lead of Systems Integration must have authority over the integration with the NR systems. Arrangements with the Surface Directorate and the NR colleagues should ensure the Lead Systems Integration can have direct and meaningful interaction with NR as he deems necessary.

Recommendation 13: Establish a Systems Integration team with integration authority for the Crossrail Transportation System (thus including rolling stock and Network Rail).

The Systems Integration Team should have a "boots on the ground" presence during the testing. They need to take the role of "beach master", being responsible for coordinating and leading contractors to successful integration, drawing on a deep content knowledge of the systems being integrated and a well developed plan of how that integration will be achieved.

The role of Systems integrator must be filled in an active manner on board each test run. CRL should step in to become more active in recording, tracking and solving on-going issues.

The train testing would require attendance from BT, Siemens as well as CRL.

Recommendation 14: Ensure the Systems Integration Team has boots on the ground and plays a leading role (beach master) in integration testing.

6.2 Collaboration

Collaboration is a critical component, especially in this phase of project delivery. Whilst relationships appeared well balanced during interviews, there was sufficient mention of issues to warrant making a note in this report. Unless all parties actively collaborate, the project will be endangered. This point should be stressed at every level of the organisation, from the most junior to the most senior.

Recommendation 15: Gather the senior managers from all contractors together – jointly address the question “What are we going to do together to get this across the line?”. Regularly follow up on commitments made.

6.3 Management of testing

Testing is a significant logistical exercise with finite resources. There are limited number of trains and an even more limited number of locations that require testing. It is absolutely imperative that testing be arranged in the most efficient manner possible. CRL should lead the test planning, from the commencement of testing the train on the COS.

The combination of testing in the COS with class 345s is a particular point of interest. Given the uncertainty over Dynamic Testing (refer section 4.3), and Functional and reliability growth (refer section 4.1), management of testing will need to be fluid and opportunistic. Every available test slot should be utilised. This will necessitate strict configuration management and the ability to understand which tests can be slotted in out of sequence.

CRL must arrange testing in order provide the best opportunity to address testing identified by the contractor, PMs and the Systems Integration Team. Tests must be critically reviewed to remove duplication of testing, and improve on inefficiencies. In essence: Be as efficient as one can be in the things that one can control.

The existing test management team will have a special relationship with the Systems Integration team; they need to collaborate closely with each other. When tests begin to span systems, then the lead for those tests should rest with the Systems Integration team, who will need to work closely with the testing team to ensure the right tests (and only the right tests) are completed, in the most efficient manner.

Recommendation 16: Testing that spans systems should be under the control of the Systems Integration Team, in close collaboration with the CRL test team.

It has not been clear how the Crossrail Transportation System will be built up through the various layers of testing. Whilst there is discussion on individual blocks of testing, there seems to be lacking an overall vision on how this will all come together. A critical component of this is understanding when one set of tests are finished and the next may be begun. Leaving it to the

testers to decide will result in program delays (the aim of a tester is to test....). There is a need to ensure clear start and end criteria are defined for each block of testing.

Recommendation 17: Ensure there is a clear vision articulated in the top level testing plan that defines how the subsystems will be brought together to deliver the Crossrail Transportation System. This should be complimented with clearly articulated start and finish criteria for each block.

A critical role for test planning will be prioritisation of testing to address program sensitive items. Transparency of the actual technical position of individual contracts will be essential in ensuring meaningful progress – there is no time left for opaque relationships. In essence, be as transparent as possible for the benefit of Elizabeth Line.

The management of testing must also take into account that systems will be evolving as patches are delivered, mods updated and new released loaded. Strong Configuration Management will be a critical determinant in driving successful testing campaign. It is imperative that CRL ensure strong configuration management across the entire delivery. This will be a key input for the management of Systems Integration. The amount of testing to be conducted, the fluid nature of that testing and the need for Crossrail to be intimately involved with its management and execution means Crossrail will need to have enough arms and legs available.

Recommendation 18: Critically evaluate the resources available in Crossrail for supporting testing. It is imperative that sufficient numbers of suitably experienced people are available to facilitate and manage testing, in close collaboration with the Systems Integration team.

6.4 Smart tooling for testing

There are a number of smart tools available in the market or in development. These include the tool for interrogating the ERTMS bus (with currently endeavours to expand this to also include CBTC). Proposals for mounting cameras in driver cabins to records rest results should be applauded as they will assist in fault identification and resolution.

Recommendation 19: Continue to look for smart tooling to assist in performing and analysing tests.

6.5 Reliability Growth

Growing the reliability of Crossrail as a working transportation system will be a critical prerequisite to commencing service in Stage 3, 4 and 5. It is imperative that serious attention be paid now to the challenge of growing reliability.

The reliability of the class 345 - RLU sets has been slow in developing to date. The reliability dashboard [21] shows a reportable reliability of 3,060 MTBSAF (miles). This is low.

There is a work stream convened to improve reliability, [22], however, it seems to be staffed exclusively by people who are busy also with delivery of rolling stock functionality. Evidence was also sighted FRACAS process underway [23]. This would indicate that steps are being undertaken to improve the reliability of the 345 units.

No reliability improvement team was identified for the infrastructure.

Crossrail should establish reliability growth teams for the infrastructure. Dedicated resources should be used to strengthen the existing rolling stock team, and create a separate infrastructure

team. The recommendation for two separate teams is motivated by the complexity of the subsystems (infrastructure and rolling stock) in their own right. Clearly a close degree of collaboration will be required between the two reliability growth teams.

Reliability growth needs to be a full time dedicated role, not a part time activity of staff that are already busy doing other things. Suitable reporting metrics should be defined to track reliability and these should be included on the project steering dashboards.

Recommendation 20: Crossrail should establish reliability growth teams for the infrastructure. Dedicated resources should be used to strengthen the existing rolling stock team, and create a separate infrastructure team. Resources dedicated to reliability growth should be in each of these teams.

7 Metrics

Tracking progress is one of the most significant challenges to be managed. The level of detail required and the sheer number of issues being managed means that information and collaboration must be fine tuned and specifically focused. The Software Quality Assurance Plan Crossrail TCMS [20] states:

“The main parameters of management reviews are project cost, schedule, scope, and quality.”

The last metric (quality) is of most interest to the ability of the railway to operate reliably. It is this metric that is the subject of this section.

7.1 Triage – Good people up front will save time downstream

Triage is the process of evaluating test / fault data and then assigning actions to relevant teams on the basis of a preliminary assessment of the cause.

The triage process conducted for rolling stock events is maturing, however it is critical that the process be operating with a success rate as close to 100% as possible. The allocation of an issue to the incorrect party not only burns resources of the one (incorrectly) investigating the issue, but also delays the rectification of the issue. There is a need for staff with deep product knowledge to be present for the triage process. Contractors must be encouraged to ensure that appropriate staff are made available.

