

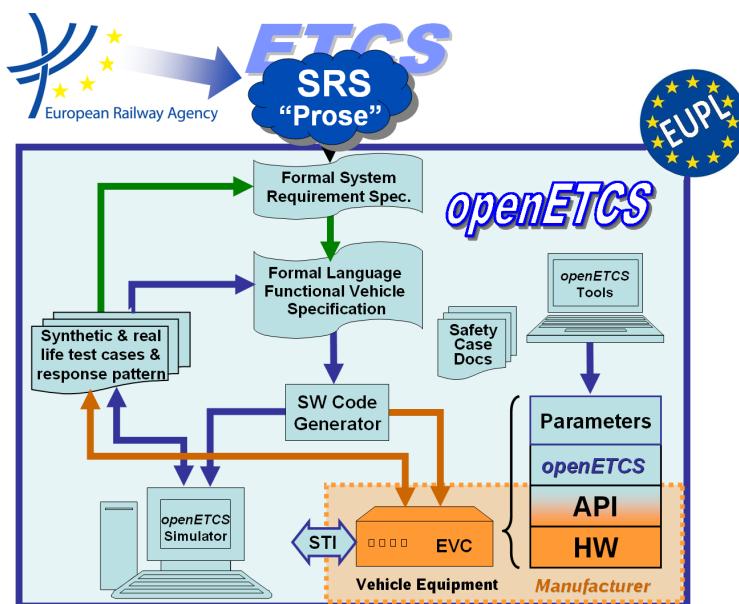
Work-Package 3: "Modeling"

D3.5.4 Appendix: Dynamic ETCS Track Model

Use Case: Amsterdam- Utrecht ETCS L2 Reference Line

Mairamou Haman Adji

August 2015



Funded by:



Federal Ministry
of Education
and Research

MINISTÈRE
DE L'ÉDUCATION NATIONALE
ET DE LA RECHERCHE



Ministère
de l'Éducation
Nationale
et de la Recherche



INVESTISSEMENTS
D'AVENIR



Région de
Bruxelles-
Capitale



GOUVERNEMENT
DU SPAIN



MINISTERIO
DE INDUSTRIA, ENERGÍA
Y TURISMO

This page is intentionally left blank

Work-Package 3: "Modeling"

**OETCS/WP3/D3.5.4 Appendix:
Trackside
August 2015**

D3.5.4 Appendix: Dynamic ETCS Track Model**Use Case: Amsterdam- Utrecht ETCS L2 Reference Line**

Document approbation

Lead author:	Technical assessor:	Quality assessor:	Project lead:
location / date	location / date	location / date	location / date
signature Jakob Gärtner (LEA Railergy)	signature Baseliyos Jacob (DB Netz AG)	signature Marc Behrens (DLR)	signature Klaus-Rüdiger Hase (DB Netz AG)

Mairamou Haman Adji

LEA Railergy
c/o LEA P&W sarl
BP14000
Yaoundé,
République du Cameroun

Track Model User's Guide

Prepared for openETCS@ITEA2 Project

Abstract: openETCS provides a formalisation of a reference ETCS onboard unit, using model-based software design based on the Scade language.

In order to complement this work with a dynamic simulation environment a ETCS track model has been developed. In contrast to pure scenario- driven approach, this model is intended to provide a simulation of dynamic behaviour of the track based on active interaction between train and track. The model has been derived from actual engineering data and events that have been collected by a train passing this reference track. This document provides an outline of the simulation concept, its implementation and is intended to serve as a quick reference guide to users and reviewers.

On purpose, it has been written in a semi- technical way in order to be understandable by a more general audience. However, some basic understanding of ETCS is helpful for the reception of this document.

Disclaimer: This work is licensed under the "openETCS Open License Terms" (oOLT) dual Licensing: European Union Public Licence (EUPL v.1.1+) AND Creative Commons Attribution-ShareAlike 3.0 – (cc by-sa 3.0)

THE WORK IS PROVIDED UNDER openETCS OPEN LICENSE TERMS (oOLT) WHICH IS A DUAL LICENSE AGREEMENT INCLUDING THE TERMS OF THE EUROPEAN UNION PUBLIC LICENSE (VERSION 1.1 OR ANY LATER VERSION) AND THE TERMS OF THE CREATIVE COMMONS PUBLIC LICENSE ("CCPL"). THE WORK IS PROTECTED BY COPYRIGHT AND/OR OTHER APPLICABLE LAW. ANY USE OF THE WORK OTHER THAN AS AUTHORIZED UNDER THIS OLT LICENSE OR COPYRIGHT LAW IS PROHIBITED.

BY EXERCISING ANY RIGHTS TO THE WORK PROVIDED HERE, YOU ACCEPT AND AGREE TO BE BOUND BY THE TERMS OF THIS LICENSE. TO THE EXTENT THIS LICENSE MAY BE CONSIDERED TO BE A CONTRACT, THE LICENSOR GRANTS YOU THE RIGHTS CONTAINED HERE IN CONSIDERATION OF YOUR ACCEPTANCE OF SUCH TERMS AND CONDITIONS.

<http://creativecommons.org/licenses/by-sa/3.0/>
<http://joinup.ec.europa.eu/software/page/eupl/licence-eupl>

Modification History

Version	Section	Modification / Description	Author
1.0	all	created document	Mairamou Haman Adjii

Table of Contents

Modification History.....	3
1 Proof of Concept based on User Stories.....	6
2 The Amsterdam- Utrecht Reference Track	8
2.1 Introduction	8
2.2 Approach.....	9
2.3 Engineering Data.....	9
2.4 Operational Rules	13
3 Simulation Concepts	14
3.1 The State of The Art in Railway (ETCS) simulation.....	14
3.2 Dynamic track simulation throughout the (open)ETCS lifecycle	15
3.3 The role of dynamic simulation in the formalisation of ERA ETCS Change Requests and in improving interoperability.....	16
4 Formal model for trackside simulation	24
4.1 Simulation concept.....	24
4.2 Fundamental modelling concept: The daisy chain	25
4.3 Where to find the information in the model	27
4.4 Track model (balises).....	28
4.5 Radio Message simulation.....	35
4.6 The radio message formal model	38
5 Implementation of additional user stories.....	40
5.1 Building your own tracks.....	40
6 Connecting with existing environments.....	41
6.1 Subset-076	41
6.2 Subset-094	41
7 Closing remarks.....	41
References	41

Figures and Tables

Figures

Figure 1. Example for a "nominal" user story: Sequence Diagram for Use Case 7	7
Figure 2. Example for a "test case" user story: Description for Use Case 13.....	8
Figure 3. Example Track Layout Plan	10
Figure 4. Variable definition for V_STATIC.....	13
Figure 5. Overview of Components in the ALSTOM EVC architecture, using TeamWork SA RT notation.....	15
Figure 6. Depiction of the openETCS Third Iteration Proof of Concept Environment	16
Figure 7. Reference test architecture for ERTMS/ETCS on-board equipment.....	17
Figure 8. Dynamic simulation for improving interoperability	17
Figure 9. SCADE cycle- based execution model.....	22
Figure 10. Raspberry Pi2 running the track model	23
Figure 11. Simplified Simulation Concept.....	24
Figure 12. Daisy Chained Balise Groups	26
Figure 13. Siemens Eurobalise	28
Figure 14. Triggering a Balise when the train is inside the defined distance bracket (view from SCADE Suite Simulator)	29
Figure 15. Triggering a Balise in the Daisy Chain.....	30
Figure 16. Engineering data for BG354 (view from SCADE model)	30
Figure 17. Interface and parameter reference for BG354 (view from SCADE model)	31
Figure 18. Interface and parameter reference for balises in BG354 (view from SCADE model)	31
Figure 19. Telegram data of BG354 (view from SCADE model).....	32
Figure 20. Sending packets from BG354 (view from SCADE model)	34
Figure 21. Balises in different local coordinate systems (depending on track sections)	34
Figure 22. Track Discontinuity modelling (view from SCADE model)	34
Figure 23. Daisy- chained Send Radio message operators (view from SCADE model)	39
Figure 24. Send Radio Message (view from SCADE model)	39
Figure 25. Merge message information into the message/ packets stream (view from SCADE model).....	40
Figure 26. Composing packets for a L2/3 Movement Authority message (view from SCADE model)	40

Tables

Table 1. Some balise positions in original format	11
Table 2. Example packet data for Gradient Profile as found in the JRU log	12
Table 3. Example packet data for Speed Profile as found in the JRU log	13
Table 4. Cross reference table for the balise groups relevant for the Proof of Concept.....	21
Table 5. Engineering data for BG354	30
Table 6. Packets sent from BG354 as found in the JRU log	33
Table 7. Cross reference table for the radio messages relevant for the Proof of Concept, partial list covering the sheets Amstel and Bijlmer	38

1 Proof of Concept based on User Stories

One of the main objectives of the openETCS project is to prove the formalisation of the EVC by validating it against a reference track. The project has selected the ETCS Level 2 track between Utrecht and Amsterdam (The Netherlands) as the reference track of choice.

openETCS is using the concept of *user stories* to define meaningful use cases from the point of view of a railway operator. DB Netz AG as the project leader has defined the following scenarios in order to focus and drive the project's priorities:

- Use case 1: Start of Mission and connection to the RBC (Issue #66)
- Use Case 2: Train is running after receiving a Movement Authority (MA); (Issue #67)
- Use Case 3: ETCS Brake intervention (revocation of MA or not allowed speed); (Issue #68)
- Use Case 4: Train is reading track information - Train is sending information to the track. (Issue #69)
- Use Case 5: Awakeness of Train with Level NTC (Issue #244)
- Use Case 6: SoM in Level NTC and Mode SN (Issue #245)
- Use Case 7: Running in Level NTC and Mode SN (Issue #246)
- Use Case 8: Change Level NTC and SN to Level 2 and Mode FS (Issue #247)
- Use Case 9: Run in Level 2 and Mode FS after MA request (Issue #248)
- Use Case 10: Change Level 2 Mode FS to Level NTC Mode SN (Issue #249)
- Use Case 11: Run in Level NTC and Mode SN (Issue #250)
- Use Case 12: End of Mission in Level NTC and Mode SN (Issue #251)
- Use Case 13: Train stops before Signal Marker Board after revoked Movement Authority (MA); (Issue #70)
- Use Case 14: Mode Change and communication with the RBC. (Issue #71)
- Use Case 15: Route is cancelled from the end of route signal. (Issue #72)
- Use Case 16: Behaviour of the OBU after a TRIP. (Issue #73)

(Non-exhaustive list: The authoritative definition of the User Stories can be found on <https://github.com/openETCS/modeling/issues> and can be identified by the issue number cited above, or by searching for the label "User Story")

The Use Cases can be roughly classified as follows:

1. Use cases that are directly derived from existing data taken from a test train passing the Amsterdam- Utrecht ETCS L2 line
2. Use cases that are derived from test requirements for the Amsterdam- Utrecht and are based on synthetic data, created on purpose.

