TESTING AND COMMISSIONING PROCESS FOR A LIGHT RAIL PROJECT

R. Sharma*

*Ove Arup & Partners Ltd, Infrastructure and Planning Midlands (Rail)
Blythe Valley Park, Solihull (West Midlands), B90 8AE, United Kingdom
Email: rohan.sharma@arup.com

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Abstract

This paper discusses a testing and commissioning model for a typical light rail project. The paper does not propose a new methodology or concept, but the idea is to consolidate different testing and commissioning exercises into a generic structure of stages, which can be applicable to any light rail project. The various stages depend on the level of testing and integration required as a project progresses from supply of equipment and installation to integration and actual operation. Systems integration is a vital aspect of the testing and commissioning programme and is discussed in brief in this context. The documentation and control necessary to complete the testing and commissioning programme are also outlined.

1 Introduction

Testing and Commissioning (T&C) is a very important phase, or series of activities, in the construction of a light rail system before it can be safely opened for commercial operation. Like in any other industry, T&C demonstrates that all technical and project requirements, as developed during the concept and design stages, are met. It ensures that interfaces between different systems and with existing and third party systems are systematically closed and integrated. T&C confirms that the railway is ready to be taken over by the employer and/or the operator.

T&C needs proper coordination between the various parties involved in a railway project. To distinguish between them, the generic terms used in this paper are:

a. **Employer** – the infrastructure owner / organisation awarding the main contract or the set of contracts;
b. **Contractor** – the main contractor along with the sub-contractors who build the railway;
c. **Manufacturer** – all contractors and sub-contractors who supply equipment, rolling stock, etc.;
d. **Operator** – the railway operator;
e. **Third party** – any organisation or system outside the main contract.

2 Planning and requirements

Testing and Commissioning physically begins during the construction period, after the Detailed Design stage is complete. The activities prior to T&C include completion of work like safety validation, submission of reports such as the compatibility of new infrastructure with existing infrastructure, rolling stock, railway operations, etc.

Usually, the employer provides a basic framework for the T&C process during the project concept phase and identifies who should be responsible for it. This framework sets out the fundamental criteria and requirements for testing a system. Based on this, the contractor(s) develop and use a detailed and overall **T&C Plan**, which defines the contractor’s systems, the interfaces between those systems and the resulting tests. The plan also reflects the necessary compliance mechanisms that will ensure that the new systems get accepted by the employer and/or the approval bodies. This plan can be specific for a system too, such as for trackwork, traction substations, etc.

In a simple scenario, a contractor’s scope of T&C tests is generally for all the works and systems in the contract(s) awarded. The contractor can appoint a T&C manager to oversee all the T&C activities. Each contractor identifies all the tests to be carried out in accordance with the employer prescribed stages structure or model. A simple T&C stage model (FAT-SIT-SAT-SATOV) is elaborated in Section 3. This overall structure can be applied across all tests in various disciplines and systems of the project.

Individual contractors and sub-contractors submit the testing and inspection methods/manuals for employer’s review. Besides, they also do the following:

- provide the procedures for reporting all tests and for authorising their acceptance on completion;
- provide a testing schedule so that the T&C dates can be incorporated in the project programme;
- provide the necessary equipment and supervisory staff to complete inspection and testing;
- ensure that safe and efficient methods of testing are used;
obtain appropriate approvals when testing on or near operational systems; and
complete all documentation after testing.

3 Testing and Commissioning Stages

This section describes in detail the testing and commissioning structure. The structure divides the T&C process into four main stages:

(i) Factory Acceptance/Inspection Test (FAT);
(ii) Site Installation Test (SIT);
(iii) Site Acceptance Test (SAT); and
(iv) Overall Site Acceptance/Performance Test (SATOV).

The process is illustrated in the stage diagram in Figure 1.