Recommendation 21: Ensure sufficient staff with deep product knowledge are available for the triage process. A commitment from contractors at senior level should be sought to ensure their best people will be available.

7.2 Prioritisation of bug fixes

The process of fixing bugs is well organised in both Bombardier and Siemens. Both companies have, and are using, well developed processes and systems to deliver their software.

CRL must ensure that the order of the bug fixes is in line with their needs in delivering a working railway. The decision on bug fix priority and scheduling does not currently have sufficient guidance from CRL.

This will become more important downstream in the testing process, when the immediate needs of the individual contractors may diverge from the needs of the systems integrator. Equally important is that the work methods of the developers be taken into account (consider inefficiencies of having to open up a module 3 separate time to fix three separate bugs, against fixing all three bugs in one rework of that module). Clearly the prioritisation will never work out perfectly, however, an informed discussion led by clients direction should provide efficiencies.

Recommendation 22: The Lead for Systems Integration should be involved with establishing the prioritisation for bug fixes. The works programs for fixing bugs should be developed with an overview of delivery of the Crossrail Transportation System

7.3 Bug / Failure resolution tracking

On of the most important tasks (arguably the most important) at this stage is fixing bugs in the software. A series of spread sheets and reports are currently being used to track bugs and the fix status. One example is the signalling tracker for Melton [18]. Given that the resources required to

fix the problems are scattered around the world, and the problems regularly require deep technical analysis from multiple parties, a collaboration tool with multiple user access would appear to be significantly more efficient than a collection of spreadsheets.

Recommendation 23: Invest in high end development collaboration tools to assist the bug solving.

7.4 Software

Production of software is one of the most difficult engineering deliverables to track. Project managers are traditionally confronted with a dark cloud of development out of which (at seemingly random intervals) springs releases addressing an even more random collection of bugs, reworks, patched, upgrades and required functionality. The lack of transparency and inherent unpredictability of the delivery makes software a very difficult commodity to manage in a major project.

Interestingly enough, the less safety critical the software, the more prone it is to delay and rework¹.

Software development proceeds through a structured approach, much the same as all engineering deliverables. There are (should be) processes in place that will lead to the development of structured code through a design and verification lifecycle. Similarly, the occurrence of defects and faults should be addressed through a structured approach, in which the defects can be tracked directly to software releases.

Safety critical software is developed in a far more structured process than non-safety software, hence, whilst taking longer to produce than non-safety software, it will usually be delivered by a predictable (and late) date. Furthermore, once delivered, it can be expected that the more safety critical the software, the less rework it will require.

It is expected that both BT and Siemens have world class processes in place for development of software.

Recommendation 24: Deep dives should be made on BT as well as Siemens delivery processes. The objective of the deep dives would be to gain visibility of the development process in sufficient granularity as to be able to track delivery of bug fixes throughout the development cycles.

Due to the current workload, and also to provide objectivity, the party making the deep dives should preferably be external to CRL. The review should have as objectives:

- Making transparent to CRL and RfL the actual progress on software delivery and:
- Allowing CRL and RfL insight when prioritising and scheduling of the bug fixes.

¹ This statement is based on a statistically insignificant sample of projects and is not in any way supported by scientific research.

7.5 Identification of meaningful metrics

The existence of these processes and systems for the development of software and fixing bugs provides a plethora of metrics that can be used to track the actual progress of the software. Care must be taken that the view presented matches the level of detail required in the reporting (tracking each bug through each step in the development lifecycle is too detailed for the management overview, but provides important insight for the PM tracking the next software release).

The graph below tracks completion of artefacts from the software development cycle (refer annex D). As each step in the process is completed, an artefact is produced as evidence. The lifecycle process is well documented, and the number of artefacts can be determined quite accurately from the outset, so tracking the documentation is a valid means to tracking completion of a production cycle.

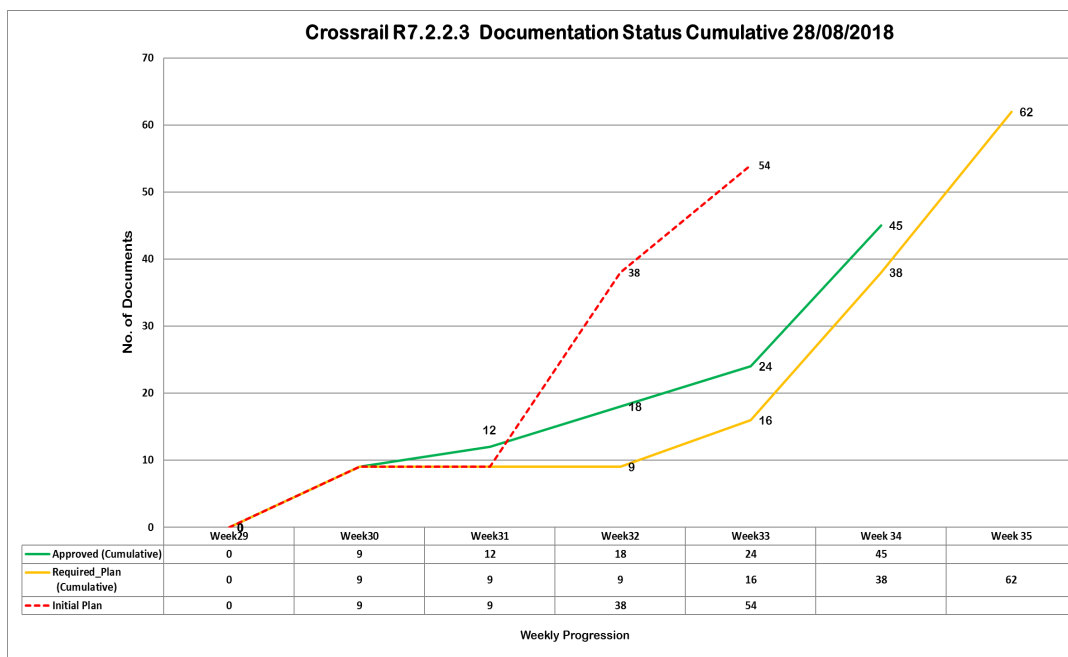


Figure 9: BT metrics for development lifecycle artefacts

This does demonstrate visibility into the progress of the Bombardier software development lifecycle. The problems that arise are that the process is non linear (so rates of delivery can not be interpreted as a solid indication of anticipated final delivery date), and the metric tracks only one cycle. Where multiple batches of software are in production, it is necessary to track multiple lifecycles.