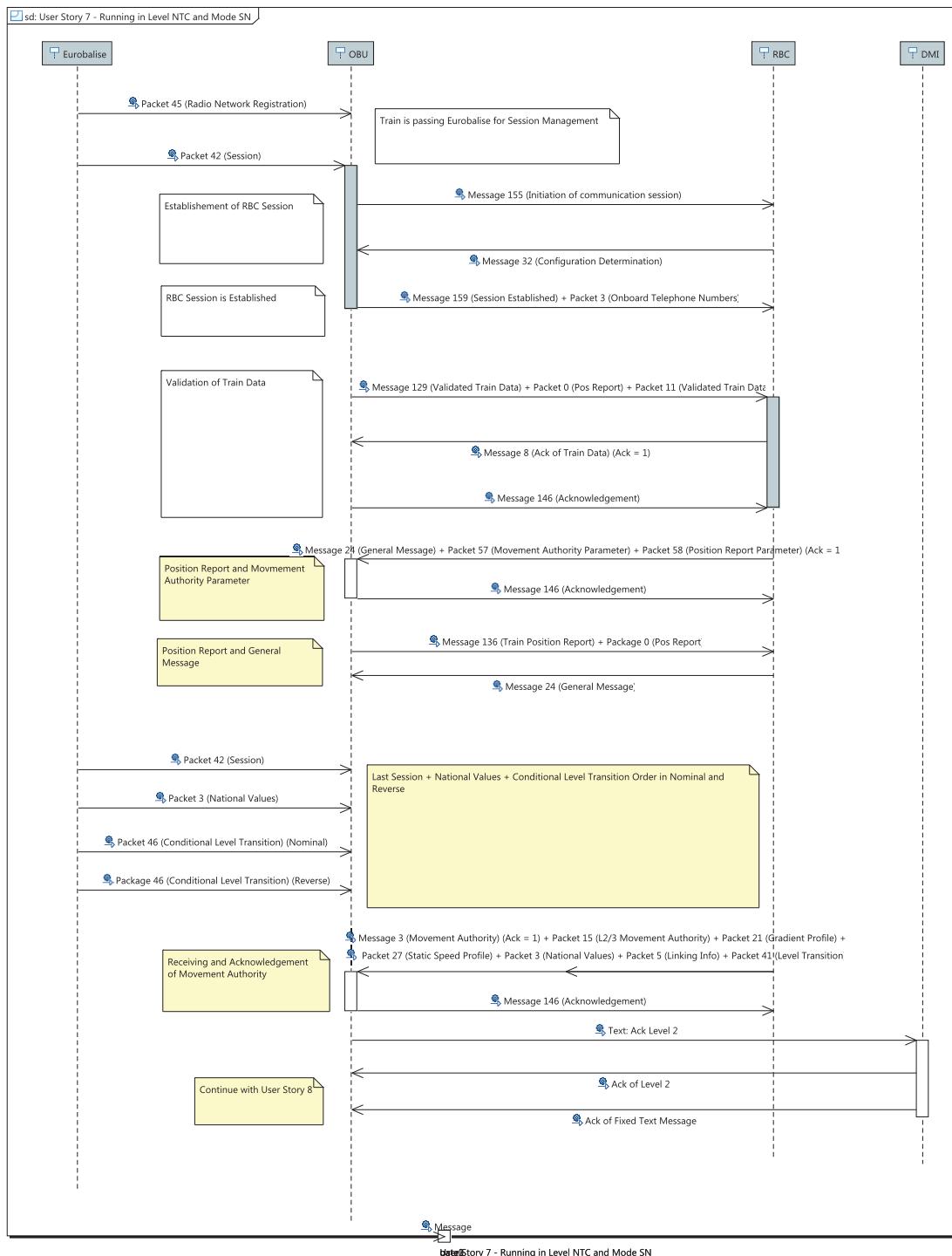
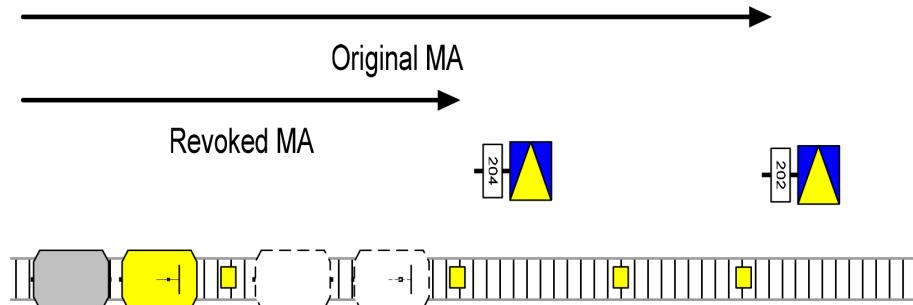


Figure 1. Example for a "nominal" user story: Sequence Diagram for Use Case 7

Objective:

This operational scenario verifies the reaction of the onboard in case of MA revocation

Diagram:

Train is running with an MA beyond SMB204. The MA is revoked by the traffic control center such that the train is able to stop before the revoked SMB204.

Figure 2. Example for a "test case" user story: Description for Use Case 13

Use case 7 (please see figure 1) is a typical use case that can be represented using the nominal behaviour taken from data recorded during a train passage.

Other use cases appear to be more complex: to reproduce them, we have to create a specific situation that may only be done at very high cost (by interrupting normal train operations for test rides) or by creating a specific simulation scenario. An example for such a scenario is Use Case 13. (see figure 2)

We had to solve the following task:

1. Find a formal representation of the Amsterdam- Utrecht ETCS Level 2 line which allows validation of the Use Cases with the openETCS EVC- model in the loop
2. Find an efficient way to model the test case scenarios
3. Propose a concept which allows *dynamic simulation*, meaning that we can actively drive a train, with a simulation environment that acts and reacts dynamically, instead of just providing playback of predefined scenarios.

2 The Amsterdam- Utrecht Reference Track

2.1 Introduction

The openETCS Proof Of Concept is based on the Amsterdam- Utrecht ETCS line. It is one of the few ETCS lines that are already operational and where engineering and JRU data were available to the consortium.

Some of the characteristics of the Amsterdam- Utrecht line [7].:

- Four tracks

- Very busy mixed traffic
- ETCS Level 2 with mixed signalling, including wayside optical signals and ATB train protection for conventional traffic
- ERTMS 2.3.0 standard (Baseline 2)

For our Proof of Concept this means that, already in the "nominal scenarios", we see transitions from the conventional ATB train protection to ETCS L2 full supervision, that we need a representation of the balises found on the track, and a simple RBC model in order to act as a counterpart to the openETCS EVC model.

We had to decide to which level of fidelity we could model the track, and due to the focus of openETCS on the EVC reference design we limited the scope to building the simulation to "what the train can see".

A full RBC model, the full set of operational rules as well as the interlocking logic are hence out of scope of this work.

2.2 Approach

As an input, we had access to a set of engineering data, track layout plans, and selected JRU recordings from an ICE3 train of consortium member DB. Furthermore we could build on some initial modelling trials that were conducted by the consortium and on a comprehensive formalisation of the ETCS language, to be found at

https://github.com/openETCS/modeling/tree/master/model/Scade/System/ObuFunctions.../ETCS_Messaging/TrackMessages

In addition we had access to a description of the operational rules for the Amsterdam- Utrecht line. The first step to creating a dynamic simulation was the analysis of the available information, in order to have a solid basis for our reverse- engineering effort.

2.3 Engineering Data

2.3.1 Track Layout Plans

The definitive source of information for the balise positions were the track layout plans that do not only allow for a direct reading of the engineering positions of the balises, but also for an understanding of the actual situation on the track, the related signals, the points and stations etc. An example is given in figure 3.

2.3.2 Balise Position Data

Table 1 gives an example of engineering data as provided for positions and orientation of balises on the reference track. The meaning of the columns is:

- NID_C: Country identifier of the track. The Amsterdam- Utrecht line has a NID_C = 426 (Subset-026 7.5.1.86)[3]
- NID_BG: Balise Group Identifier. (Subset-026 7.5.1.85)[3]
- Lint: Track section (not used for our model)

