SPECIFICATION AND DESIGN OF A MODULAR AND EXTENSIBLE ARCHITECTURE FOR TESTING MOVING BLOCK SYSTEMS

ACHILA MAZINI, MOHAMED SAMRA, LEI CHEN, MARCELO BLUMENFELD & GEMMA NICHOLSON
University of Birmingham, UK

ABSTRACT

Testing train control systems is a crucial task to ensure their reliable and safe performance. Although testing systems and strategies for ETCS Level 2 are in place, as moving block/ETCS Level 3 systems are specified, the necessity to appropriately minimise the reliance on on-site tests, in light of increased testing scenarios, highlights the need to extend current testing capabilities to enable the operational paradigm shift of moving block. This paper, which reports on the results of the MOVINGRAIL project funded by the Shift2Rail programme, presents a testing solution for moving block systems to serve as a baseline for increasing the reliability of current laboratory and test practices. To obtain a good understanding of stakeholders' needs and requirements, a workshop was held with key stakeholders from industry and academia who are involved in railway signalling systems to discuss the current capabilities and the challenges that the transition from ETCS Level 2 to moving block may raise in the testing domain. Based on the outputs from the workshop, three important requirements for successful moving block testing formed the foundational assumptions used to define a modular and extensible architecture for testing moving block signalling systems. The components and interfaces of an integrated test system that is backwards compatible, i.e., it applies to all levels of ETCS, including future virtual coupling, regardless of system supplier, are then defined.

Keywords: testing, test architecture, ETCS-L3, moving block systems.

1 INTRODUCTION

In conventional railway systems, train detection and movement authority rely on trackside equipment. In this regime, track lines are strategically divided into predefined sections, also called fixed blocks (FBS), and a long separation between two trains is required, limiting the capacity of the railway line.

Moving block systems (MBS) represents a paradigm shift. Under MBS operation, the train detection no longer relies on trackside equipment. Instead, the safety-critical task of determining whether a section of track is occupied is performed by the on-board computer and the radio block centre (RBC) [1]. As a result, the integrity of trains (i.e., that there are no loose carriages or wagons) must be verified by train-based equipment rather than trackside systems. Another distinguishing characteristic of MBS is that blocks are not defined by pairs of fixed points on the line and movement authorities can be allocated to the next obstruction point on the track (i.e., by the rear of a preceding train) and move with trains.

It logically follows that the introduction of the new paradigm increases the operational complexity, and the challenge is then to guarantee that the system fulfils the safety requirements while operating trains closely to each other. In this scenario, testing plays an important role to guarantee that the quality and reliability of the system are being fulfilled. As moving block systems creates an infinite number of movement authority generation possibilities, it results in the exponential expansion to the number of scenarios that must be tested. Furthermore, as the positioning and train integrity are managed on-board rather than from the trackside, the architecture of both the on-board and trackside components differ between FBS and MBS. Cases where communication is lost, and wagons are unintentionally detached from the train, must also be managed differently. Although testing techniques and

WIT Transactions on The Built Environment, Vol 213, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/CR220131

strategies are currently in place for conventional railway system, as moving block system are introduced, testing techniques and strategies must be appropriately extended to consider the specific differences of MBS.

This paper reports the results of the *Work Package 2: Approaches for Testing Moving Block Systems* [1], [2] of the MOVINGRAIL project funded by the Shift2Rail programme. Here, a testing solution is defined to serve as a baseline to increase the reliability of current laboratory and adapt current test practices to accommodate testing for MBS. This has been approached by holding a workshop with key stakeholders from industry and academia who are involved in railway signalling systems to discuss the current capabilities and the challenges that the transition from conventional railway systems to moving block may raise in the testing domain. Based on the outputs from the workshop, three important principles for successful moving block testing formed the foundational assumptions used to specify a modular and extensible architecture, as well as related interfaces, for testing moving block signalling systems.

2 REQUIREMENTS SPECIFICATION

At a workshop held in May 2019 discussion facilitation sessions were conducted with key stakeholders to elicited requirements for MBS testing. The workshop was attended by 40 experts from industry and academia who are involved in railway signalling systems, including design and development, testing, and regulation. Of the 40 participants, 23 fully completed the 15 questions of the questionnaire, regarding: current testing process and the gap to zero-on-site testing, the format of a realistic moving block testing strategy, and ideas about how to bridge the gap between current testing capability and moving block testing. The full questionnaire and aggregated anonymised results can be found at https://beardatashare.bham.ac.uk/getlink/fiNYac39GLAxPfS7s5WWRvi9/ [1].