Dashboards were sighted showing percentage of bugs cleared allocated across testing facilities. Whilst the total could be seen to be tracking down, there was not and insight into overall quality of the software being delivered. Similarly, metrics that report on percentage of functions delivered were set apart from the overall functional requirement. Tracking of functions delivered against a particular release (functions working in that release divided by total functions expected in that release) needs to be complimented with a view on how many functions are to be delivered in the entirety of the contract, and where the current software is against that target.

The point of this section is not to criticise all of the metrics that are being used, but rather to encourage those using the metrics to develop a deep understanding of what is should be measured and challenge the metrics with which they are presented.

Recommendation 25: Identify meaningful metrics to track software development. These metrics should be generated directly from the software development process (to prevent rework). Metrics should track to delivery of functionality towards the contracted specifications. More specific metrics should be defined for tracking bug fixes through the development process.

8 Commencement of Stage 4 and Stage 5

Revised opening dates, as shown in the table below.

	Commencement Date Existing	Commencement Date Proposed
Stage 3	9 Dec 2018 ³	Autumn 2019 ²
Stage 4	19 May 2019 ³	September 2019 ¹
Stage 5	15 December 2019 ³	December 2019 ¹

Table 1: Commencement dates for Stage 3, Stage 4 and Stage 5

Note to table

- 1: Dates as proposed in the "Checkpoint 2 – Stages 3,4 and 5 Schedule Implications" presentation , Sheet 13, Base case [1]
- 2: Date taken from public announcement of Crossrail of delay
- 3: Date as detailed in P05 Full PDF pack [26]

The analysis of the risk is a look into the technical and operational readiness of the Crossrail Transportation System. It will be the technical and operational readiness that will define constraints within which the operational plans can be developed. The constraints placed by the timetabling process are defined under the NR processes. Whilst these are acknowledged, they are not further considered in the following discussion.

8.1 Risk analysis

Stage 3 represents delivery of significant part of the Crossrail technical functionality. Transitions from both Great Eastern as well as Great Western will have been completed along with the systems in the COS. There remain, however, many on going project elements both in the surface section as well as with the Rolling stock. These elements are, to a great degree, independent of the delivery of Stage 3.

The assessment of the risks to the revised opening dates for Stage 3,4 and 5 should consider three separate classifications of risk being:

- Existing unaffected risks
- New risks and
- Existing affected risks

Existing unaffected risks

There are existing risks associated with the delivery of Stages 4 and Stages 5 which are independent of any Stage 3 (COS) delivery. The On Network Works are not (or marginally at most) influenced by any delay in Stage 3 works. For example:

- Great Eastern Traction Power upgrades;
- DOO CCTV Shenfield and Liverpool Streets;
- Inner west station upgrades;
- Outer west Platform extensions and DOO CCTV

The risk associated with the delivery of these elements is the same now as it was before the revised schedule. These risks can be set aside for the present analysis.

New risks

These are risks that are introduced by the revised schedule. The relevant characteristic of the proposed commencement dates is a compression of time between Stage commencements. This will introduce new risks where work streams are compressed and may need to be executed in parallel. For example:

- Conversion of 345 to FLU at the same time as delivery and reliability growth;
- Liverpool Street platform remodelling at the same time as other ONW;
- Remodelling of Plumbstead Sidings at the same time as operating (a reduced number of) works trains.

The compression risk should be able to be effectively managed through careful planning and provision of additional resources.

Recommendation 26: Conduct a comprehensive review of planning and resource requirements associate with compression of the timeline.

Existing affected risks

Some risks associated with Stage 4 and Stage 5 are impacted on by Stage 3 scheduling changes. Two risks in particular are of concern here

- Operational readiness: the risk that the operations teams are not ready in time. The increase in this risk occurs to the need to be on a learning curve for successive stages in close succession, arguably leaving no time to achieve a comfortable level. This risk can be well mitigated as discussed below in section 0.
- System Reliability: The risk that the Crossrail Transportation System (thus rolling stock as well as infrastructure) will not have sufficient time to achieve an acceptable level of reliability. A shorter time means less train kilometres, which is strongly correlated to less reliability growth. This risk is difficult to mitigate: If the reliability growth program is doing all that it can, it is impossible to inject additional time between two fixed dates.

The conclusion to be drawn from this analysis (albeit brief), is that the key factor driving risk is the reliability of the Crossrail transportation system. This is exactly the same issue that brings so much uncertainty onto the prediction of the Stage 3 Commencement date.

In essence – no one knows, and only time will tell.

Recommendation 27: Decide on commencement dates for Stage 4 and Stage 5 after there is a better indication of the reliability of the Crossrail Transportation System.

8.2 Operational de-risking of Stage 5.

Stage 5 represents a significant change in operational responsibilities. MTR-C will need to take over certain train services and station operations.

If these operational responsibilities can be taken over in advance of the Stage 5 delivery date, then the commencement of Stage 5 is reduced to “merely” a timetable change. RfL is investigating, and has started work towards realising this advance take over of responsibilities. The approach is for MTR-C to take over responsibilities as follows:

- 1) Take over Western inner stations; Now complete.
- 2) Operate 2 tph service with 345 trains between Paddington – Hayes & Harlington (now running).
- 3) Operate 2 tph with leased class 360 units (the old “Heathrow Connect”) between Heathrow – Paddington. (now running).
- 4) Replace class 360 with class 345 and increase the frequency to 4 tph between Paddington – Heathrow (also defined as Stage 2, Phase 2).
- 5) Run class 345 empty sets to Reading from November 2018. This will be increased to 4 tph for the commencement of Stage 5 (to make a total of 8 tph between Paddington – Hayes & Harlington, all in passenger service).

After the implementation of these steps, MTR-C will be operating all stations and services required for Stage 5 - prior to the commencement of Stage 5. The final transition to Stage 5 will consist of:

- Adding 2tph to Heathrow (making 6 tph to Heathrow and 10tph into Paddington -12tph in peak); and
- Sending services into the COS (putting them all down the tunnel) rather than terminating at Paddington.

This approach will ensure the operational risk from the commencement of Stage 5 is well mitigated.

(note: This situation is not relevant for Stage 4 as all staff are in position for the commencement of Stage 3 – there are no new additional roles for Stage 4.)

8.3 Combining Stage 3 and Stage 4

Stage 3 and Stage 4 could be combined. This approach would effectively bypass stage 3. This is by no means a desirable option as it carries all of the risks associated with Stage 3 opening and then adds the further complication of the (Stage 4) transition to the Great Eastern and interleaving services. In short: all of the problems but none of the benefits.

8.4 Combining Stage 4 and Stage 5

Stage 4 and Stage 5 could be combined into a single step. Whilst on paper, this would increase the time available for the commencement of Stage 4/5 (as there is no time between Stage 4 and Stage 5), it would not for all practical purposes provide and benefit. The transition to a joint Stage 4/5 would technical and operationally be two separate transitions.