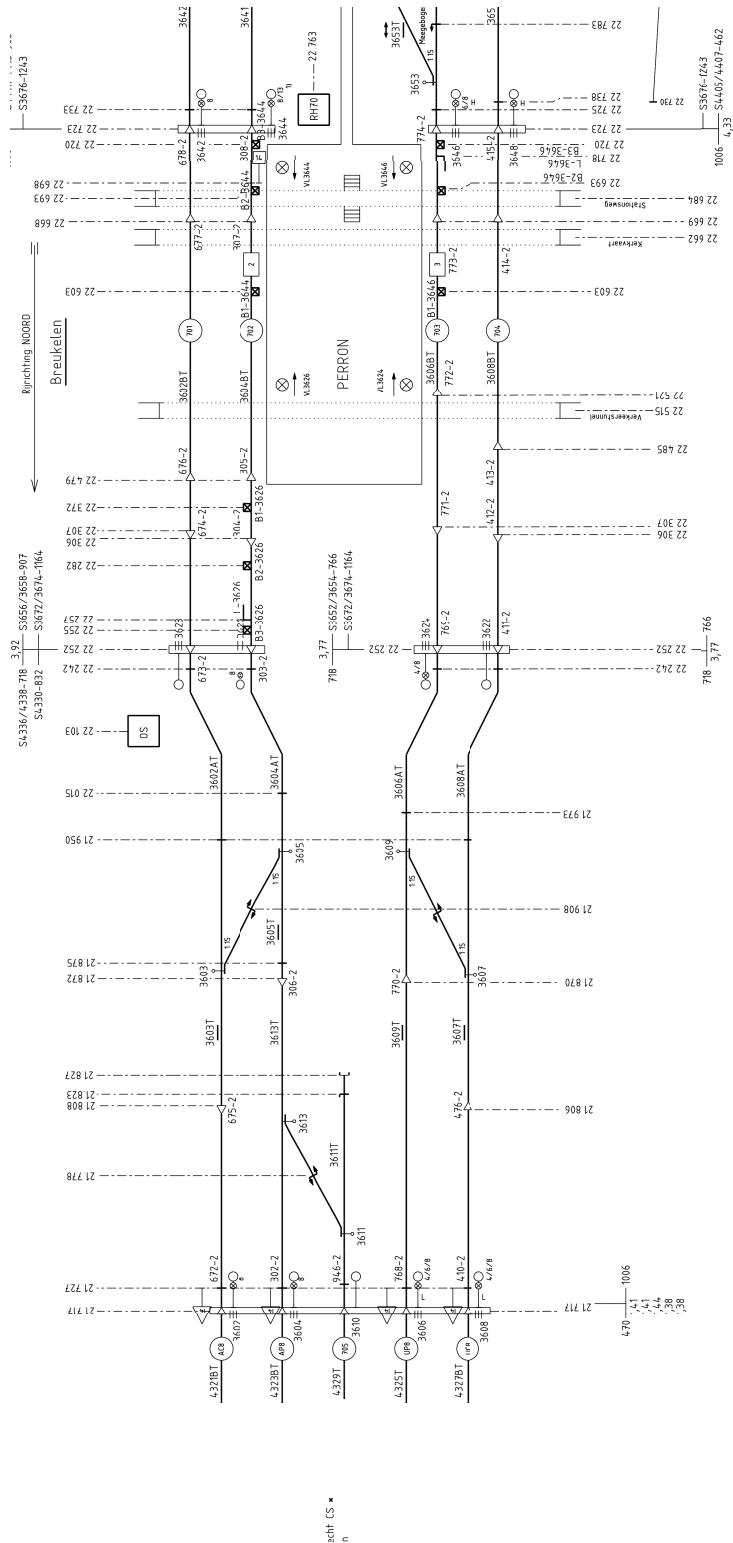


Figure 3. Example Track Layout Plan

NID_C	NID_BG	Lint	km	Or BG	Or Line	Line no
426	352	Asd-Asa	105017	Utrecht	Z	spoor UB
426	353	Asd-Zvg	1565	Utrecht	Z	spoor UB
426	354	Asd-Zvg	3185	Utrecht	Z	spoor UB
426	355	Asd-Zvg	4040	Utrecht	Z	spoor UB
426	356	Asd-Zvg	4197	Amsterdam	Z	spoor UB
426	357	Asd-Zvg	4252	Amsterdam	Z	spoor 508
426	358	Asd-Zvg	4428	Amsterdam	Z	spoor 508
426	359	Asd-Zvg	4598	Utrecht	Z	spoor 508
426	360	Asd-Zvg	4650	Utrecht	Z	spoor 508
426	361	Asd-Zvg	5083	Amsterdam	Z	spoor 598
426	362	Asd-Zvg	5137	Amsterdam	Z	spoor 598
426	363	Asd-Zvg	5372	Utrecht	Z	spoor 598
426	364	Asd-Zvg	5425	Utrecht	Z	spoor 598
426	365	Asd-Zvg	5598	Amsterdam	Z	spoor 608
426	366	Asd-Zvg	5649	Amsterdam	Z	spoor 608
426	367	Asd-Zvg	5805	Amsterdam	Z	spoor 608
426	368	Asd-Zvg	5945	Utrecht	Z	spoor 608
426	369	Asd-Zvg	6000	Utrecht	Z	spoor 608
426	370	Asd-Zvg	6940	Amsterdam	Z	spoor UB1
426	371	Asd-Zvg	6990	Utrecht	Z	spoor UB1
426	372	Asd-Zvg	7424	Amsterdam	Z	spoor UB2
426	373	Asd-Zvg	7625	Amsterdam	Z	spoor UB2
426	374	Asd-Zvg	7857	Utrecht	Z	spoor UB2
426	375	Asd-Zvg	8325	Amsterdam	Z	spoor UB3
426	376	Asd-Zvg	8774	Amsterdam	Z	spoor UB3
426	377	Asd-Zvg	9144	Amsterdam	Z	spoor UB3

Table 1. Some balise positions in original format

- km: Engineering location of the balise group. Please note that this position is the *trackside view* of the balise group. The train is not aware of this absolute location reference.
- Or BG: Orientation of the balise group. The orientation is given with reference to the driving direction towards Amsterdam and Utrecht, respectively. A train driving in direction of Utrecht would see a balise group with orientation "Utrecht" as nominal, "Amsterdam" would be seen as "reverse".
- Or Line: Nominal direction of the track. "Z" means that the main direction of the track is southbound, which means towards Utrecht.
- Line No: Section number. Not used for our simulation.

The full table is available in Appendix 1.

2.3.3 Message and Packet Data

Message and Packet Data were not available as a set of engineering data. The project could however evaluate a set of JRU data from actual train passages on the Amsterdam- Utrecht corridor. One such data set was selected and used as a reference input for our balise and RBC message simulation. The data were available in the form of annotated .csv files, which have been published

```

NID_PACKET(8bits) = Gradient Profile(21)
Q_DIR(2bits) = Reverse(0)
L_PACKET(13bits) = 222bits(222)
Q_SCALE(2bits) = 1m(1)
D_GRADIENT(15bits) = 7890.0m(7890)
Q_GDIR(1bits) = Uphill(1)
G_A(8bits) = 2%(2)
N_ITER(5bits) = 7(7)
1: D_GRADIENT[1](15bits) = 220.0m(220)
Q_GDIR[1](1bits) = Uphill(1)
G_A[1](8bits) = 8%(8)
2: D_GRADIENT[2](15bits) = 420.0m(420)
Q_GDIR[2](1bits) = Uphill(1)
G_A[2](8bits) = 4%(4)
3: D_GRADIENT[3](15bits) = 140.0m(140)
Q_GDIR[3](1bits) = Downhill(0)
G_A[3](8bits) = 4%(4)
4: D_GRADIENT[4](15bits) = 120.0m(120)
Q_GDIR[4](1bits) = Downhill(0)
G_A[4](8bits) = 12%(12)
5: D_GRADIENT[5](15bits) = 320.0m(320)
Q_GDIR[5](1bits) = Downhill(0)
G_A[5](8bits) = 5%(5)
6: D_GRADIENT[6](15bits) = 110.0m(110)
Q_GDIR[6](1bits) = Uphill(1)
G_A[6](8bits) = 2%(2)
7: D_GRADIENT[7](15bits) = 178.0m(178)
Q_GDIR[7](1bits) = Uphill(1)
G_A[7](8bits) = End of gradient profile(255)"

```

Table 2. Example packet data for Gradient Profile as found in the JRU log

on the Github repository as part of the User Story documentation. As an example, we present in Table 2 an instance of a packet 21 (Gradient Profile) which was sent as part of a Level2/3 Movement Authority Message.

A full description of the packet definition can be found in Subset-026 (7.4.2.6) [3]. The actual semantics of the packet are not interesting for us. Our only task is to interpret them in the right way so that they will be correctly decoded once they reach the EVC model.

In order to avoid transcription errors, we want to use the data from the JRU trace "as raw as possible". For that purpose, a detailed analysis of the contents of this log file is required: The file is a result of a script interpreting the raw data: bits are converted to integers, and some comments are added. If we take the first line of the packet:

NID_PACKET(8bits) = Gradient Profile(21)

Here, we can easily understand that in the original packet (bitstream), the value used 8 bits, and has been interpreted as decimal number (21). If we take another line, the interpretation is equally straightforward:

D_GRADIENT(15bits) = 7890.0m(7890)

We could easily say that there is a 1:1 translation of the real value (7890.0m) and the representation found in the JRU data (7890). However, this is only due to the following line:

Q_SCALE(2bits) = 1m(1)

which just means that the values for distance have to be scaled with a factor of 1m.

If we look at packet 27 (international static speed profile), we can see another interesting aspect:

```
NID_PACKET(8bits) = International Static Speed Profile(27)
Q_DIR(2bits) = Reverse(0)
L_PACKET(13bits) = 86bits(86)
Q_SCALE(2bits) = 1m(1)
D_STATIC(15bits) = 7890.0m(7890)
V_STATIC(7bits) = 160km/h(32)
Q_FRONT(1bits) = Train length delay on validity end point(0)
N_ITER(5bits) = 0(0)
N_ITER(5bits) = 1(1)
1: D_STATIC[1](15bits) = 1508.0m(1508)
V_STATIC[1](7bits) = End of SSP(127)
Q_FRONT[1](1bits) = Train length delay on validity end point(0)
N_ITER[1](5bits) = 0(0)"
```

Table 3. Example packet data for Speed Profile as found in the JRU log

Looking at the line:

V_STATIC(7bits) = 160km/h(32)

we can see that the representation in the JRU log (32) and its interpretation (160km/h) do not have the same scale. [3] (7.5.1.171) gives the following information:

7.5.1.171 V_STATIC

Name	Basic static speed profile		
Description	Basic static speed profile speed after discontinuity (k).		
Length of variable	Minimum Value	Maximum Value	Resolution/formula
7 bits	0	600 km/h	5 km/h
Special/Reserved Values	121-126	Spare	
	127	Non numerical value telling that the static speed profile description ends at D_STATIC(n)	

Figure 4. Variable definition for V_STATIC

This means that V_STATIC is using a scaling factor of 5 to encode the speed.

We conclude, that in general, we will provide a track simulation model (balises positions, messages and packets) containing the *integer representation* as found in the JRU log. We will rely on the TrackMessages library to correctly translate the values into the proper scaling for use onboard the EVC. Initially this decision was only taken in order to reduce room for interpretation/transcription errors when building the track simulation model, however, in context of WP5 (Demonstrator) this decision has proven to be very valuable, as it created a requirement for development of a full formalisation of Subset-026, Chapters 6, 7, and 8.

2.4 Operational Rules

As a reference, we had access to the operational rules for the Amsterdam- Utrecht corridor [9]. Due to the limited scope of the project, we did not attempt to create simulation models based on this document, we rather used it as a means to validate our model.

Future work, possibly in the following months of this project, may include some basic research on formalisation of such operational rules.

3 Simulation Concepts

3.1 The State of The Art in Railway (ETCS) simulation

The ETCS requirements provides extensive specification on test formats and a test environment, for example in Subset-076 and Subset-094. Current ETCS Simulation Environments allow to:

- Use a set of offline tools to prepare track and scenario data
- Run a train through the hardcoded scenarios, interacting with the (real or simulated) EVC and accepting input from a driver
- Use a simulated EVC
- Use a simulated DMI (Driver Machine Interface)
- Emit messages, packets and telegrams (priorly prepared) through a trackside simulator

openETCS is aiming in providing an *open, formal executable specification of the EVC kernel*, in order to serve as a functional reference and as a basis for working on novel approaches for interoperability.

We therefore require a simulation concept that supports the development, validation and maintenance of this openETCS kernel, and complements it also after the completion of this project. Some objectives we identified were:

- *Dynamic Behaviour*: The trackside simulation should be able to actively act and react. In other words, instead of reacting to predefined scenarios, all input parameters should be independent of each other.
- The approach should allow *blackbox* as well as *whitebox* simulation.
- The simulation model should allow certification as a verification tool (in the context of EN50128)
- The system should be hardware- independent
- The system should at least cover all functionality of the current state of the art
- The approach should allow deployment through all phases of EVC and track development, testing and validation, including the development of the openETCS kernel itself.

3.2 Dynamic track simulation throughout the (open)ETCS lifecycle

Our concept is aiming at covering all aspects of verification and validation throughout the openETCS lifecycle, and in the lifecycle of ETCS onboard and trackside installations in general. Not all points are relevant for openETCS, but rather lay the grounds for ongoing work of the openETCS foundation and for industrial exploitation.

3.2.1 User Validation

The term *User Validation* refers to the practice to use simplified simulation models during the day-to-day analysis and development work.

openETCS is using SCADE Suite as standard development tool.

During system analysis and development cycle, each SCADE user can iteratively cycle through analysis / design/ simulation in order to understand the requirements, model them, and functionally validate them. This approach strongly supports the distributed and agile openETCS process. Where appropriate, users can integrate the track simulation model, fully, or in part, in their development cycle.