Overall, the results from the survey highlighted three important aspects for moving block testing. Firstly, responses emphasised the greater complexity of moving block systems, meaning that a wider array of possible scenarios need to be tested for the system to be deemed reliable. That leads to the second priority, where testing should be automated and conducted off-site whenever possible to avoid escalating costs. This contrasts with the current reality where manual processes are still prevalent in the organisations, from the generation of test cases (62%) to the analysis of results (73.3%). Finally, respondents recognised the greater safety criticality of moving block systems compared to their predecessors. Operating with shorter safety margins inevitably carries higher risks, so test strategies need to cover as many scenarios of degraded operation as possible.

Therefore, as determined from stakeholder interviews and reviews of the literature, the key point to achieve a robust testing solution for moving block systems relies on increasing the reliability in current laboratory test practices and providing a test environment that is able to reproduce relevant operational scenarios and conditions as realistically as possible. The key design principles used for the specification of the testing architecture derived from those premises and have been organised into seven key requirements, as follows.

1. The testing system and strategy shall be backwards compatible with all official ETCS baseline versions, as well as capable of upgrade to support virtual coupling and future versions of ERTMS/ETCS.
2. The architecture shall be a single integrated system that is capable of supporting testing by different stakeholders, suppliers, and with different test objectives.

3. The simulation models shall cover the complete railway system including railway infrastructure, rolling stock, timetables, railway operation rules and simulated train movements
4. The specification of components and interfaces shall cover commonly required functionalities to support a wide range of operational scenarios, to include (1) functionalities and requirements (main objective); (2) potentially safety critical instances; (3) common failures in previous systems
5. The use of hardware-in-the-loop (HIL) solutions shall be implemented to achieve close to real operation as much as possible.
6. The implementation of the functions in the adaptor shall be considered as the responsibility of each company.
7. The testing system shall be capable of running routines of different levels of automation (e.g., manual, fully automated)

3 ARCHITECTURE OVERVIEW

The system architecture shown in Fig. 1 [2] follows the requirements defined in the previous section. The architecture is considered an extension of the test architecture for fixed block systems defined in [3], as it adds up the specific components needed to enable a moving block system including the train integrity monitoring systems, as well as the use of virtual balises for train positioning.

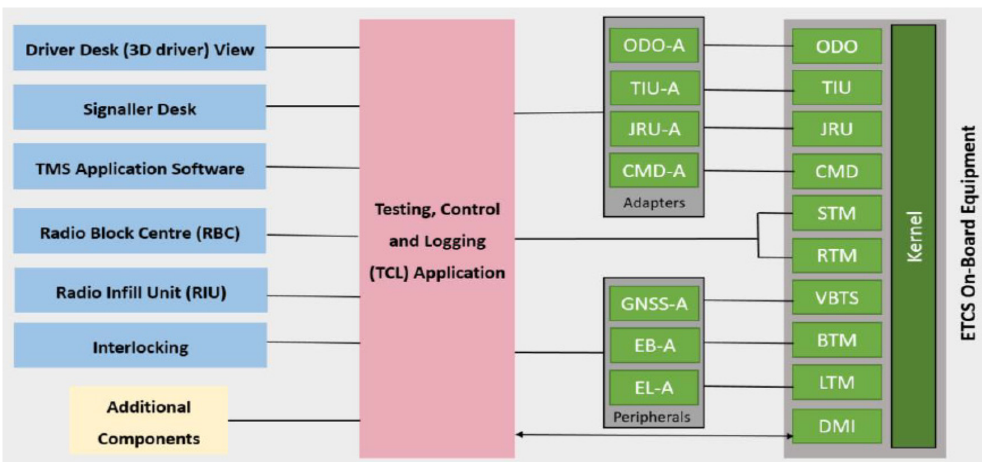

Figure 1: ERTMS test architecture.

The architecture illustrated in Fig. 1 is divided into four principal groups: The first group, in pink box, represents the test execution domain and contains the test control and logging unit (TCL); The green boxes indicate all the onboard related components; The third group, in blue, represents the external entities that are part of the test environment, such as simulators or any hardware-in-the-loop (HIL) components. The fourth and last group is shown in yellow and anticipates the existing of additional components or external tools that can be attached to the architecture as per the stakeholder's needs.