Furthermore, it would be ill advised to proceed with a joint Stage 4/5 opening for the simple reason that any problems (especially during the commencement) will impact the Great Eastern, Great Western and COS. It is a high-risk option that brings little (if any) benefit.

8.5 Swapping Stage 4 and Stage 5

Stage 5 sees 24 tph along the COS (12 tph from the Great Western, and 12 shuttles within the COS). The turning capacity at Abby wood is limited to 12 - 15 tph.

Without the ability to run trains onto the Great Eastern, it would not therefore be possible to run the Stage 5 services.

One option could be to reduce the number of COS shuttle services planned for Stage 5. The number of services through COS would remain the same as in Stage 3, however the trains would be bringing passengers with them into COS, thereby significantly reducing the available passenger capacity (number of "empty seats") within the COS.

Given the programme for completion of works required to commence Stage 5 (in particular the On Network Works), the swapping of Stage 4 and Stage 5 would effectively mean that stage 4 is simply delayed until after Stage 5. Stage 5 can not be moved forward, it is constrained by delivery of a number of project elements. The impact that this delay would have on Great Eastern service, the Liverpool Street platform changes (and associated blockade) and passenger service have not been reviewed during the execution of this report.

Recommendation 28: Investigate the full consequences of swapping Stage 4 and Stage 5. Consideration should be given to increasing the turnaround capacity at Abby Wood through back stepping of drivers.

Response Summary:

The decision on commencement dates for Stage 4 and Stage 5 should be driven by the reliability of the Crossrail Transportation System as it is operating after each successive Stage. If the Crossrail Transportation System is working with a high degree of reliability, then making commencing Stage 4 in November 2019 and Stage 5 in December 2019 would not be a problem.

Planning to do so would not be prudent for a number of reasons, namely:

- it is highly unlikely that the CrossRail Transportation System will have achieved a suitable level of Reliability by that time;
- Any problems with commencement of Stage 4 would need to be addressed in within one month, before they would be compounded by Stage 5 commencement;
- Things during railway commissioning's rarely "all go well"; and
- Timetable changes (would this even be possible?).

In essence, making a decision at this point in time For a Nov / Dec start of service would be a huge gamble based on insufficient information. A more appropriate strategy would be to delay the decision on commencement dates until the last possible moment in order to have more insight into the Crossrail Transportation System reliability growth.

If the decision can not be delayed, then the most appropriate decision would be to aim to commence Stage 4 in Dec 2019 and Stage 5 thereafter.

9 The Rannachan Report

An independent report was prepared by Ian Rannachan [16]. Whilst the focus of that report was slightly different to this review, there are points where both reports draw conclusions on the same matters. This section is provided to assist the reader in making the link between these two reports. This section makes a comparison of the relevant headline conclusions and recommendations from the Rannachan report with the position presented in this report.

Both reports seem to agree on durations and logic. The main difference is in the proposed philosophy to move forward: being the difference between “construction completion” and “operational commencement”.

Extracts from the Rannachan report [16].	Conclusion from this report
Routeway: I have low confidence that the 21 Oct 2018 date for completion of routeway to support the start of 5x2 Dynamic Testing can be achieved.	Agreed that C610 will not be entirely complete, but they should move aside to allow train testing. Refer section 3.3
There is a balance to be struck to ensure that the volume of works being moved post the start of 5x2 DT into the 5x2 DT restricted working regime is minimised. It is my view that the end of December would be a more balanced date.	Partially agreed. The balance should be in favour of class 345 testing, rather than completion of route works. (refer sections 2 and 3.3)
I have low confidence that the train software (BT and Siemens) will have been sufficiently tested to support start of 5x2 Dynamic testing on 22 Oct 18.	Agreed – but testing of the train on COS should begin anyway. Refer section 4.1
While it is true that 5x2 Dynamic Testing could begin without having completed all 27 tests this approach is likely to import risk into the subsequent four pass dynamic test plan.	Agreed, it will import risk, but give an overall program advantage, hence the need for function development and reliability growth. Refer section 4.1
The duration for dynamic has been established reflecting a four pass testing scenario with an overall duration of 16 weeks. I believe that a fifth path (four-week cycle) risk provision be added to this duration.	Agreed that more time will probably be required, but the precise definition of 5 passes will probably not materialise. Refer section 4.3
Trial Running and Trial Operation: The durations allowed for these activities appear to be supported by defined test plans. I would agree that the addition of a four week risk period to cover “Reliability Risk”, as shown in the “current view of MOHS in section 3, would be prudent.	Agreed but another approach used. A focus on reliability growth from the commencement of testing in COS. Refer section 4.1

Extracts from the Rannachan report [16].	Conclusion from this report
<p>The start of 5x2 Dynamic Testing should be delayed to 7 January 2019 start. By doing so the four pass 5x2 Dynamic Testing plan is likely to be significantly de-risked.</p>	<p>Not Agreed Testing of the train in COS should begin as soon as possible Refer section2</p>
<p>Routeway to complete and fully test their works, except for SCADA testing by end of December 2018. By doing so the volume of physical works and testing left to complete in the routeway will have been substantially reduced.</p>	<p>Not Agreed Here is the difference of between “construction completion” and “operational commencement” Refer section2</p>
<p>Train software (BT and Siemens) testing must complete the minimum of 27 of the 29 tests before the start of 5x2 Dynamic testing. The extra period of time that would be created by delaying the start of Dynamic Testing can effectively be used to ensure that a fully tested train is available at the start of dynamic testing.</p>	<p>Not Agreed Here is the difference of between “construction completion” and “operational commencement” Refer section2</p>
<p>An action plan is required with a view to delivering a step change in C660 testing work processes and resource / supervision levels. The objective of this initiative being to target completion of C660 testing and assurance by April 2019 as opposed to June 2019.</p>	<p>Agreed Refer section 3.1</p>

Annex A: List of Interviewees

The following persons were interviewed in the course of this audit:

Name	Company	Role
[REDACTED]	Crossrail	Chief Executive
[REDACTED]	RfL	Operations Director
[REDACTED]	Crossrail	Head of Planning
[REDACTED]	Crossrail	Technical Director/Close Out Director
[REDACTED]	Crossrail	Central Section, Delivery Director
[REDACTED]	Crossrail	Rail Systems Delivery Director
[REDACTED]	Crossrail	Stations Delivery Director
[REDACTED]	Crossrail	Head of Integration
[REDACTED]	Crossrail	Signalling & Communications Delivery Director
[REDACTED]	Crossrail	Chief Engineer
[REDACTED]	Crossrail	Testing & Commissioning Programme Director
[REDACTED]	Crossrail	T&C Manager / Deputy Chief Engineer
[REDACTED]	Crossrail	
[REDACTED]	Crossrail	Test and Commissioning Strategy Manager
[REDACTED]	MTR-C	Managing Director
[REDACTED]	MTR-C	Programme Director
[REDACTED]	RfL	Deputy Director Operations
[REDACTED]	RfL	Deputy Director (Rolling Stock/Depot)
[REDACTED]	RfLi	Head of Engineering
[REDACTED]	RfLi	Head of Infrastructure
[REDACTED]	RfLi	
[REDACTED]	LU	Director of Asset Operations
[REDACTED]	LU	Programme Manager – LU Crossrail Team
[REDACTED]	ATC	Project Director (contract C610)
[REDACTED]	Siemens	Project Director (C620 and Bombardier signalling sub contract)
[REDACTED]	Bombardier	Head of UK
[REDACTED]	Aspect Green Consulting Ltd	Director
[REDACTED]	TfL	Crossrail, NED and LU Managing Director
[REDACTED]		Crossrail, NED
[REDACTED]		Crossrail, NED

Annex B: Document list

The following documents were referenced during the course of the review.

- [1] Checkpoint 2 – Stage 3, 4 and 5 Schedule Implications, Presentation to Sponsor Board 3rd September (file: Checkpoint 2_Stage 3_Sponsors_Final.pptx)
- [2] MOHS Sept 2018 Update – Plan for the Plan (file 20180906 MOHS Update Sept 2018 Plan.pptx)
- [3] Trace Restrictions Matrix, 7 Sept 2018 (file: Trace Restrictions Matrix Rev 20.1 amendment.pdf)
- [4] Email from Phil Clayton 31 August 2018 08:30 Subject Readiness for 5:2,
- [5] Bombardier’s Software Development Lifecycle, undated (file: Bombardier’s Software Development Lifecycle.pptx)
- [6] Triage Process Overview, 16 March 2018 (file:Triage_Process_Overview_20170316.pptx)
- [7] Weekly Progress Report Bombardier, 31 Aug – 4 Sept 2018, (file: Crossrail Weekly Report 31.08.2018 V3.0.ppx)
- [8] MOHS Review 3 Aug 2018, (file 201803 MOHS Review 3 Aug Final.pdf)
- [9] Stations Schedules Review 21 August 2018 (file: 20180821 Stations Schedule Review.pptx)
- [10] Siemens Testing & Commissioning Strategy , C620-SIC-R2-STP-CR0001-50027, 20-06-2016 (file: C620-SIC-R2-STP-CR001-50027_Rev5 30 06 16.pdf)
- [11] Testing & Commissioning, Entry Into Main Dynamic Testing Regime, 24/08/2018, Doc: CRL1-XRL-O8-STP-CR001_Z-50003 (file: CRL1-XRL-O8-STP-CR001_Z-50003 Entry into Main Dynamic Testing Regime r1.docx)
- [12] Glossary of Handover Related Terminology and Abbreviations, Document Number: CRL1-XRL-Z-GUI-CR001-50038 (file: CRL1-XRL-Z-GUI-CR001-50038_.docx)
- [13] Crossrail Regulatory Approvals Generic Presentation, undated (file Crossrail Regulatory Approvals Generic Presentation.pptx)
- [14] Crossrail Board Report Period 4 2018-19, 24 June 2018 – 21 July 2018 (file: P04-Board Report Board Issue.pdf)
- [15] Note: “Response to A Pitt email of Aug 27th 2018”, undated (file Response to A Pitt email of Aug 27th 2018:
- [16] Crossrail MOHS Schedule Peer Review. A Report Prepared by Ian Rannachan, Independent Reviewer September 2018 DRAFT Monday 21 August 2018 (file: Crossrail Peer Review MOHS DRAFT 21 August 2018.doc)
- [17] Handover Strategy (Update), 31 August 2018 Rev 2 (file: Handover Strat-290818-JM-rev5.pptx)
- [18] Signalling tracker Melton, undated (file: Signalling Melton Open_Monitor Tracker 060918.xlsx)
- [19] Configuration management plan Crossrail, 2015-02-03 (file: Q234-BMB-R1-STP-CR001-50069 Rev 1.0.pdf)
- [20] Software Quality Assurance Plan Crossrail TCMS, 2016-11-14 doc 3EER400018-8368 (file: Q234-BMB-R1-RSP-CR001-50147 Rev 2.0.pdf)
- [21] Crossrail 345 – RLU Reliability Dashboard, report date 06/09/2018 (hardcopy)
- [22] FLU Reliability Growth Workstream 060918.xls (file: COS Reliability Growth Workstreams 060918 DRAFT FOR COMMENT.pdf)
- [23] Report Action Sheet PDF Version – Site – Data Refreshed 05/09/2018 (hardcopy)
- [24] Semi Annual Construction Report 19 17 September 2017 – 31 March 2018, DRAFT CRL Excom version (hardcopy)
- [25] Crossrail Board report Period 4 2018-19 (file P04-Board Report Board Issue.pdf)
- [26] Period 5 Programme Delivery Board full Pack 28 August (file: P05 Full PDB Pack.pdf)
- [27] Meeting Minutes, Trial Running Working Group Meeting 11 (file: Trial Running Working Group Meeting 11.docx)
- [28] Trial Running Strategy, Doc: CRL1-XRL-R-STP-CR001-50001 (file: Trial Running Strategy v3.0 .docx)
- [29] T-Minus readiness Review criteria (file: T-Minus Readiness Review Tracker (Trial Running) Rev 1.0.xlsx)
- [30] List of 29 tests, hardcopy, no date
- [31] Crossrail Schedule Assurance Review (SAR), the Assignment brief (file: Crossrail Schedule Assurance Review - 13.8.18 (John Boss))