3.2.2 openETCS system integration

openETCS system integration can be grouped into two main issues:

1. Integration of the various parts of the openETCS EVC kernel (Figure 5 provides an example of an EVC functional breakdown)

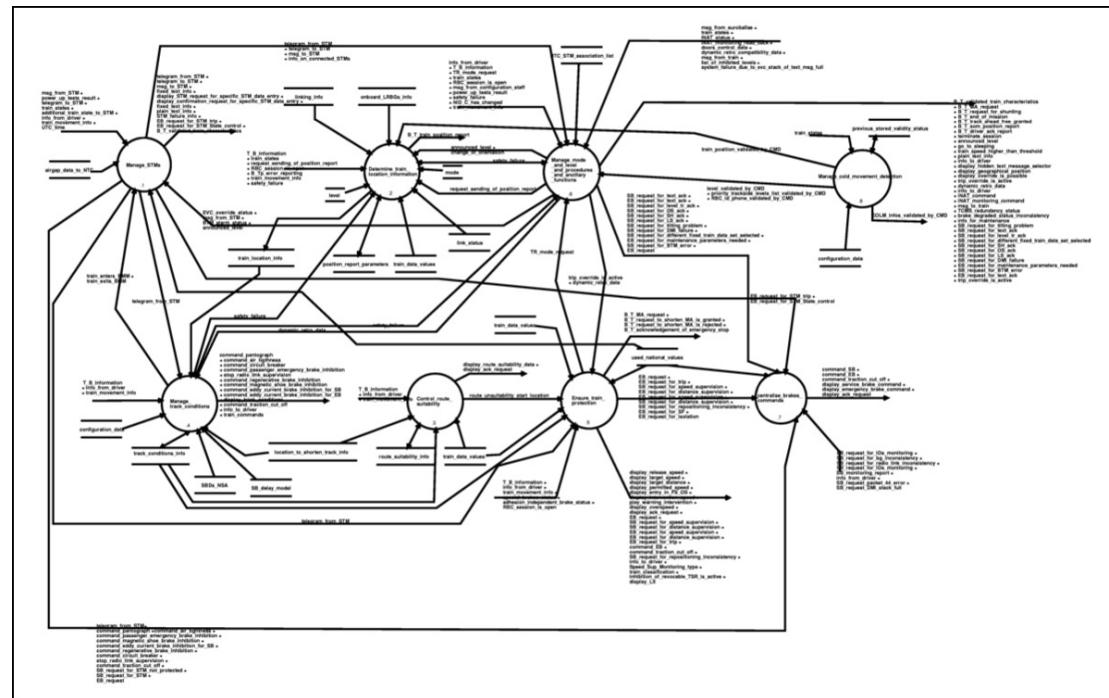


Figure 5. Overview of Components in the ALSTOM EVC architecture, using TeamWork SA RT notation

2. Integration of the different modules of the Proof of Concept. (Figure 6 shows the user interface of the environment used to integrate the different elements of the Proof of Concept) During the 3rd iteration effort of openETCS, a model- level integration environment was created. It includes, on model level, the following elements:

- (a) The openETCS EVC kernel formal model
- (b) The openETCS DMI formal model
- (c) A simple environment toolbox, containing a train model, odometry model, and a telegram/ packet generator
- (d) A boilerplate to interact with the system (driver inputs, graphical outputs)



Figure 6. Depiction of the openETCS Third Iteration Proof of Concept Environment

For the full Proof of Concept, the complete track model is being integrated into the integration environment, allowing to develop, validate and demonstrate the Use Cases.

3.3 The role of dynamic simulation in the formalisation of ERA ETCS Change Requests and in improving interoperability

The complexity of the ETCS software requirements specification and its history of incremental changes make for its reputation to lacking stringency, consistency and a clear, unified concept. The original objective of a unique set of requirements that, if only correctly implemented, would guarantee interoperability, looks quite utopian. At best, there is a common syntax, but there is no common grammar, as far as the interactions between trackside and onboard are concerned. openETCS's original concept has addressed the main problem of ETCS by building an openly available formal model, which is a possible basis for a formalisation of the ERA ETCS change request process.

Subset-94 [6], see Fig. 7 describes functional requirements for an on-board Reference Test Facility. In section 5.1.1.1 it states "*The test architecture described in this document is focused on performing the tests defined in Subset-076-6-3 (...), and hence, the compliance with Subset-026*" In consequence this would mean that if any ETCS Onboard Unit would pass the tests as described in Subset-076 [5] on an on-board Reference Test Facility, it should work on any validated ETCS infrastructure, which is not really the case.

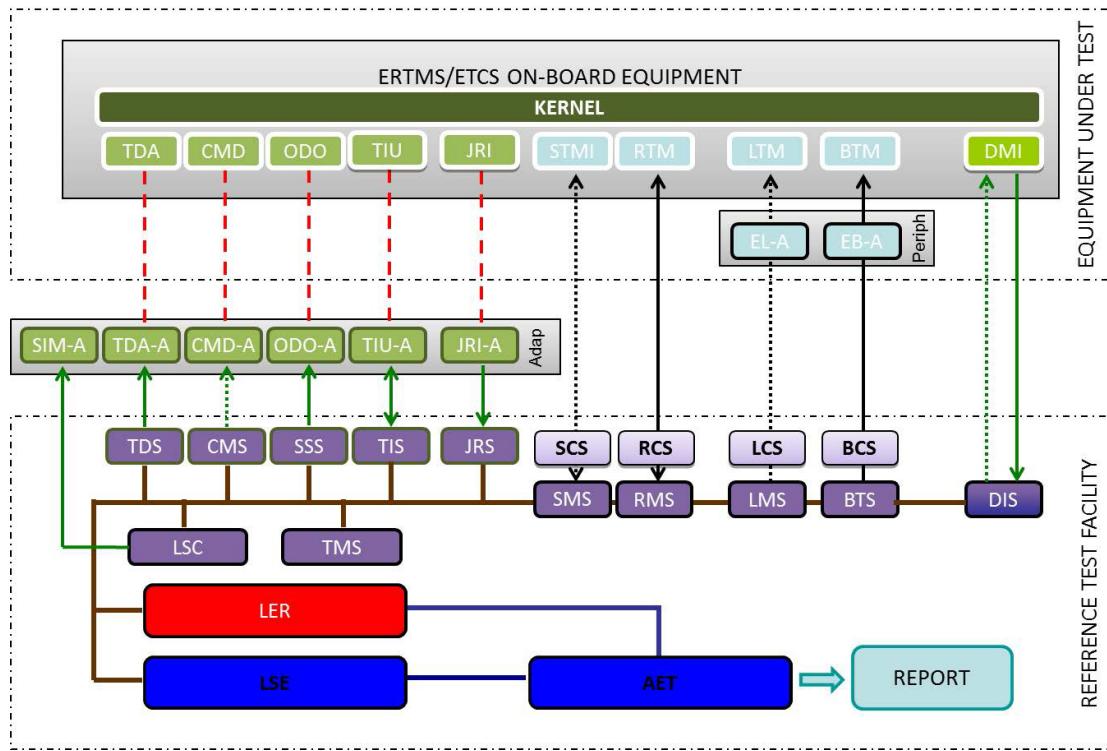


Figure 7. Reference test architecture for ERTMS/ETCS on-board equipment

We believe that providing a formal model of the onboard functionality is only half of the solution: It needs to be complemented by a formal model of the trackside functionality. The validation of the onboard against Subset-076 and the other relevant standards referenced in the CCS TSI is not sufficient, we need to harmonise the onboard and the track *before* we start the actual (real-world) track implementation. Only that way we can reduce the effort and make progress towards the goal of "Zero Onsite Testing".

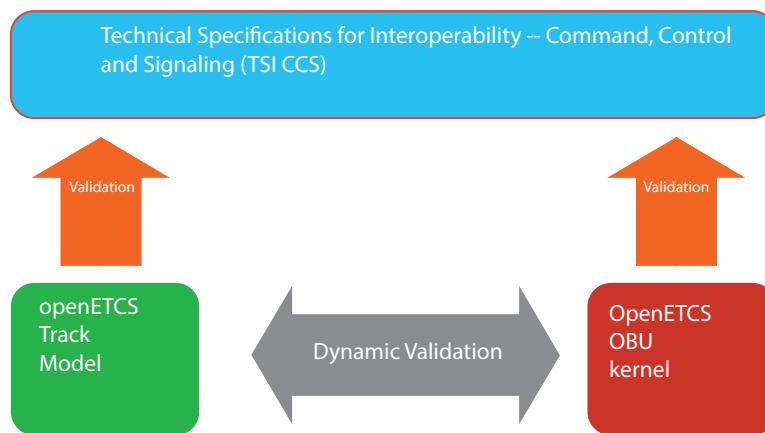


Figure 8. Dynamic simulation for improving interoperability

The validation against the relevant standards referenced in the Document "Applicable standards in HS Control-Command and Signalling TSI (2006/860/EC)" [1] is complemented by extensive validation using the co-simulation of the openETCS formal, executable specifications for the trackside and the onboard functionalities.

As a first step, a validation process for the formal track model must be established.

3.3.1 Validation of the openETCS Dynamic Simulation Model against the existing, scenario- based test cases for the Reference Track

During the analysis and design phase of openETCS, the Track Model is being validated by WP4. We have taken care that the basic interface concepts and data structures at the component boundaries are compatible with the standard approaches as described in Subset-076 [5] and Subset-094 [6], however such integration is beyond the scope of this work.

WP4 is validating the Track Model against the script- driven simulation scenarios used by the team members of work package 4. In addition, peer review is being provided by WP4.

The objective of this exercise is to ensure equal behaviour of the dynamic simulation model as compared to the conventional approach, as far as appropriate.

3.3.2 Checking the track model's consistency by comparing engineering data and packet data

During analysis of the initial Track Model, some discrepancies between the balise positions as defined in the engineering data and the related data concerning linking distance as recorded in the JRU have been discovered. We created a cross reference file (see Table 4) using a spreadsheet tool.

The columns must be read as follows:

- NID_C: Country identifier of the track. The Amsterdam- Utrecht line has a NID_C = 426 (Subset-026 7.5.1.86)[3]
- NID_BG: Balise Group Identifier. (Subset-026 7.5.1.85)[3]
- Corrected pos.: Engineering position *after correction* based on linking data (in Meters)
- Difference: Difference (in Meters) between the engineering position and the corrected position (positive numbers move the balise group down the track, e.g. towards Utrecht)
- Or: Orientation of the Balise Group as defined in the engineering data
- Or US: Orientation of the Balise Group from the train's perspective as it runs from Amsterdam towards Utrecht, as defined in the User Stories (=US)
- Packets: Packets emitted from a particular Balise Group

NID_C	NID_BG	Corrected pos.	Difference	Or	Or US	Packets
426	352			Utrecht	nominal	P45
426	353			Utrecht	nominal	P42
426	354	3185	0	Utrecht	nominal	P42,P46,P46,P3
426	351	3997	2	Utrecht	nominal	none
426	355	4051	11	Utrecht	nominal	P42,P46
426	356	4205	8	Amsterdam	reverse	P41
426	357	4255	3	Amsterdam	reverse	none
426	358	4430	2	Amsterdam	reverse	none
426	359	4599	1	Utrecht	nominal	none

Continued next page...

NID_C	NID_BG	Corrected pos.	Difference	Or	Or US	packets
426	360	4654	4	Utrecht	nominal	P137
426	361	5082	-1	Amsterdam	reverse	none
426	362	5136	-1	Amsterdam	reverse	none
426	363	5374	2	Utrecht	nominal	none
426	364	5428	3	Utrecht	nominal	none
426	365	5600	2	Amsterdam	reverse	none
426	366	5655	6	Amsterdam	reverse	none
426	367	5807	2	Amsterdam	reverse	none
426	368	5948	3	Utrecht	nominal	none
426	369	6001	1	Utrecht	nominal	P137
426	341	6472	2	Amsterdam	reverse	none
426	370	6940	0	Amsterdam	reverse	none
426	371	6993	3	Utrecht	nominal	none
426	372	7426	2	Amsterdam	reverse	none
426	373	7626	1	Amsterdam	reverse	none
426	374	7858	1	Utrecht	nominal	none
426	375	8326	1	Amsterdam	reverse	none
426	376	8775	1	Amsterdam	reverse	none
426	377	9146	2	Amsterdam	reverse	none
426	378	9561	3	Utrecht	nominal	none
426	379	9615	3	Utrecht	nominal	none
426	380	9842	1	Amsterdam	reverse	none
426	381	9896	3	Amsterdam	reverse	none
426	382	10096	3	Amsterdam	reverse	none
426	383	10596	4	Amsterdam	reverse	none
426	384	11026	4	Utrecht	nominal	none
426	385	11091	7	Utrecht	nominal	none
426	386	11280	5	Amsterdam	reverse	none
426	387	11334	5	Amsterdam	reverse	none
426	388	11834	7	Amsterdam	reverse	none
426	389	12582	12	Utrecht	nominal	none
426	390	12689	11	Amsterdam	reverse	none
426	391	13190	12	Amsterdam	reverse	none
426	392	14064	7	Utrecht	nominal	none
426	393	14172	6	Amsterdam	reverse	none
426	394	14879	2	Amsterdam	reverse	none
426	395	15575	-2	Utrecht	nominal	none
426	396	15684	-2	Amsterdam	reverse	none

Continued next page...