Each component, as well as their interfaces with the testing environment (i.e., TCL) are summarised in the following sections. More details can be found in Deliverable D2.2 [2].

3.1 Testing domain

3.1.1 Testing, control and logging application

The testing, control, and logging application (TCL) is the main component in the testing domain. The TCL manages the simulation and testing configurations and processes to represent the state of the railway network and traffic. It acts as a central unit between the external simulators, HIL components, and the ERTMS/ETCS on-board constituent. This paper summarises the TCL interfaces and functionalities. Further details can be found in [3].

The TCL entity is capable of initiating several distinct functions such as providing multi-train simulation, occupying and clearing train detections based on train movement, feeding coherent train position, speed, and acceleration to the odometry via the intermediate interface, logging data, checking train integrity, generating DMI actions, and simulating a complete railway system with mixed traffic operation (i.e. freight and passenger) and mixed signalling types (i.e. ETCS-fitted and unfitted trains).

Besides, the TCL application allows the setup, execution and analysis of the test scenarios specified in [5]. The TCL is able to fulfil the testing objectives of different stakeholders and provide a compliant Form Fit Function Interface Specification (FFFIS), where defined.

The next sections of this document highlight the distinct functionalities of the TCL entity when connected to each of the components showed in Fig. 1.

3.2 External entities domain

3.2.1 Traffic management system

The traffic management system (TMS) application is connected to the TCL to manage timetables and enable multiple train simulation. The TMS should be able to implement basic features that include [2]:

(i) Train tracking;
(ii) Interlocking commands and/or automatic route setting (ARS);
(iii) Infrastructure controls (e.g., traction system, reduced adhesion areas);
(iv) Train status;
(v) Conflict detection and resolution.

Under moving block operation, the TMS incorporates more functionality than the other levels of operation. These functionalities include [3]:

(i) Setting/clearing areas where the track status is UNKNOWN;
(ii) Moving points within a known area by emergency procedure;
(iii) Providing an estimated train location to the trackside component;
(iv) Providing the Staff Responsible (SR) distance to the trackside;
(v) Validating the SR distance calculated by the trackside;
(vi) Activating and disabling shunting areas;
(vii) Establishing and removing temporary shunting areas;
(viii) Activating and deactivating dynamic radio holes.

The high-level functional requirements of the TMS can be found in [6], while moving block focused requirements are detailed in [7].

The architecture to interface the TMS with the TCL is shown in Fig. 2 [2]. The TCL aims to interface with any TMS provided by an appropriate supplier. In Fig. 2, the TCL forwards the static variables including the network topology and timetable information and the dynamic variables originated from the RBC/interlocking to the TMS. These dynamic variables include the position updates for all trains in the control area being monitored by the TMS. Additionally, TMS sends back the control plans to the TCL including the signalling instructions. Another functionality of the TCL is logging the simulation scenario and the passed variables.

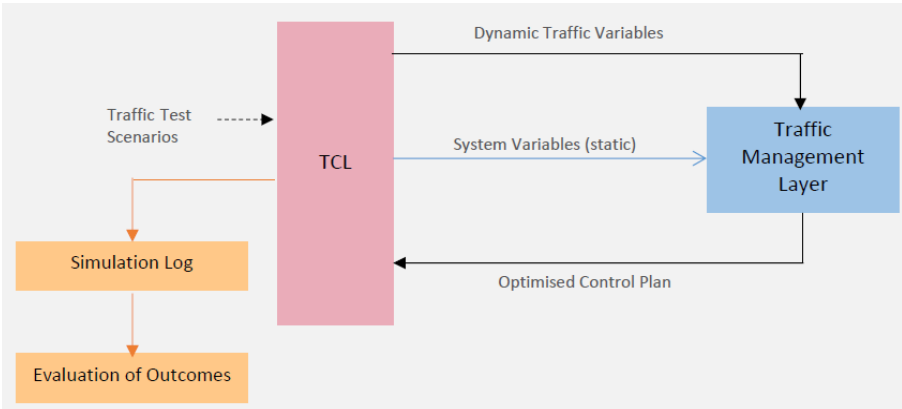

Figure 2: TMS framework.