3.1 Factory Acceptance/Inspection Test (FAT)

The FAT stage is the testing of equipment and equipment components during production in the factory or in similar conditions. This initial stage of the T&C process confirms that the supply of individual components and equipment is according to the design and the overall project requirements. This stage gives the proof that all the components and equipment meet the specifications. FATs normally take place at the manufacturer’s premises but can also take place at the contractor’s premises for certain equipment.

Factory Acceptance Tests should be done for all the individual components and equipment, and in relation to systems, to all the hardware and software. In terms of hardware, two types of tests can be performed – routine tests and type tests.

Routine tests are done for each piece of equipment and components and include tests such as visual inspection, dimension check, electrical conductivity check, insulation check, calibration, mechanical and hydraulic tests and any other compliance tests. Type tests are performed on a sample of the complete equipment of each type, rating, etc. based on agreed standards or a technical constraint in the contract. These can include tests like mechanical strength, electromagnetic compatibility, electrical characteristics, reliability tests, etc. Type tests should be witnessed by the contractor’s or employer’s representatives.

The FAT stage may also include some integration tests at the manufacturer’s factory, which are performed to test the integration of the components that make equipment.

Each software system (such as the line signalling system, vehicle detection system, supervisory control, etc.) can be tested using a test bench to simulate inputs and outputs. This also allows as much integration testing as possible, thereby reducing the overall integration risks to equipment at later stages. Each software FAT should take place in an environment as close as possible to the operational environment.

3.2 Site Installation Test (SIT)

The SIT stage is the testing stage following the installation of equipment and sub-system on site. The goal of the SITs is to demonstrate that all the equipment or sub-systems are correctly installed and wired, are checked and are suitable for operation. The tests mainly consist of visual inspection, standalone or no-load tests and some operational tests. The SITs can be carried out on a site by site basis and in phases as the railway line sections get built and equipped. They can be extended section by section until all the line has been tested. These sections can be established according to infrastructure contraints such as the track layout, the location of crossovers, etc., line constraints such as the overhead contact system, the location of sub-stations, etc., and other third party and project management restrictions.

Consider an example of the SCADA (Supervisory Control and Data Acquisition) system. A SIT could include checking that a ‘Remote Terminal Unit’ has been installed with correct components, cables neatly and securely terminated, etc.

In general, the site inspection and testing check for correct equipment type, quantities, any damage, correct installation and integration in the sub-system, and any damage after installation. Particular tests can include electrical continuity and insulation tests, functional level tests such as on exchange of data, some low level standalone operational tests, etc.

SITs for train on-board equipment are performed on the train and therefore can be completed at the rolling stock manufacturer’s factory, but can also be repeated at the employer’s site.

3.3 Site Acceptance Test (SAT)

The SAT stage is the stage when all installed equipment and sub-systems are tested. This stage shows that all the various equipments and sub-systems can functionally operate, thus fulfilling all the performance requirements.

This pre-commissioning stage can be split into two sub-stages – the first where all the systems are under a predefined scope (SAT-Internal), and the second where at least one of the systems under test for integration is outside this predefined scope (SAT-External). This split up should be defined by the employer and is usually based on the contractual scope. It can be based on other criteria such as the complexity and extent of interfaces with third party, between different types of contracts for various contractors, between major disciplines, geographical and physical constraints, etc. Like the SITs, SATs can be carried out in phases too.

The difference between the two sub-stages can be clarified by an example. Consider the overhead line electrification (OHLE) system. The SAT-Internal could include testing of the installed OHLE wires alongwith the traction feeder...
In systems which are densely integrated, like those on any railway, it is these integration tests that need special attention because of the inherent complexity of the interfaces between the systems. Usually, SAT tests can be quite comprehensive in order to close all interfaces and can include a range of tests such as verification of inputs and outputs for operating equipments, recording of tolerance margin for interfaces (e.g. ‘Sound Noise Ratios’ in Passenger Announcement system), etc.