NID_C	NID_BG	Corrected pos.	Difference	Or	Or US	packets
426	397	16376	-3	Utrecht	nominal	none
426	398	17075	-4	Utrecht	nominal	none
426	399	17202	-9	Amsterdam	reverse	none
426	400	17820	-4	Utrecht	nominal	none
426	401	18432	-4	Utrecht	nominal	none
426	402	18737	-1	Amsterdam	reverse	none
426	403	19327	0	Utrecht	nominal	none
426	404	19891	2	Utrecht	nominal	none
426	405	20230	3	Amsterdam	reverse	none
426	406	20749	4	Utrecht	nominal	none
426	407	21198	6	Utrecht	nominal	none
426	408	21594	6	Amsterdam	reverse	none
426	409	21669	6	Utrecht	nominal	none
426	410	21723	6	Utrecht	nominal	none
426	476	21813	7	Utrecht	nominal	none
426	411	22258	6	Amsterdam	reverse	none
426	412	22313	7	Amsterdam	reverse	none
426	413	22494	9	Utrecht	nominal	none
426	414	22681	12	Utrecht	nominal	none
426	415	22734	11	Utrecht	nominal	none
426	416	23032	13	Amsterdam	reverse	none
426	417	23086	15	Amsterdam	reverse	none
426	418	23146	14	Utrecht	nominal	none
426	419	23957	22	Amsterdam	reverse	none
426	420	24505	30	Utrecht	nominal	none
426	421	25291	36	Amsterdam	reverse	none
426	422	25934	34	Utrecht	nominal	none
426	423	26453	33	Amsterdam	reverse	none
426	424	27245	35	Utrecht	nominal	none
426	425	27311	33	Utrecht	nominal	none
426	426	27558	33	Amsterdam	reverse	none
426	427	27612	34	Amsterdam	reverse	none
426	428	27783	35	Utrecht	nominal	none
426	429	28121	35	Amsterdam	reverse	none
426	477	28460	36	Utrecht	nominal	none
426	430	28760	33	Utrecht	nominal	none
426	431	28814	35	Utrecht	nominal	none
426	432	29289	34	Amsterdam	reverse	none

Continued next page...

NID_C	NID_BG	Corrected pos.	Difference	Or	Or US	packets
426	433	29343	32	Amsterdam	reverse	none
426	434	29412	34	Utrecht	nominal	none
426	435	29466	32	Utrecht	nominal	none
426	436	29691	30	Amsterdam	reverse	none
426	437	29757	31	Amsterdam	reverse	none
426	438	30565	31	Utrecht	nominal	none
426	439	30794	31	Amsterdam	reverse	none
426	440	31502	32	Utrecht	nominal	none
426	441	32165	31	Amsterdam	reverse	none
426	442	32327	32	Utrecht	nominal	none
426	443	32381	31	Utrecht	nominal	none
426	444	32867	32	Amsterdam	reverse	none
426	445	32921	34	Amsterdam	reverse	none

Table 4. Cross reference table for the balise groups relevant for the Proof of Concept

We assumed the JRU data to be more accurate than the original engineering data, as the Amsterdam- Utrecht track is already operational and the packet data must therefore be considered as definitive.

Note: As the Balise Groups with NID_BG 352 and 353 are not linked, no correction data are applicable.

3.3.3 Validation of the openETCS EVC kernel against the reference track

Once the reference track model is considered to correctly reflect the infrastructure and events as recorded for the "real" reference track, it can be used to validate the functionality of the openETCS kernel against the reference track, as depicted in Figure 8 above.

Once this achieved, we can consider the Reference Track Model and the Reference ETCS kernel to be interoperable, at least to the extent that the User Stories cover the actual operational situation on the track.

Extending this approach to full CCS TSI coverage would assure that both the Track and the EVC models are TSI compliant, and they are interoperable as well.

Within the openETCS effort, we will limit our efforts to demonstrating functional interoperability between the reference track and onboard.

3.3.4 Validation of tracks and OBUs against the openETCS reference EVC

openETCS has claimed as one of its main objectives to create a *Reference ETCS Kernel*, against which future onboard system may be validated.

We intend to extend this concept to validating new Dynamic Track Models against the openETCS kernel as well, with the ultimate objective to have a library of validated tracks against which future Onboard Unit implementations can be tested.

The extension of the validation concept beyond the current reference track model for the Amsterdam- Utrecht corridor is beyond the scope of the openETCS effort.

3.3.5 Verification and Validation in an EN50128 SIL4 context

openETCS has chosen the SCADE¹ Suite from Esterel Technologies as software development tool. The rationale behind this decision was to enable a future development of a CENELEC EN 50128 SIL4² compliant ETCS reference kernel.

We decided to use the same development environment for the Track Model. This will enable us to certify the Track Model (and the process to create such models) in EN50128 context, meaning that it can be used as basis for a trusted and certified verification and validation tool suite.

Process definition and certification are beyond the scope of openETCS. We will concentrate on demonstrating functional aspects.

3.3.6 Transferring the concept to WP5 (Demonstrator)

As we can generate C- code from the Track Model, it is also possible to embed the Track Model into external simulation and testing environments. As a first trial, we have generated code for the model and embedded it onto a Raspberry Pi2 hardware, which can be coupled to WP5 demonstrator hardware via Ethernet. (See figure 10)

Of course, the generated code can also easily be integrated on any other hardware platform. Thanks to the cycle- based execution model of SCADE, this is very straightforward.

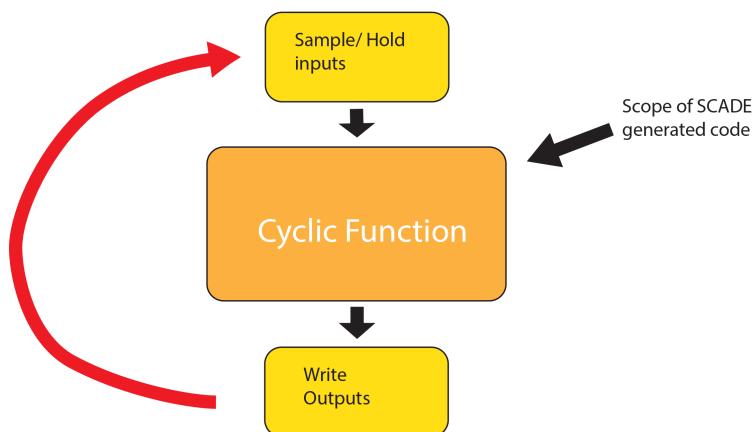


Figure 9. SCADE cycle- based execution model

The cyclic function contains the complete Track Model.

¹SCADE = Safety Critical Application Development Environment

²European Committee for Electrotechnical Standardization standard for Safety Critical Software Development in Railways, Safety Integrity Level 4



Figure 10. Raspberry Pi2 running the track model

4 Formal model for trackside simulation

4.1 Simulation concept

The simulation of the track can be seen as an integral part of a simulation and validation facility. While, at the moment, the openETCS demonstration environment is not designed to be Subset-094 compliant, its basic concept is similar and extension to a full onboard-unit test facility is possible in the future.

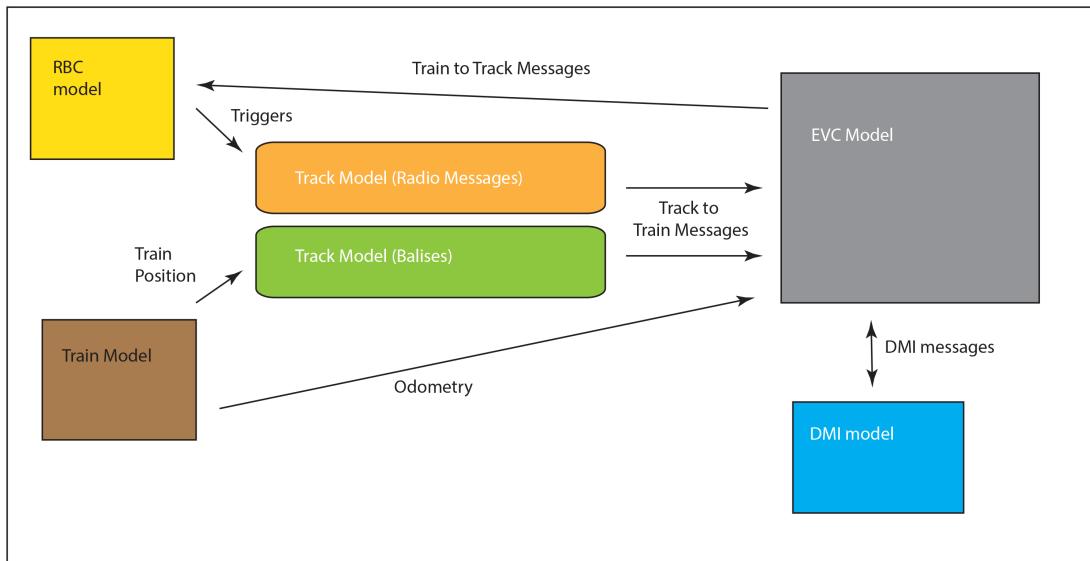


Figure 11. Simplified Simulation Concept

4.1.1 Scope of the model

The scope of the model is defined by the User Stories. A full balise and RBC model exists for the southbound track of the western pair of tracks on the Amsterdam- Utrecht corridor, between the stations Amsterdam Amstel and Utrecht CS.

4.1.2 Overview

The Track Model consists of two main parts:

- The balise model:
 - The balise model receives a single input from the *train model*, which provides information on the nominal train position.
 - The balise model sends messages and packets to the *EVC Model* when the train passes a position where a balise is located
- The radio message model:
 - The radio message model gets a command from the *RBC model*, called a "trigger" which serves as an identifier to release a specific message with its packets
 - The radio message model sends messages and packets to the *EVC Model* when the RBC model commands.

This functional breakdown assures that the RBC logic and the RBC messages are only loosely coupled.

- Changes to operational rules (under which circumstances does the RBC send a specific message?) is under the sole responsibility of the RBC model.
- Changes to packet contents are under the sole responsibility of the Track Model (radio message model)

4.1.3 RBC model

While the RBC³ model is outside the scope of this work, it is essential for its functioning. The RBC model

- Receives Train to Track Messages from the *EVC Model*
- Processes the messages in line with preset rules and procedures (our RBC model is very much simplified as we do not attempt to simulate interlocking behaviour)
- Dynamically generates messages as required
- Dynamically triggers sending of messages from the radio message model as required

From point of view of the radio messages model, the only "interesting" information from the RBC model is the trigger which corresponds to preset parameters in the radio message model in order to send a message and its packets.

4.2 Fundamental modelling concept: The daisy chain

The basic design pattern of the track model (balise as well as radio message models) is the daisy chain. The idea is to have reusable, similar components with an extremely simple interface, from which we can construct a track model by simple concatenation. Figure 12 provides a simple example. The model describes a track section (as seen on the track layout sheet 7 Bijlmer-Abcoude) which contains 3 balise groups.