Annex C: List of recommendations

- Recommendation 1:** Start testing the class 345 in the COS as soon as possible. 13
- Recommendation 2:** Accumulate miles as possible, as often as possible. If the class 345 is not being used for tested, then it should be out building up miles 14
- Recommendation 3:** Perform a deep dive review on the C660 scope, planning and outstanding works. Confirm that there is a valid prioritisation of I/O and that scope sheading has been explored to the maximum. Confirm progress of recruitment of radio testers against the remaining work scope. Confirm the maximum has been achieved with all possible mitigation measures..... 16
- Recommendation 4:** Romford control system was conspicuously absent from most discussion. It is recommended that a deep dive be undertaken on the control system specification and delivery to understand where the critical issues are, and achieve a good sense of comfort that they are being adequately managed. This should be a matter of urgency for the Systems Integration team. 16
- Recommendation 5:** Review the staffing needs and arrange now for sufficient staff to be available when the rush of assurance documents begins. 17
- Recommendation 6:** Start an action to push through assurance documentation that may not be entirely complete – but is in a state ready for the assurance process..... 17
- Recommendation 7:** The process for Trial Running preparation needs to be “un-parked” to develop the final test scripts and fine-tune the acceptance criteria. The work stream should look to identify synergies with the Trial Operations preparations, keeping always in mind that Trial Operations and Trial Running have different goals..... 19
- Recommendation 8:** Critically evaluate the list of “29 tests”, identify those that can be completed after the commencement of Dynamic testing. Prioritize activities to ensure the key tests from the 29 are passed before Dynamic Testing begins. 22
- Recommendation 9:** Create a milestone to check technical progress on functional development and reliability growth. The milestone will mark change in focus towards Dynamic Testing 22
- Recommendation 10:** A work group should be engaged to ensure all test scripts are detailed as a matter of urgency..... 23
- Recommendation 11:** Create a milestone during Dynamic Testing to trigger the definition of the Stage 3 commencement date. 24
- Recommendation 12:** CRL should make a special action to chase though all maintenance and as built documentation – ensuring that the documentation maintains a significant priority in overall delivery. 27
- Recommendation 13:** Establish a Systems Integration team with integration authority for the Crossrail Transportation System (thus including rolling stock and Network Rail). 28
- Recommendation 14:** Ensure the Systems Integration Team has boots on the ground and plays a leading role (beach master) in integration testing..... 29
- Recommendation 15:** Gather the senior managers from all contractors together – jointly address the question “What are we going to do together to get this across the line?”. Regularly follow up on commitments made. 29
- Recommendation 16:** Testing that spans systems should be under the control of the Systems Integration Team, in close collaboration with the CRL test team. 29

- Recommendation 17:** Ensure there is a clear vision articulated in the top level testing plan that defines how the subsystems will be brought together to deliver the Crossrail Transportation System. This should be complimented with clearly articulated start and finish criteria for each block. 30
- Recommendation 18:** Critically evaluate the resources available in Crossrail for supporting testing. It is imperative that sufficient numbers of suitably experienced people are available to facilitate and manage testing, in close collaboration with the Systems Integration team. 30
- Recommendation 19:** Continue to look for smart tooling to assist in performing and analysing tests. 30
- Recommendation 20:** Crossrail should establish reliability growth teams for the infrastructure. Dedicated resources should be used to strengthen the existing rolling stock team, and create a separate infrastructure team. Resources dedicated to reliability grown should be in each of these teams. 31
- Recommendation 21:** Ensure sufficient staff with deep product knowledge are available for the triage process. An commitment from contractors at senior level should be sought to ensure their best people will be available..... 32
- Recommendation 22:** The Lead for Systems Integration should be involved with establishing the prioritisation for bug fixes. The works programs for fixing bugs should be developed with an overview of delivery of the Crossrail Transportation System 32
- Recommendation 23:** Invest in high end development collaboration tools to assist the bug solving. 33
- Recommendation 24:** Deep dives should be made on BT as well as Siemens delivery processes. The objective of the deep dives would be to gain visibility of the development process in sufficient granularity as to be able to track delivery of bug fixes throughout the development cycles. 33
- Recommendation 25:** Identify meaningful metrics to track software development. These metrics should be generated directly from the software development process (to prevent rework). Metrics should track to delivery of functionality towards the contracted specifications. More specific metrics should be defined for tracking bug fixes through the development process. 35
- Recommendation 26:** Conduct a comprehensive review of planning and resource requirements associate with compression of the timeline. 37
- Recommendation 27:** Decide on commencement dates for Stage 4 and Stage 5 after there is a better indication of the reliability of the Crossrail Transportation System..... 37
- Recommendation 28:** Investigate the full consequences of swapping Stage 4 and Stage 5. Consideration should be given to increasing the turnaround capacity at Abby Wood through back stepping of drivers. 39

Annex D: TAG Activity Development

TAG	Activity	Applicability	Guidelines
TAG 0 – Planning (Documentation)	Milestone Review	Every release iteration until system maturity	See TAG guidelines (refer [6])
TAG 1 - System Design	Milestone Review	Every release iteration until system maturity	See TAG guidelines (refer [6])
TAG 2 - Software Requirements	Verification Review	Every release iteration	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 3 - Software Overall Test Specification	Verification Review	Every release iteration	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 4 - Software Architecture Design	Verification Review	Every release iteration	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 5 - Software/Hardware Integration Test Specification	Verification Review	Every release iteration	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 6 - Software Detail Design / Component Design	Verification Review	Every release iteration, only for components with SIL level > SIL 0	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 7 - Software Component Test Specifications	Verification Review	Every release iteration, only for components with SIL level > SIL 0	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 8 - Source Code Review	Inspection	Every release iteration	See section 6.2
	Verification Review		(refer section 6.2)
TAG 9 – Software Integration and Software Component Test Review	Verification Review Audit	Every release iteration Component Test result review only for components with SIL level > SIL 0	(refer section 6.2) See TAG guidelines (refer [6])
TAG 10 – Hardware/Software Integration Review	Verification Review	Every release iteration	(refer section 6.2)
	Audit		See TAG guidelines (refer [6])
TAG 11 – Overall Software Test Report	Ad-hoc testing	Every release iteration	Test Cases development guidelines
	Verification Review		(refer section 6.2)

TAG	Activity	Applicability	Guidelines
	Audit		See TAG guidelines (refer [6])
TAG Σ (SIGMA – Software Integration Gate for Maturity Analysis)	Milestone Reviews	Every release iteration	See TAG guidelines (refer [6])
	Inspections		
	Audits		
	FAls		
	Test Readiness Review		
TAG 12 – Verification & Validation	Verification Review	Final release iteration	See section 6.2
	Additional ad-hoc testing by Validator		
TAG 13 – Development Close- out	Milestone Review	Final release iteration	See TAG guidelines (refer [6])

Table 9 TAG Review Schedule from Software Quality Assurance Plan TCMS [20]
Table 10 has a comprehensive mapping of documentation from 50128:2011 to the corresponding BT document, and the parties responsible for its production review and approval.