3.2.2 Signaller desk

The signaller desk is a system that simulates the train traffic control by signallers and dispatchers with a similar UI to a real traffic control room. The signaller desk interface, represented in Fig. 3, requires a large amount of information that is to flow between the TCL application and the signaller desk which includes [2]:

(i) Traffic state including the speed and location of all of the trains in the signaller's area;
(ii) Interlocking state, including route setting, point settings, and signal aspects (based on the ETCS level being tested);
(iii) Train movement authorities.

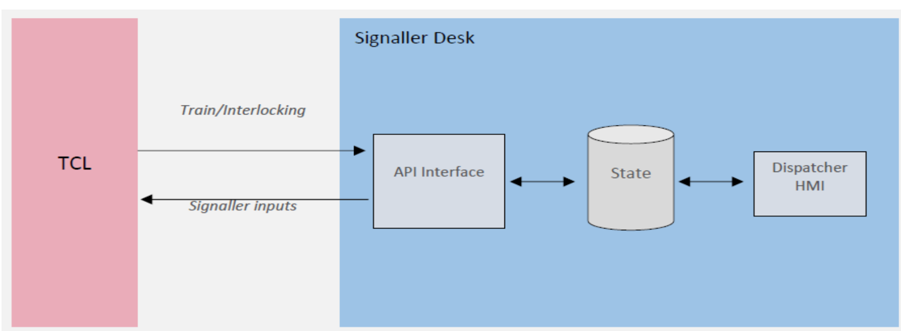

Figure 3: Signaller desk interface.

The TCL works on forwarding the needed information from RBC/Interlocking and TMS to the signaller desk as well as logging the simulation data.

3.2.3 Driver desk with 3D views

The driver desk is an optional element that is able to provide a 3D graphics view of the simulated railway environment. The driver desk consists of two main components with separate user datagram protocols (UDP) interfaces, as shown in the example desk in Fig. 4.

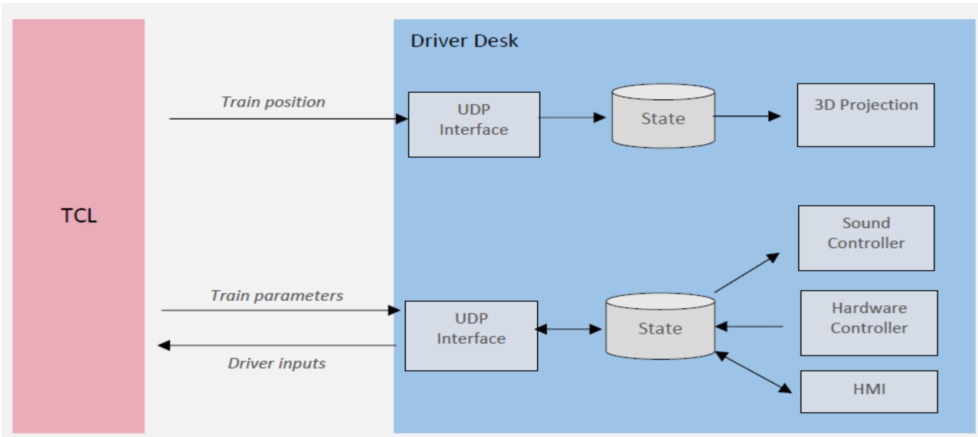

Figure 4: Driver desk architecture.

The first component is the driver 3D view, which represents a common driver's view outside of the train's window, while the cab controller is the second component, formed by a number of sub-components, such as the sound and hardware controller, with data flowing both to and from the TCL components. Both components have a local state object that contains the contextualised state of the train which the driver desk represents. Concomitantly, the TCL works on forwarding the RBC/interlocking data to the driver desk and it logs all of the simulation data.

3.2.4 Radio block centre

The radio block centre (RBC) is a computer-based system responsible for managing the data exchange between the onboard and trackside. The data exchanged is then used to define the movement authorities to allow the safe movement of trains on the railway infrastructure area under the responsibility of the RBC [8].

The RBC in a moving block system acquires a new set of functionalities that include handling the movement and recovery of trains with failed communication, along with managing radio hole that is either static (predefined since the RBC was commissioned (e.g., a tunnel)) or dynamic (occurs after the RBC was commissioned (e.g., base station failure).