In cases where interfaces are highly complex, where failures are difficult to correct or where many interfacing systems may require substantial modifications, interim SATs can take place to pre-verify performance of the interfaces and designs in order to minimise modification and cost of re-work at a later stage. These interim SATs can happen immediately after SITs or in some cases overlapped with the FAT stage. Train on-board systems, for instance the on-board vehicle detection system, usually go through this stage.

Protocols for the central control and communications system can be pre-tested on site or at a factory location. For example, in case of a line extension programme, communications equipment can be integrated from trackside cabinets up to a certain location during SAT-Interim and then can be tested up to existing central control room during the SAT sub-stages.

3.4 Overall Site Acceptance/Performance Test (SATOV)

Overall testing (SATOV) can be defined as set of activities that prove that the overall system will operate satisfactorily in actual service. SATOV stage requires the operation of substantial amounts of systems on a coordinated basis, in a manner which is similar to the operation of systems in commercial service. This would involve performing all functional tests on all equipment and systems with operator involvement.

This commissioning stage can only begin when all the earlier stages are complete. There are, of course, exceptions such as opening of a control centre when a small section of line is ready while the rest of the line(s) open progressively. SATOV concludes the T&C process and proves that the final system will operate and meet the totality of the employer’s requirements. As this stage involves all parties, including the operator and local authorities (if needed), top level coordination by the employer and the contractors is essential.

SATOVs can be split into two – SATOV-Equipment and SATOV-Line. As the name suggests, SATOV-Equipment are SATOV tests covering all the equipment supplied under the project scope, the successful completion of which is essential for systems acceptance. This can include functional tests (to prove that all equipment will work properly under actual operating conditions), full load tests (to prove that the system operational performances are in compliance with the
specification and employer requirements), degraded mode tests (such as checking ‘incident recovery time’, etc.), and endurance tests (to prove that the system correctly operates over long periods of use).

Note that SATOV-Equipment could be considered an extension of SAT-External but they are not the same. SAT-External is limited to system interface tests with another discipline or contract sufficient for site acceptance, while only satisfactory completion of SATOV-Equipment will deem the system ready for hand-over to the employer/operator.

SATOV-Line is a trial run period that commences after SATOV-Equipment and hand-over. All the equipment is placed under operation with actual train running. This trial period length is specified by the employer and during which time all SATOV-Line tests should be performed. Usually, they should be completed within a specific period after hand-over.

SATOV-Line demonstrates the functional operations and performances of the equipment in the actual railway line operating environment. It consists of the functional tests, maximum operating load tests, degraded mode tests, endurance tests, and the validation of performance requirements.

However, the above explanation for SATOV-Line can be slightly biased as it represents a testing stage from the infrastructure point of view. This is because the SATOV stage for new trains can begin whenever they are trialled, which could be on an existing line. Therefore, this SATOV-Line can double up as the overall testing of both old and new rolling stock in actual operation on the new infrastructure.

Although the contractors participate and provide technical support, the ultimate responsibility for carrying out the SATOV-Line tests after the hand-over lies with the employer, in close coordination with the operator of course.

4 Systems Integration

4.1 Definition and Context

Systems Integration (SI) is defined as the process of bringing together of the component subsystems into one system and ensuring that they function together as a system. Systems integration activities correspond to the right hand side of the famous ‘V’ life-cycle, although they are generally planned well in advance.

In T&C context, the SI process can be defined to occur once each supplier has installed and tested his system in isolation and is satisfied that it is ready to be integrated into the overall system. In other words, SI begins during the SAT stage and continues to the end of the commissioning stage until the railway system becomes ready for commercial operation. However, as indicated in Section 3, SI in reality does begin off-site during the FAT stage itself and also progresses in the SIT stage, albeit at a low level.

4.2 Systems integration during Testing & Commissioning

In this paper, it is not intended to explain in detail the entire SI planning for various systems making a railway as it is beyond the scope of the main theme of the T&C process. It was, however, felt necessary to discuss it briefly as T&C cannot progress and be completed without SI. The following paragraphs tell how SI fits in line with the T&C process.