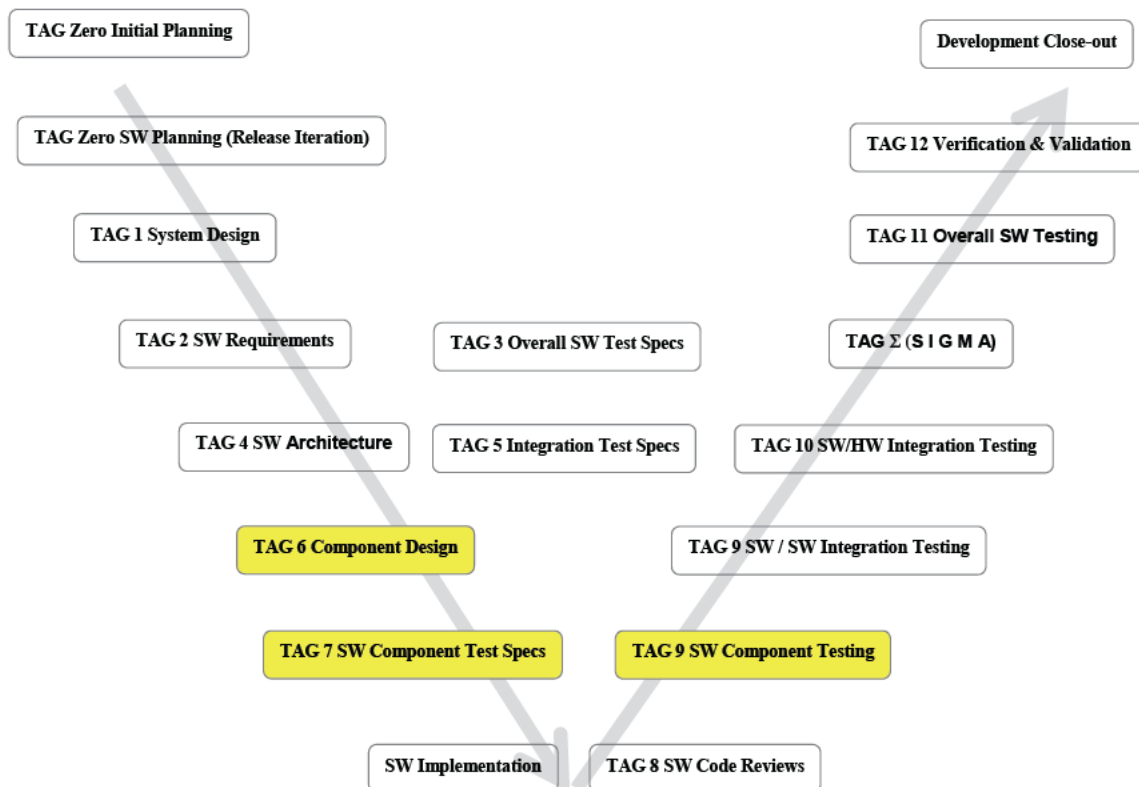


Figure 10: Bombarrier Tag Review for project Lifecycle

The above figure is extracted from Software Quality Assurance Plan TCMS [20] This is text book stuff. You see everything here that you would expect to see.

Annex E: Definition of Stages

Stage 1

Operation of Class RLU 345s on Liverpool Street to Shenfield route. Commenced and in operation.

Stage 2, Phase 1:

Services commence

- 2 tph between Paddington and Hayes & Harlington using RLU Class 345s
- 2 tph between Paddington and Heathrow using leased C360 units

Commenced and in operation.

Stage 2, Phase 2:

Full scope of Stage 2: 4 tph between Paddington and Heathrow using FLU class 345s. Not yet Commenced, Commencement is dependent upon completion of ERTMS.

Stage 3

15 tph Elizabeth line services between Paddington and Abbey Wood through COS

Stage 4

Elizabeth Line through services extended to Shenfield.

- 24tph FLUs in the COS.
- 12tph COS to Shenfield.
- 4 RLUs Gidea Park to Liverpool St High Level (Peak)

Stage 5

Elizabeth Line fully opened. Through running Great Western – COS.

- 6tph Heathrow to Paddington low level
- 2tph Maidenhead to Paddington low level
- 4tph Reading to Paddington low level

Annex F: Siemens 29 tests for Melton

- Test of emergency stop button
- Check for rollback protection
- Test of EB and service brake functions
- Train run in CBTC PM with ETCS cut off
- Train run in CBTC PM with ETCS enabled
- Determination of deceleration / braking values
- Train run in CBTC AM with ETCS cut off
- Train run in CBTC AM with ETCS enabled
- Push out operation (delocalised failed train)
- Push out operation (localised failed train)
- Pull Out operation
- Door Control Tests “full auto” with ETCS cut off
- Door Control Tests “auto open” with ETCS cut off
- Door Control Tests “auto close” with ETCS cut off
- Door Control Tests “manual” with ETCS cut off
- Door Control Tests with ETCS enabled
- Redundancy tests in SA
- Redundancy tests in CTC/PM
- Redundancy tests in CTC/AM
- Redundancy tests in CTC/AM with ETCS enabled
- DTRO-F with ETCS cut off
- DTRO-F with ETCS enabled
- DTRO-B with ETCS cut off
- DTRO-B with ETCS enabled
- Redundancy test during DTRO-F with ETCS cut off
- Redundancy test during DTRO-F with ETCS enabled
- Transition TPWS/AWS to CBTC (Cab 1 leading)
- Transition TPWS/AWS to CBTC (Cab 2 leading)
- Transition CBTC to TPWS/AWS (Cab 1 leading)
- Transition CBTC to TPWS/AWS (Cab 2 leading)

(Note: It is unclear why there are 30 tests on the list of 29 tests [30])

Annex G: State of delivery

An investigation was undertaken to “add colour” to the reports provided. This was a separate piece of work with a view to assess the progress of delivery against the currently known deadlines (i.e. prior to any revised schedule being announced within the project).

The conclusion from this investigation corroborates the positions presented in this report. The table below presents summary findings from Period 5 Crossrail reporting and discussions with Crossrail staff..