More information regarding the interface between radio communication systems can be found in [10]. In addition, [9] specify the additional RBC functionalities introduced for moving block system. Moreover, [11] details the prospect of having one hardware-in-the-loop RBC under test sharing the environment with a simulated RBC.

The interface functionalities between TCL-RBC ate detailed in [12]. The following sections describe the role of the RBC and how it interacts with the other components of the test architecture.

3.2.5 Radio infill unit

As the test architecture is expected to be applicable to various ETCS levels, this section covers the radio infill unit (RIU), which is an optional component that is applicable to ETCS level 1 only. The RIU provides the signalling information in advance to the train by GSM-R transmission. In the test environment, the RIU corresponds to the real equipment provided by the supplier and no functional modifications compared to the commercial version are allowed.

The RBC and RIU equipment will interface with the TCL via the API mechanism, as seen in Fig. 5 [2]. Moreover, the RBC/RIU Adaptor Unit has the potential to enable the attachment of various RBC/RIU constituents to the test environment. More details on that can be found in [3].

Furthermore, the RBC and RIU can be integrated with the onboard radio transmission module (RTM) to constitute the radio base system (RBS). The RBS framework is part of the

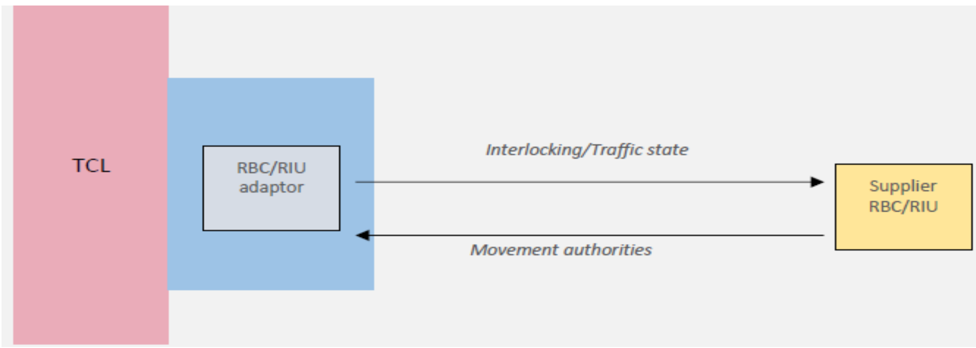

Figure 5: TCL-RBC interface.

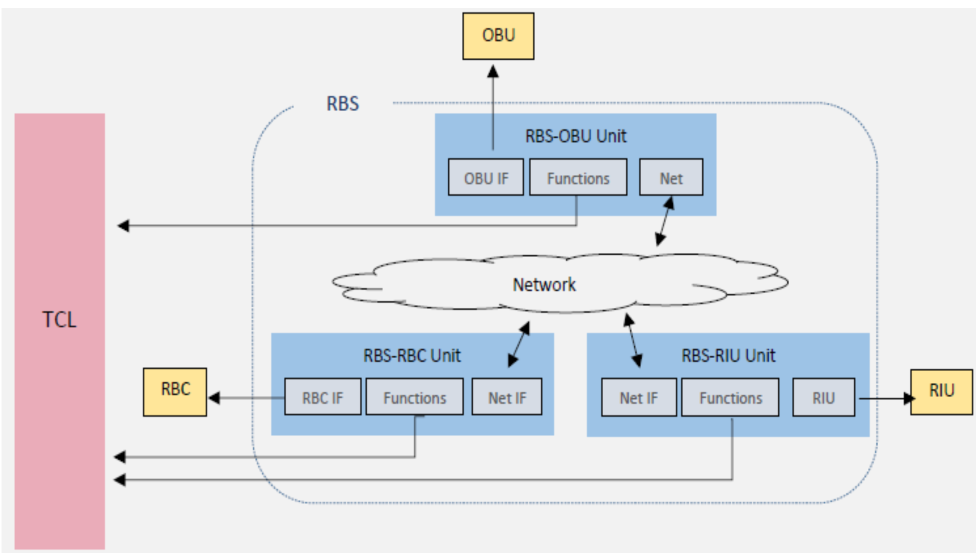

Figure 6: RBS interface.

TCL layer, and its duty corresponds for establishing a connection between its sub-systems while monitoring the message transfer between them, as shown in Fig. 6 [2]. This framework is expandable to accommodate multiple RTM, RBC, and RIU units in the test environment as per the stakeholders' needs.