We can describe this design pattern as follows:

- The model consists of several SCADE operators that follow an identical pattern. Each operator models a Balise Group.
- The first operator receives its inputs from the calling operator (which in this case represents a section of the reference track)
- The following operator receives its inputs from the first operator (for message/ packet data) and from the calling operator (for the train position)
- Operators can be daisy chained infinitely
- The last operator in the chain provides its output to the calling operator
- If any of the operators sends a message and or/ packets, they pass through all the subsequent operators, so that at the output of the last member of the chain the desired packets and messages are sent.

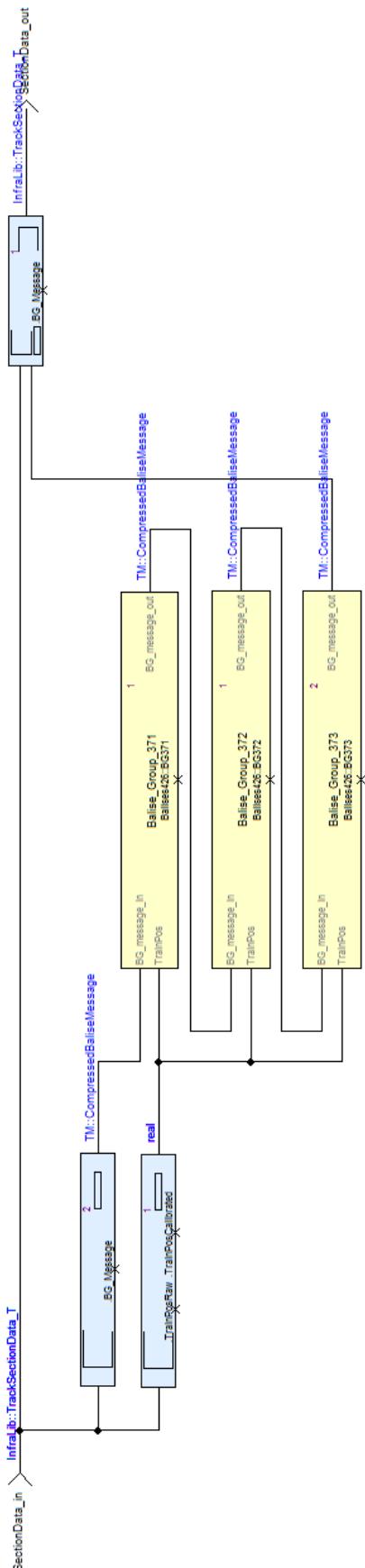


Figure 12. Daisy Chained Balise Groups

As we will see in detail, we have used the daisy chain pattern in order to provide a structured, hierarchical model. There are several layers of daisy chains, which can be concatenated:

1. Tracks
2. Sections (Sheets)
3. Balise Groups

Tracks, Sections and Balise Groups share the same semantics and interfaces and can be concatenated between each other.

It is however recommended to maintain the hierarchical structure as in the reference track model when constructing new tracks. If we go one hierarchy level down, there is a daisy chain of balises inside each balise group model. This pattern is more rigid, and will be described in the relevant section where we will discuss *design templates* in more detail.

Inside each balise, there are again daisy- chained operators to build messages and packets. Again, these will be discussed in more detail in the design templates chapter.

Equally, the radio message model is built using the same design principles.

4.3 Where to find the information in the model

The model is organised in SCADE packages. Each package contains specific elements or information.

The main elements:

- The Amsterdam Utrecht Reference Line: **AmsterdamUtrechtL2**
The track model is then hierarchically structured:
 - Main balise model: **Amsterdam_Utrecht_Lijn1_balises**
The balise model is grouped according to the Track Topology Sheets (**SheetXX_Name_Balises**), which in turn contain the models for the balise groups, balises and for sending the packets.
 - Main radio message model: **Amsterdam_Utrecht_Lijn1_RBC**
The radio message model is grouped according to the Track Topology Sheets (**SheetXX_Name_RBC**), which in turn contain the models for sending the messages and packets.
- The balise data for the Amsterdam- Utrecht Reference Line (NID_C=426): **Balises426**.
The corrected balise positions are visible in the engineering data, as we have expressed them using SCADE constant expressions in the format OriginalPosition + Correction
- The packet and message data for the Amsterdam- Utrecht Reference Line: **Packets426** and **Messages_426**, respectively.
- A packaging for the User Stories (with the original June 2015 milestone): **US_Integration_June**.

There are some additional packages (that a normal user of the track model can ignore):

³RBC = Radio Block Center

- **FirstTest:** The first, short test track that was used to validate the concept
- **AmsterdamUtrechtL1:** A first version of the track model, containing Linking information sent from balise groups (That's why we called it "L1", for ETCS Level 1)
- **AmsterdamUtrechtL2_original:** A version of the test track with balise positions (defined in **Balises426_original** not aligned with the linking information)
- **Internal_Tests:** Some test routines that were used for user validation of the track model and the underlying libraries (such as TrackMessages)
- **Basics, Infra426:** internal definitions

4.4 Track model (balises)



Figure 13. Siemens Eurobalise

The track model provides the EVC kernel with a view of the balise infrastructure. The main functions of this model are:

- When the train passes a balise group, it receives the telegrams of the balises, in the right sequence. The information is complete enough for the EVC to derive the BG's orientation and to position it using odometer data and, if applicable, linking information.
- When the train passes a balise, it receives the packets contained therein, if applicable.

The main idea of the model is that it should dynamically react to a passing train. Instead of hard-wired scenarios, the simulated train can move forward, backwards, come to standstill and change speed, without any impact on the representation of the track in the simulation. The only determining factor for receiving balise information is whether or not the front end of the train is "close enough" to a balise in order to "see it".

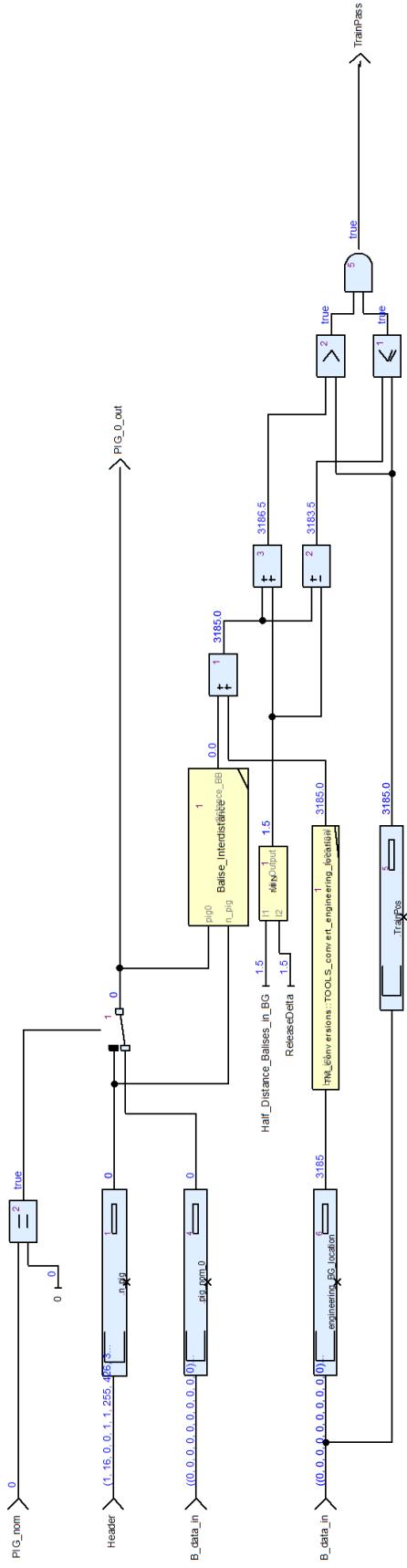


Figure 14. Triggering a Balise when the train is inside the defined distance bracket
(view from SCADE Suite Simulator)

4.4.1 Concept

A real-world balise transmits its telegrams when a train passes. In our simulation, we try to model this as close as possible: As soon as a balise "sees" that a train is passing over it, it actively sends the information (telegram header and packets) through the daisy chain. At the end of the model, the resulting telegram and packets are transmitted to the simulated EVC.

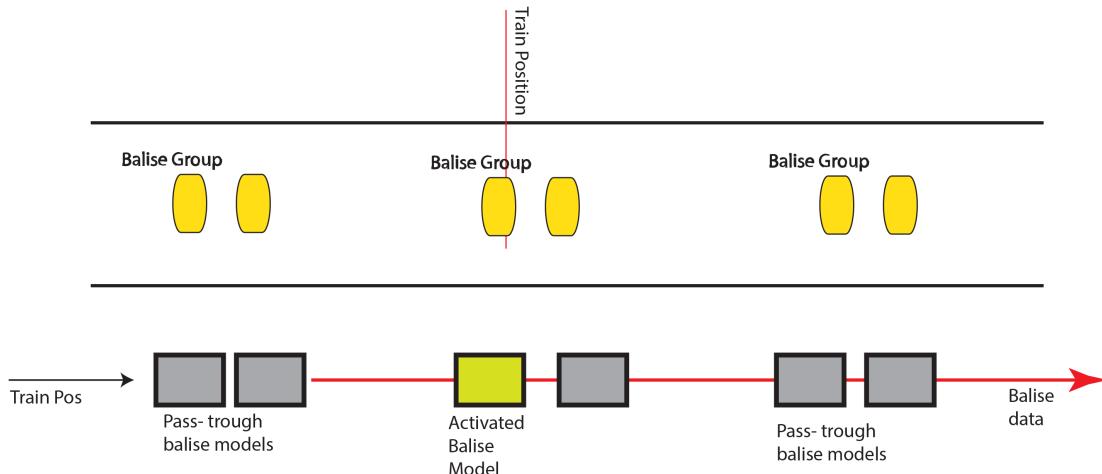


Figure 15. Triggering a Balise in the Daisy Chain

On model level we use the SCADE function *InfraLib::Balise_localisation* (see Figure 14), which checks whether the Balise is within a predefined distance bracket from the nominal train position.

Note that this function takes into account the variable N_PIG, which determines the position of a given balise ("I am the 1st") inside a balise group in order to determine the balise position.

4.4.2 The Balise Group Model

We will not explain the models in full, but limit the discussion to the parts of the model that are track and data-specific.

As the Amsterdam-Utrecht track is an ETCS Version 2.3.0 Level 2 track, we only see balise groups with 2 balises per group. We present BG354. The relevant (corrected) engineering data are as follows:

NID_C	NID_BG	Lint	km	Or BG	Or Line	Line no
426	354	Asd-Zvg	3185	Utrecht	Z	spoor UB

Table 5. Engineering data for BG354

In the SCADE model, these data are defined as a *constant expression*:

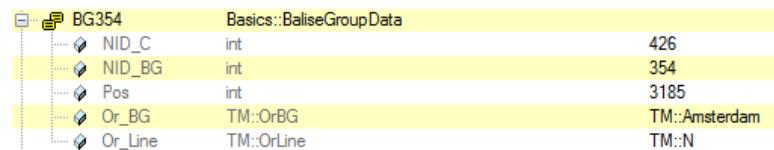


Figure 16. Engineering data for BG354 (view from SCADE model)

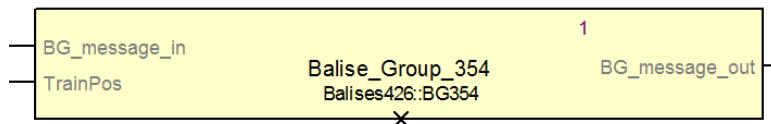


Figure 17. Interface and parameter reference for BG354 (view from SCADE model)

Figure 17 shows an external view of the operator implementing BG354.