Item	Summary finding
<p>Readiness of infrastructure to commence dynamic testing on 22 October 2018</p>	<p>The evidence viewed suggests that Systemwide and SS&P infrastructure will not be sufficiently complete to enable entry into main dynamic testing on 22 October 2018 and, according to emerging reporting, it appears that late November 2018 may be the earliest achievable date.</p> <p>At the time of this review it is acknowledged that concerted effort is on-going to inform the T-4 dynamic testing Go/NoGo meeting on 21 September 2018.</p> <p>A realistic schedule for completing the infrastructure prerequisites contracts cannot be confirmed until:</p> <ul style="list-style-type: none"> • Clarity is achieved on the extent to which the ‘essential’ <i>Entry into Main Dynamic Testing Regime</i> pre-requisites must be completed. • Crossrail delivery translates relevant contract deliverables into the requisite level of detail (for example, the completion of specific scope ‘lots’ to the required assurance level) and instructs its contractors accordingly to ensure the essential prerequisites will be achieved. For example, this may require re-prioritisation of stations contract schedules to support C610 and C660. • Crossrail delivery confirms the integrated order in which essential prerequisites will be achieved. This will define the achievable milestone for entry into dynamic testing.
<p>Readiness of C660 and Stations, Shafts and Portals (SS&P) to support Stage 3 opening in July 2019</p>	<p>There is a significant risk that entry into trial operations by May 2019 will not be achieved by SS&P and C660 for a combination of reasons:</p> <ul style="list-style-type: none"> • The biggest perceived risk is agreement to over-optimistic milestones to achieve a SS&P and C660 schedule that has a high number of concurrent activities reliant on scarce resources to achieve delivery for Trial Operations in mid May 2019. • Approximately 70% equipment that C660 test and commission is physically delivered by others and it is particularly dependent on stations to complete sufficient scope to enable it to commence full testing and commissioning. With half of station TOSDs becoming due in October and November 2018, IRN productivity must show a marked increase at Period 6. If not, C660’s schedule will become more compressed and the likelihood of delay to Staged Completion milestones will increase. • C660’s resource challenge is significant and should mitigation not succeed, at least four stations may be delivered after May 2018, missing the target of mid May 2018 to achieve Staged completion ahead of Trial Operations commencing. This is subject to specific mitigation but,

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	<p>coupled with the complexity of C660's scope, there is a need to be realistic.</p> <ul style="list-style-type: none"> • The capacity of qualified resource to attend and enable both SS&P and C660 tests and also authorised staff to witness tests is a recognised constraint. TOSD presents a risk that sub-contract staff may be difficult to re-mobilise to support C660 completion. • The gateway between SS&P and C660 testing requires rigorous control to ensure that C660 is presented with 'complete' and certified works that it may then finalise against, for example fully complete input/output schedules and complete installation and pre-commissioning testing. Commissioning / handover verification from Tier One contractors must be faultless. • The Testing and Commissioning progress across the project coupled with the emerging schedule to complete Stage 3 suggests that those receiving assurance and accepting the railway for use are likely to face a significant challenge. It is recommended that a detailed schedule be prepared to demonstrate that CEG, RfLI, TfL and others are sufficiently resourced and have sufficient time to prioritise the completion of assurance to open Stage 3. • Although it is intended to stagger the Staged Completion of stations, this appears to be on the basis of the milestones achievable to Crossrail delivery assuming that all stations must be delivered for Stage 3. Although it is desirable to open all stations some, such as Paddington, are essential. It is recommended that the prioritised order of station delivery is considered before fixing the final delivery strategy for Stage 3 opening. <p>SS&P and C660 recognise the above issues and their respective leadership is currently implementing a range of mitigations to recover from the late delivery experienced to date and to support the new strategy. Measures being introduced that merit the support of other Crossrail functions include:</p> <ul style="list-style-type: none"> • An emphasis on exposing real issues within the supply chain now, to ensure that appropriate attention is given to these and that a challenging but realistic schedule is agreed. A 'master integrated schedule of prerequisites' to support TOSD and Staged Completion milestones is being prepared to underpin the October 2018 MOHS update. This may present differences to the proposed strategy of achieving Staged Completion ahead of Trial Operations. • A recognition that behaviours at all levels of delivery throughout Crossrail and its supply chain must change rapidly to identify, challenge and address real issues. Behaviour must focus on solving problems to achieve Crossrail's strategy, rather than protecting narrower delivery or commercial objectives held by parts of Crossrail and / or its supply chain. • The creation of a Stations Planning Authority that will determine how and when to allocate scarce resources to support the strategic delivery of the programme. This may also address access issues and other essential coordination with non SS&P contracts and third parties. To operate for the benefit of Crossrail's strategy the SPA must be unfettered by the commercial interests of the supply chain.
Readiness of	In relation to a forecast Stage 3 opening date of July 2019, RfL Operations advise

Item	Summary finding
Romford Route Control Centre (RCC) in relation to Stages 3, 4 and 5	<p>that it requires the fully agreed functionality of the signalling control and associated systems (power and SCADA control desks) at Romford RCC by 15 April 2019. This is to enable trial running and subsequently trial operations ahead of opening the railway. The following matters require consideration in relation to this requirement:</p> <ul style="list-style-type: none"> • Although not all of the expected signalling control functionality required by RfL will be delivered by the signalling control system, it is understood that an agreement of what will be delivered has been agreed. It not expected that the agreed requirements will be altered, but certainty that the agreed requirements will be fulfilled in full by 15 April 2019 is the expectation that RfL has set. • In confirming the detailed schedules to support the 8 October 2018 MOHS update, it is necessary that Crossrail delivery confirm that it can meet RfL Operations' completion requirements. • Although the Automatic Train Supervision (ATS) software has been written against the agreed requirements, functionality remains to be refined, fully tested and integrated. ATS is necessary at the transitions with Network Rail and is essential that the western transition with Network Rail is operational for Stage 3. Transitions are discussed further below in relation to Stages 4 and 5. • Detailed Human Factors work is planned but has not been completed. This is necessary for the Safety Case and Stage 3 opening. • Training of RfL has commenced but cannot be completed until Siemens deliver a final update to simulators enabling full functionality. This was due in June 2018 and the latest forecast for RfL to receive the updated simulator software drop is 29 October 2018. • RfL Operations has encountered and continues to mitigate its own challenges with staff resourcing. RfL has indicated that certainty of Crossrail the trail operations milestone is important in enabling it mitigate its resourcing issues and it would value early warning of any potential delay to the 15 April 2019 target date. <p>In addition to completion of the western Network Rail transition for Stage 3, the eastern Network Rail transition is required for Stages 4 and 5. Details of the transition solution and its progress are unclear and it is recommended that Crossrail's systems integration team is extended across the interface with Network Rail to gain confidence that integration will be achieved that satisfies both Crossrail and Network Rail technical and operational requirements. Examples of matters that indicate that clear oversight is required include:</p> <ul style="list-style-type: none"> • Network Rail is delayed in completing communications scope between its signalling control centres and the Romford RCC. Until this work is completed (there is no connection at Romford yet) the transition tests cannot be performed in full. This work is understood to be technically straightforward, but Crossrail cannot complete transition testing without this in place. • The transitions rely on Network Rail's supplier Resonate to configure an innovative 'Ripple Berths' software solution. It is understood that Resonate has no previous experience of delivering this type of solution and, as Resonate is Network Rail's supplier, Crossrail does not have any

Item	Summary finding
	<p>technical oversight over its progress in achieving the solution required.</p> <ul style="list-style-type: none">• Further possessions are necessary to complete transition testing, although the number of tests and possessions and their timing has not yet been resolved. This requires resolution to ensure testing may be completed ahead of 15 April 2019.