3.3 Onboard domain

3.3.1 Onboard system

Comprising a combination of hardware and software elements, the main objective of the on-board unit (OBU) is to provide automatic train protection (ATP). Partnering with the ETCS trackside system and data entered by the driver, the OBU monitors the position of the train and determines the safe area in which the train is allowed to move. Should the train surpass this area, then the OBU acts to control the speed of the train and bring it to a stand [13].

In the test architecture, the OBU consists of a number of modules that interface with the TCL, as defined in Fig. 1. The following sections will focus on defining the TCL-OBU constituents interfaces highlighting the TCL functionality in case of OBU absence.

3.3.1.1 Odometry unit

The onboard odometry unit connects with the TCL application through an adapter named ODO-A. The communication between the TCL and the OBU ODO is unidirectional, as shown in Fig. 7 [2].

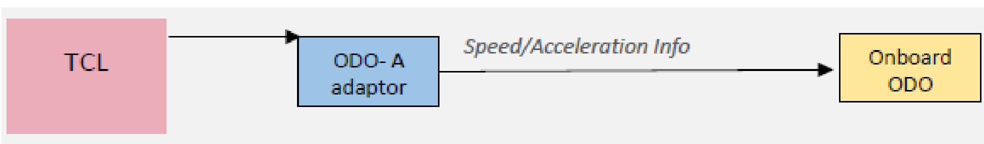

Figure 7: TCL/ODO unit interface.

The TCL layer and ODO-A can either generate multiple signals to make sure that the train is moving within the desired speed, acceleration, and designated area. Alternatively, the ODO-A may feed the desired speed, acceleration, and location uncertainty to the systems, replacing the ODO hardware when convenient. Another approach supported by this configuration includes the execution of type-testing the ODO unit itself without considering the TCL and ODO-A. Further information regarding the characteristics of this interface can be found in [14].

3.3.1.2 Train interface unit

The train interface unit (TIU) maintains a bi-directional communication with the onboard TIU through the TIU adapter (i.e., TIU-A), as shown in Fig. 8 [2]. With it, the TCL is able to forward and log the correspondent data passed between the components. For that, the TCL deals with a set of inputs for the TIU that are categorised either as dependent (e.g., special brake status, traction status) or independent (e.g., train integrity, train data) inputs. The communication between the TCL and TIU should adhere to all the train interface information presented in [4] and [15].

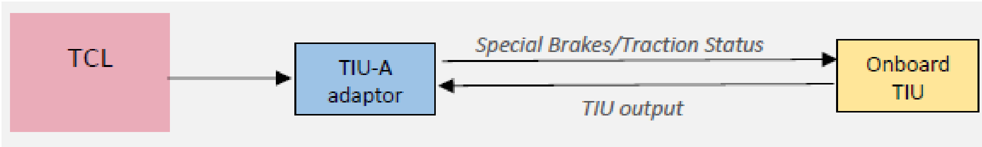

Figure 8: TCL/TIU unit interface.

3.3.1.3 Onboard train integrity

Monitoring the status of the rear of the train to guarantee the movement coherence is the principal feature in the onboard train integrity (OTI) that it is needed for the moving block concept. The OTI is considered as an additional subsystem included to the onboard TIU to replace the trackside train detection equipment in the management of the train integrity functionality.

The OTI is responsible for handling the communication between the master and slave modules to ensure that the train tail status is determined and monitored. Further details regarding the functional requirements and between the OTI and on-board TIU are available in [16].

3.3.1.4 Juridical recording unit (JRU)

The communication between the JRU and TCL is unidirectional through the intermediate adapter (i.e., JRU-A) and the main role of the TCL is to forward and collect the data passed between the JRU and the European virtual computer (EVC). The communication diagram between them is identical to the one shown in Fig. 6.

3.3.1.5 Cold movement detection (CMD)

The communication between the cold movement detection (CMD) and the TCL is unidirectional through the intermediate adapter (i.e., CMD-A). Within it, the duty of the TCL is to provide information to the OBU CMD unit such as: train has moved, train has not moved, or fail state. The communication diagram that represents this it is identical to Fig. 6. Additional information about the CMD and the adapter can be found in [14].