The interface is defined as follows:

- input **BG_message_in**: data from daisy- chained BGs before
- input **TrainPos**: Train Position from simulation environment
- parameter ⁴ **Engineering_Data**: static definition of engineering data (from Figure 16)
- output **BG_message_out**: data to daisy- chained BGs after

Looking inside the model (see Fig. 18), we will find two balises: Balise_354_0 and Balise_354_1. Again, the daisy- chain pattern has been used in order to allow for a flexible design pattern (in the chapter "Explaining the templates", we will see how to design BGs with a different balise count between 1 and 8).

The most important about this design pattern is that the ordering of the balises in a group is significant. If balise Balise_354_0 is the first in the chain and Balise_354_1 the second, then the passing train will see the BG as having nominal orientation. If the order is inverted, then the train will consider the BG to be oriented as reverse.

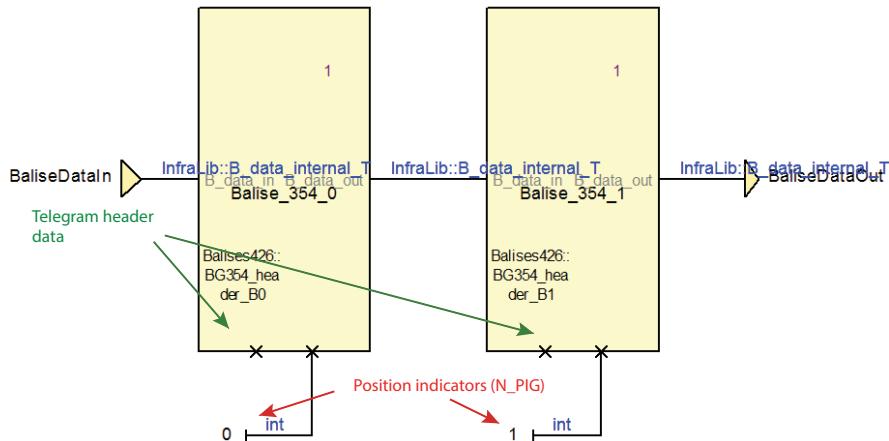


Figure 18. Interface and parameter reference for balises in BG354 (view from SCADE model)

The *position indicators* are a fixed part of the design pattern. They must not be altered, and their order and position is fixed. The *telegram header data* are used to generate the telegram headers sent to the EVC in case a train "passes" the balise, and also to calculate the balise position with reference to the engineering data. This means that the balise with the parameter N_PIG=0 will release its telegram when the train passes the nominal position of the BG, while for balises with

⁴defined as "Hidden Input" in SCADE

a different N_PIG an offset will be used. The offset is also correctly calculated for reverse BGs. The orientation of the BG is determined by the N_PIG information in the *telegram header data*. If N_PIG of the balise that is connected to the *position indicator* 0 = 0, then the BG is considered to be in nominal orientation. (of course, a reversing train will encounter it as reverse).

BG354_header_B0 TM::BaliseTelegramHeader_int_T		
q_updown	int	1
m_version	int	16
q_media	int	0
n_pig	int	0 ← Position of the balise in the group (0 means 1st, 1 means 2nd)
n_total	int	1 ← Total count of balises in the group (0 means 1, 1 means 2)
m_dup	int	1
m_mcount	int	255
nid_c	int	426
nid_bg	int	354
q_link	int	1
BG354_header_B1 TM::BaliseTelegramHeader_int_T		
q_updown	int	1
m_version	int	16
q_media	int	0
n_pig	int	1 ← Position of the balise in the group (0 means 1st, 1 means 2nd)
n_total	int	1 ← Total count of balises in the group (0 means 1, 1 means 2)
m_dup	int	2
m_mcount	int	255
nid_c	int	426
nid_bg	int	354
q_link	int	1

Figure 19. Telegram data of BG354 (view from SCADE model)

Since the parameter n_pig in the constant expression BG354_header_B0 is connected to the balise model with the position indicator 0, it is considered to be the 1st balise of a group in nominal orientation.

4.4.3 Sending balise telegrams and packets

Again, the daisy-chain design pattern is being used. While the telegram headers are sent by using internal logic in the balise model itself, a more elaborated design schema is used to send the packets that may be contained in a balise.

Comparing the packet data as found in the JRU log, we can see that the ordering of the send-packet operators in the balise is similar. This means that also the telegram will contain the packets in the same order as found in the JRU data.

The packet-specific send operators can be freely concatenated. They assure that all packets are merged into a message in a correct way. (For a deeper discussion of the underlying libraries, check the projects **BaliseLib.etc** and **TrackMessages.etc** that are part of the openETCS effort.)

NID_PACKET(8bits) = Session Management(42)
 Q_DIR(2bits) = Nominal(1)
 L_PACKET(13bits) = 113bits(113)
 Q_RBC(1bits) = Establish communication session(1)
 NID_C(10bits) = 426
 NID_RBC(14bits) = 1(1)
 NID_RADIO = Anonymous(lenght is more than 32bits or variable)
 Q_SLEEPSESSION(1bits) = Ignore session management information(0)"

 NID_PACKET(8bits) = Conditional Level Transition Order(46)
 Q_DIR(2bits) = Nominal(1)
 L_PACKET(13bits) = 42bits(42)
 M_LEVELTR(3bits) = Level STM(1)
 NID_STM(8bits) = ATB
 N_ITER(5bits) = 1(1)
 1: M_LEVELTR[1](3bits) = Level 2(3)"

 NID_PACKET(8bits) = Conditional Level Transition Order(46)
 Q_DIR(2bits) = Reverse(0)
 L_PACKET(13bits) = 39bits(39)
 M_LEVELTR(3bits) = Level STM(1)
 NID_STM(8bits) = ATB
 N_ITER(5bits) = 0(0)"

 NID_PACKET(8bits) = National Values(3)
 Q_DIR(2bits) = Nominal(1)
 L_PACKET(13bits) = 186bits(186)
 Q_SCALE(2bits) = 1m(1)
 D_VALIDNV(15bits) = 0.0m(0)
 N_ITER(5bits) = 1(1)
 1: NID_C[1](10bits) = 426
 V_NVSHUNT(7bits) = 40km/h(8)
 V_NVSTFF(7bits) = 40km/h(8)
 V_NVONSIGHT(7bits) = 40km/h(8)
 V_NVUNFIT(7bits) = 10km/h(2)
 V_NVREL(7bits) = 15km/h(3)
 D_NVROLL(15bits) = 5.0m(5)
 Q_NVSRBKTRG(1bits) = No(0)
 Q_NVEMRRLS(1bits) = Release only at standstill possible(0)
 V_NVALLOWOVTRP(7bits) = 0km/h(0)
 V_NVSUPOVTRP(7bits) = 40km/h(8)
 D_NVOVTRP(15bits) = 200.0m(200)
 T_NVOVTRP(8bits) = 60s(60)
 D_NVPOTRP(15bits) = 60.0m(60)
 M_NVCONTACT(2bits) = Train trip(0)
 T_NVCONTACT(8bits) = 35s(35)
 M_NVDERUN(1bits) = Yes(1)
 D_NVSTFF(15bits) = Infinity(32767)
 Q_NVDRIVER_ADHES(1bits) = Allowed(1)"

 NID_PACKET(8bits) = End of information(255)"

Table 6. Packets sent from BG354 as found in the JRU log

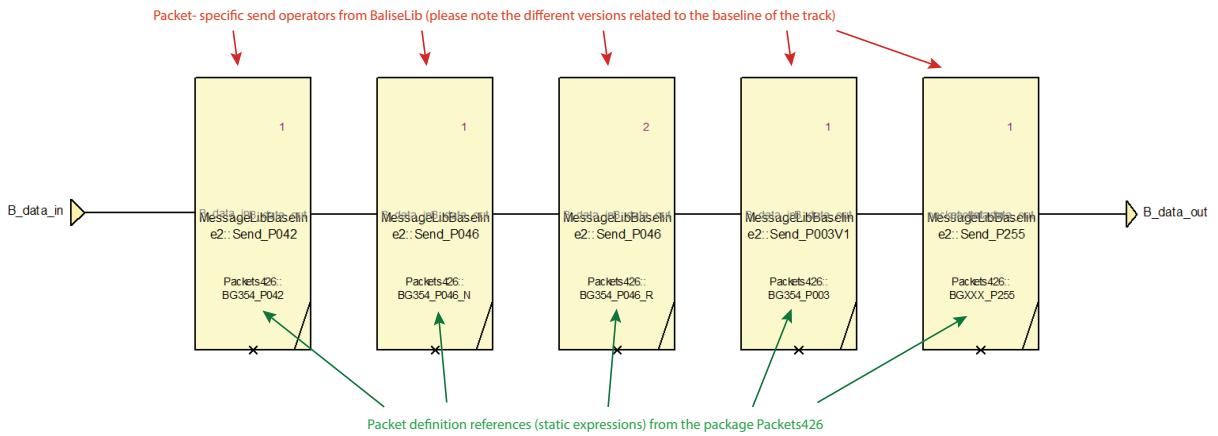


Figure 20. Sending packets from BG354 (view from SCADE model)

(Note: The packet definitions for BG354 in the SCADE model can be found in Packets426::BG354_Pxxx)

4.4.4 Driving the train: Train Position vs. Balise Position

Looking at the track topology maps, we can see that the engineering positions of balise groups that a train may pass can be on different track sections that may exhibit different origins for the distances (kilometres). These different coordinate systems are of course also reflected in the engineering data.

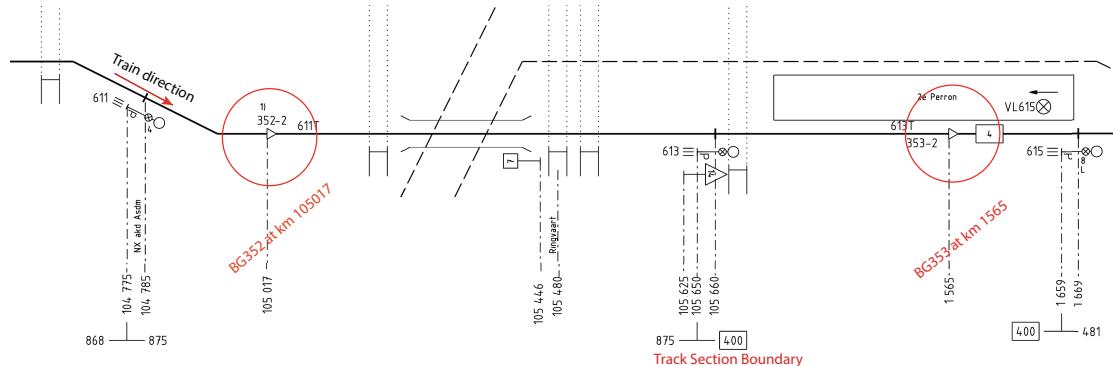


Figure 21. Balises in different local coordinate systems (depending on track sections)

Our train "knows nothing" about those coordinate systems: It starts at position 0 and while it drives on, the train position increases steadily when the train moves forward, and decreases when it moves backwards.

On the other hand, the balises will only emit their telegrams when they see that the train position equals their own location (see figure 14).

We therefore need a method to position the train correctly inside the track sections.