In a typical new light rail project, the employer would generally require a Systems Integration Plan in place which should demonstrate how the SI requirements can be met. The SI Plan can describe the strategy, the suitable integration approaches, the order of incremental integration, pre-conditions and requirements. Obviously, integration of systems means identifying, managing and closing individual interfaces. The employer might also require a formal Interface Management Plan to facilitate this.

Irrespective of the system discipline, the SI process can be represented as shown in the Figure 2. This diagram divides the SI process in two – the right hand side for the brand new systems and the left hand side for the existing systems. The triangle on the right shows that the integration for new systems ideally begins during the FAT stage while maximum integration takes place during the SATOV stage.

![Figure 2: Systems Integration during the T&C Stages](image)

The different blocks on the left hand side of the T&C model depict different approaches that can be adopted to integrate existing systems. Modification of certain existing equipment...
can take place independent of the T&C process for a new line. This can happen, for example, when a new line is being constructed or an existing line extended, thereby requiring modification of existing equipment on an existing line.

Third party systems can be integrated during the SAT-External stage. Replacement, upgradation and migration of equipment can be carried out during the SATOV-Equipment stage. Speaking of migration, some systems such as SCADA can be tested independently using a test bench or a mimic and then migrated to the actual central control room where the original system gets upgraded. Finally, the train on-board systems can be integrated during the SATOV-Line trail run stage.

5 Testing and Commissioning Control

Testing & Commissioning becomes a part of the overall works programme schedule. One of the main reasons is because different equipment, systems and sections need to be tested and commissioned at different times. Further, each equipment and sub-system has its separate FAT/SIT/SAT schedule. Also, some specific SITs or SATs of a particular system (e.g. cable transmission network) have to be completed before SITs for other systems to begin (e.g. passenger displays at stations). All tests have to be witnessed by representatives of various parties. Thus, T&C requires a formal and agreed system of coordination and control.

5.1 Control Documentation

A Testing & Commissioning Plan can form the basis of the entire T&C process and structure and can provide details on other control documents. The two other most important sets of documents can be Test Procedures and Test Reports. Test Procedures or Specification documents can contain information on aspects like inspection and testing conditions, testing equipment, drawings, detailed description of operations to be carried out, checklists, test sheets, pass/fail criteria, etc. The test procedures can also be directly given by the manufacturer or the approval body, e.g. the structure guage testing procedures based on British Standards or EC ‘Technical Specifications for Interoperability’.

Test reports can contain information like the testing date, participants, reference codes, product configuration, summary of tests performed, filled checklists and test sheets, defects, remedial actions, recommendations, etc.

Further, test certificates are used to certify that equipment or sub-system is according to requirements. Certificate sign-off is based on results from the test and the checksheets in the test reports. Certification allows that the inspected equipment can be considered useful or ready to be commissioned. In cases when further work is required, interim certificates can be produced and signed. The employer defines at what stage gates submission and sign-off of reports and certificates are required (usually at all four stages).

4.2 Compliance

The underlying purpose of the elaborate T&C process is to identify erroneous and non-complying components, equipment or sub-systems as early as possible in order to rectify them. Components and whole equipment can be rectified during installation based on manufacturer’s procedures. However, this may not be always possible and may require further work and more coordination. In any case, non-compliance reporting should be mandatory. This may consist of producing documents like snag lists, compliance matrices, test registers, etc. Here the T&C process interacts with the employer’s and contractors’ quality management system.

Conclusion

The Testing & Commissioning model outlined in this paper is fairly classic and more or less suitable to any light rail project. T&C planning begins in the concept phase of a project and the actual T&C activities are imperative in order to formally complete the construction works and to safely open a light rail line for public use. This paper also throws light on the significance of systems engineering and integration and its practical relevance to a railway project.

Limitations

Although this T&C process may be applicable to all rail modes, due to limited research at this stage, it is felt that it could only be applied to light rail systems. The paper discusses a simple and broad T&C model and hence does not identify the best practice or give actual results from real projects.

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