3.3.1.6 Specific transmission module

The TCL is responsible for manage a bidirectional link with the onboard specific transmission module (STM) equipment, and the messages should fir the guidelines provided in [17]. The TCL is also responsible for applying the protocols defined in [18], [19] to encode/decode message exchanges with the equipment.

3.3.1.7 Balise transmission module

The TCL interfaces with the OBU balise transmission module (BTM) and generates a balise telegram that is compliant with the requirements details in [22]. In addition, the TCL manages a group of balise telegrams that can be loaded in the configuration phase or generated dynamically as the simulation is executed. These telegrams contain the balise location information and can be defined by a single balise or balise groups. More details on the TCL functional interface with the BTM can be found in [14].

3.3.1.8 Virtual balise transmission system (VBTS)
The VBTS is considered to be a promising approach that might replace the current balise transmission module for train positioning. As the system is seen as only a prospect system, it was not specified in Fig. 2. However, the TCL should face no problem in interfacing with the VBTS, as it does with the BTM, and supervise the generation of the virtual balise telegram that is compliant with [21]. Also, the TCL is expected to be able to oversee a set of virtual balise telegrams that is either loaded in the configuration phase or updated dynamically as the simulation runs.

3.3.1.9 Loop transmission module (LTM)
The loop transmission module (LTM) is only applied for the L1 instance of ETCS. In terms of connection with the TCL, the test domains interfaces with the LTM to generate an Euroloop message that should fit the specifications in [23]. On top of that, the TCL is also responsible for overseeing a list of Euroloop messages that contains the Euroloop start and end location to be used for the correct loop signal generation. More details on the TCL functional interface with the LTM can be found in [14].

3.3.1.10 Driver machine interface
The test domain interfaces directly with the driver machine interface (DMI) to log every input and output on the DMI device in a digital format. An additional option includes the use of the TCL to automate the DMI inputs without the need of having test engineers performing manual interventions to execute a certain test sequence. Further details on the TCL functional interface with the DMI can be found in [14].

4 IMPLEMENTATION ROADMAP

The key goal of the implementation roadmap is to present the role of the test architecture and interfaces presented in this paper, in addition to the processes and technologies determined in several other projects, in the process of achieving a feasible test environment that can be integrated within the organization(s) current test process.

Fig. 9 summarises the key steps for the development and deployment of a test solution suitable for testing MBS, which includes highlighting the specification of requirements and safety aspects of the target system, in addition to the definition of current testing techniques and strategies available in the industry to guide the definition of a test strategy that considers current test practices.

This paper, which reports the MOVINGRAIL Work Package 2 results, builds on these specifications to specify, and design a modular and extensible architecture to serve as a baseline for different suppliers and organisations.

However, considering the general approach of the architecture, the feasibility analysis and implementation plan now rely on each organisation, as it should consider the organisation's testing and business objectives, as well as the internal assessment of current test capabilities, which includes software, hardware, test cases availability, data, and procedures currently in place for all the test activities.

5 CONCLUSIONS

Testing train control systems is essential to ensure their reliable and safe performance. As moving block/ETCS level 3 systems are specified, testing systems and strategies must be appropriately extended. Therefore, this paper, which reports on the results of the MOVINGRAIL project funded by the Shift2Rail programme, presented a modular and

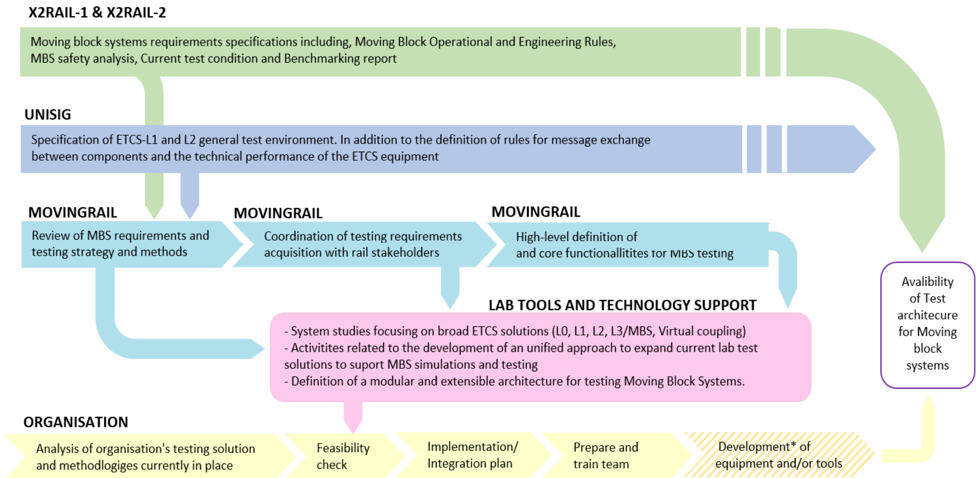

Figure 9: MBS testing architecture roadmap.

extensible architecture for testing of future moving block signalling systems to serve as a baseline for different companies and suppliers. The proposed architecture highlights the extended functionalities of existing sub-systems, including the TMS and the RBC, needed for moving block system operations. Furthermore, the architecture listed the newly added sub-systems that are unique for ETCS-L3 such as the train integrity (as part of the TIU) and prospect systems such as the VBTS for more accurate train positioning. It is expected that the architecture will be also appropriate for the current ETCS-L2 and ETCS-L1. To achieve this, the architecture has maintained the components that are needed for ETCS-L1 such as the LTM and RIU. An implementation roadmap is then presented to discuss the role of test architecture and interfaces presented in this paper to collaborate in the development of a feasible test environment that can be integrated within the organization(s) current test process.

ACKNOWLEDGEMENTS

This project has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No. 826347. The authors would also like to thank the support from the Birmingham Centre for Railway Research (BCRRE) and the UK Railway Research and Innovation Network (UKRRIN).

REFERENCES

[1] MOVINGRAIL D2.1, Moving Block Signalling System Test Strategy, rev 2.0.0 29/02/2020.
[2] MOVINGRAIL D2.2, Moving Block Signalling System Test Methods, rev 5.0.0 14/07/2020.
[3] UNISIG SUBSET-111: IOP Test Environment Definition UNISIG, rev 3.5.0, 17/02/2016.
[4] UNISIG SUBSET-026: System Requirements Specification, rev 3.6.0, 25/05/2016.
[5] UNISIG SUBSET-076-6-3: Test Sequences, rev 3.2.0, 30/05/2017.
[6] In2Rail, Deliverable D7.1, State-of-the-Art and High-Level Requirements, 2016.

[7] X2Rail-2, Deliverable D5.1, Moving Block System Specification, 2019.
[8] UNISIG SUBSET-026-2: System Requirements Specification, rev 3.6.0, 13/05/2016.
[9] X2Rail-2, Deliverable D6.3, Description of use-cases for new TMS principles, 2018.
[10] X2Rail-1, Deliverable D6.1 Current test condition and benchmarking report, 2017.
[11] UNISIG SUBSET-039: FIS for the RBC/RBC Handover, v3.2.0, 17/12/2015.
[12] UNISIG SUBSET-111-3: Interoperability Test Environment Definition (FFFIS for TCL-RBC adaptor), rev 3.5.0, 17/02/2016.
[13] Digital Railway, ETCS Onboard System Definition. http://digitalrailway.co.uk/wp-content/uploads/2019/04/153821-NWR-REP-ESE-000005-ETCS-Onboard-SDD_3.0.pdf. Accessed on: 22 Apr. 2020.
[14] UNISIG SUBSET-94: Functional requirements for an onboard reference test facility, rev 3.1.0, 24/04/2017.
[15] UNISIG Subset-034: Train Interface FIS, rev 3.2.0, 17/12/2015.
[16] X2Rail-2, Deliverable D4.1, Train Integrity Concept and Functional Requirement Specification, 2017.
[17] UNISIG SUBSET-058: Application Layer STM FFFIS, rev 3.1.0, 16/12/2015.
[18] UNISIG SUBSET-056: Safe Time Layer STM FFFIS, rev 3.0.0, 29/02/2012.
[19] UNISIG SUBSET-057: Safe Link Layer STM FFFIS, rev 3.1.0, 16/12/2015.
[20] A11 T6001, Radio transmission FFFIS for Euroradio, rev 13.0.0, 18/12/2015.
[21] X2RAIL-2, D3.1, System Requirement Specification of the Fail-Safe Train Positioning Functional Block, 18/12/2018.
[22] UNISIG SUBSET-036: FFFIS FOR Eurobalise, rev 3.1.0, 17/12/2015.
[23] UNISIG SUBSET-044: FFFIS for Euroloop, rev 2.4.0, 29/02/2012.