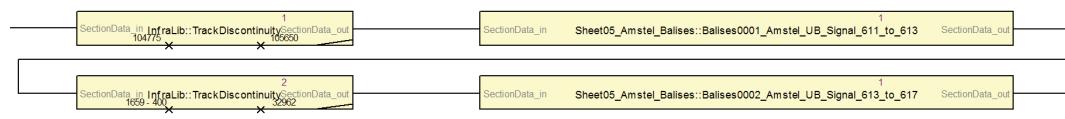


Figure 22. Track Discontinuity modelling (view from SCADE model)

The operator InfraLib::TrackDiscontinuity takes two parameters:

- *StartSection*: kilometre at the start of the track section
- *EndSection*: kilometre at the end of the track section

When placed in the daisy chain *before* the concerned track section, the balises inside this section will see the simulated train in their local coordinate system. Track sections with such discontinuities can be concatenated. Each section will see the train in its local coordinate system.

When comparing the model with the track layout plan, we can observe that the section in the Scade Operator *Balises0001_Amstel_UB_Signal_611_to_613* are between km 104775 and km 105650, which is between signal 611 and signal 613.

For the section in the Scade Operator *Balises0001_Amstel_UB_Signal_613_to_617*, we had to define the beginning of the section to start also at signal 613. As there is no absolute kilometre value describing the position of this signal in the coordinate system of the following track, we have simply defined a constant expression to define the parameter *StartSection* by using the available distance information between signal 613 and BG353. The *EndSection* parameter is the latest position known from the User Story definition and is in fact located at Utrecht CS.

4.5 Radio Message simulation

The basic design principles used for the balise model (daisy chaining, merging of packets into a compressed format) apply also for the radio message model.

The main differences are:

- While balises contain a telegram header which always contains the same set of information, plus a set of packets (at least a packet 255), radio messages are composed of a Message (as defined in Subset-026 chapter 8 [4]) plus optional packets.
- The balise model activates a balise when a train passes, while the radio message model expects an external trigger signal which comes from the RBC model.

4.5.1 Base data for the radio message model

The only available source of information for the creation of the radio message simulation model are the data logged in the JRU files provided as part of the User Story definitions.

As part of our analysis work, we have created a cross- reference table for the simulated radio messages.

The columns must be read as follows:

1. **NID_MESSAGE**: Message (as defined in Subset-026 chapter 8 [4]).
The messages are defined as constant expressions in the package *Messages_426* and named using the format **LRBG_nn.D_ddddd_f_Mmmm** with:
 - **nnn** = NID_BG value of NID_LRBG (the NID_C value is assumed to be 426, as already expressed in the package name)
 - **ddddd** = the integer part of the distance from the LRBG where the radio message was recorded, in meters. The number is padded with leading zeroes if less than the 5 significant digits exist.

- **f** = the fractional part of the distance from the LRBG where the radio message was recorded, in tenths of meters.
 - **mmm** = the NID_MESSAGE. Padded with leading zeroes if less than 3 significant digits exist.
2. **Packets:** Optional packets, as defined in Subset-026 chapter 8 [4] and described in detail in Subset-026 chapters 7 [3] and, where applicable in chapter 6 [2].
The packet definitions in the form of SCADE constant expressions can be found in the package *Packets426*.
3. **Trigger:** Integer value. The radio message simulation model observes the input *Trigger* which is propagated through all Send Radio Message operators that are daisy-chained to form the simulation model. If an operator receives a trigger value corresponding to its local trigger parameter definition, it will release the message and all optional packets it contains and forward them through the daisy chain to the EVC. The trigger has, by convention, the format nnnddddf with:
- **nnn** = NID_BG value of NID_LRBG (the NID_C value is assumed to be 426, as already expressed in the package name)
 - **dddd** = the integer part of the distance from the LRBG where the radio message was recorded, in meters. The number is padded with leading zeroes if less than 5 significant digits exist.
 - **f** = the fractional part of the distance from the LRBG where the radio message was recorded, in tenths of meters.
4. **LRBG:** NID_BG value of NID_LRBG (the NID_C value is assumed to be 426).

Important note: This value refers to the LRBG known to the train at the reception of the message. It may differ from the LRBG which is referenced in the message itself!

5. **Distance:** Distance from the LRBG at which the message was received according to the JRU data, in meters, resolution 0,1m

NID_MESSAGE	Packets	Trigger	LRBG	Distance
32	None	353003192	353	319.2
8	None	353004219	353	421.9
24	P57	353004310	353	431.0
24	None	353004413	353	441.3
24	None	353004972	353	497.2
24	None	353006561	353	656.1
24	None	353008532	353	853.2
24	None	353010375	353	1037.5
24	None	353012387	353	1238.7
24	None	353014483	353	1448.3
24	None	354000537	354	53.7
24	None	354000902	354	90.2
3	P15, P21, P27, P3, P5, P41, P65	354002753	354	275.3

Continued next page...

NID_MESSAGE	Packets	Trigger	LRBG	Distance
24	None	354004835	354	483.5
24	None	354006798	354	679.8
24	None	351000333	351	33.3
3	P15, P21, P27, P3, P5, P41, P65	351000549	351	54.9
24	None	351000656	351	65.6
24	None	351000723	351	72.3
15	None	355000894	355	89.4
24	None	355001262	355	126.2
24	None	355001330	355	133.0
15	None	356000485	356	48.5
24	None	357000389	357	38.9
24	None	357000591	357	59.1
24	None	357001511	357	151.1
24	None	358000540	358	54.0
24	None	358000916	358	91.6
15	None	358001231	358	123.1
24	None	359000371	359	37.1
24	None	359000500	359	50.0
24	None	360000516	360	51.6
24	None	360000980	360	98.0
24	None	360001835	360	183.5
24	None	360002492	360	249.2
24	None	360002766	360	276.6
24	None	360003507	360	350.7
24	None	360004244	360	424.4
24	None	361000278	361	27.8
24	None	361000442	361	44.2
24	None	362000298	362	29.8
24	None	362000347	362	34.7
24	None	362000769	362	76.9
24	None	362001089	362	108.9
15	None	362001249	362	124.9
24	None	362001364	362	136.4
24	None	362001588	362	158.8
24	None	362001820	362	182.0
24	None	362002166	362	216.6
24	None	362002273	362	227.3
24	None	362002606	362	230.6

Continued next page...

NID_MESSAGE	Packets	Trigger	LRBG	Distance
3	P15, P21, P27, P3, P5, P41, P65	362002307	362	230.7
3	P15, P21, P27, P3, P5, P41, P65	362002389	362	238.9
24	None	363000258	363	25.8
24	None	364000173	364	17.3
24	None	364000366	364	36.6
3	P15, P21, P27, P3, P5, P41, P65	364000911	364	91.1
24	None	364001742	364	174.1
24	None	365000582	365	58.2
24	None	366000521	366	52.1
24	None	367000154	367	15.4
24	None	367000599	367	59.9
24	None	367001513	367	151.3
24	None	368000592	368	59.2
24	None	369000733	369	73.3
24	None	369001060	369	106.0
15	None	369002313	369	231.3
24	None	369002772	369	277.2
24	None	369004516	369	451.6
24	None	341000724	341	72.4
15	None	341001344	341	134.4
24	None	341001559	341	155.9
24	None	341003500	341	350.0

**Table 7. Cross reference table for the radio messages relevant for the Proof of Concept,
partial list covering the sheets Amstel and Bijlmer**

Remark: with the exception of the message received at LRBG=353 and the distance=431.0, General Messages (M024) are not part of this model, but are dynamically created inside the RBC model.

4.6 The radio message formal model

4.6.1 Concatenating operators

As the design principles have already been discussed in the *Balise Model* chapter of this text, we will mainly highlight the differences. Figure 23 shows an example of a send radio message model.

- The name of the operators corresponds with the name of the message definition (for example LRBG_353_D_00319_2_M032; see also the legend for table 7)
- At the hidden inputs we see the trigger value (for example 353003192)



Figure 23. Daisy- chained Send Radio message operators (view from SCADE model)

4.6.2 Activating the send function

Going one level deeper inside the operator *Send_RBC_LRBG_353_D_00319_2_M032*, we see (figure 24) that:

- If The trigger value received from RBC (via RadioDataIn) equals the parameter (via TriggerValue), then the function *Build_RBC_Message_LRBG_353_D_00319_2_M032* is activated,
- Otherwise, the RadioDataIn value is just propagated to the output R_data_out.

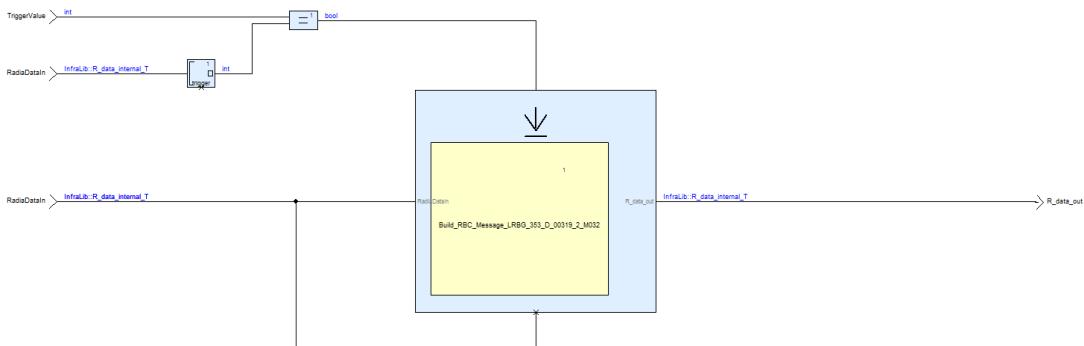


Figure 24. Send Radio Message (view from SCADE model)

This means that if the trigger is valid, the messages and packets defined in this operator will be merged to the data flow representing the radio messages. Otherwise, any other messages defined elsewhere will be passed along the daisy chain.

4.6.3 Merging information

If the RBC commands that a message be sent, we have to merge the defined message and packet information onto the data flow that runs along the daisy chain. In our example in figure 25, a message 32 must be sent, which contains no optional packets.

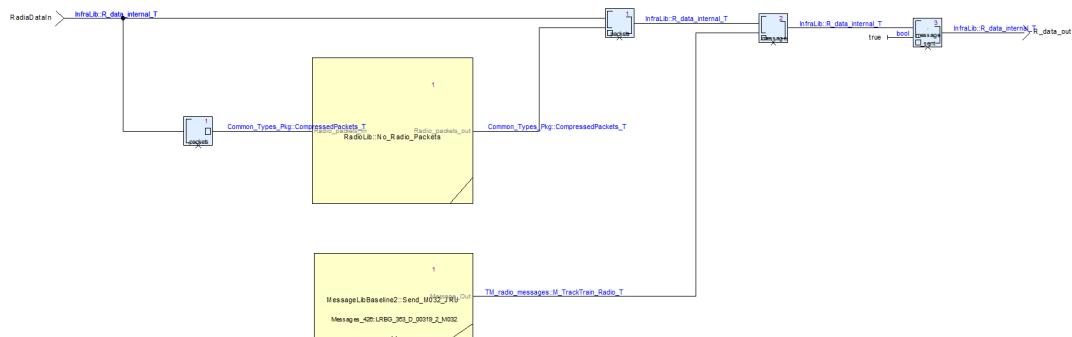


Figure 25. Merge message information into the message/ packets stream (view from SCADE model)

The operator *RadioLib::No_Radio_Packets* simply passes along the packet stream without adding any information.

If we look at a different message (Message 3, L2/3 Movement Authority), we explore the operator *SendRadioPackets_LRBG_351_D_00054_9_M003*, which plugs in the same place as our *RadioLib::No_Radio_Packets*. This operator merges a set of packets into the packet stream. We can see that the pattern is identical to sending packets from a balise. Even the data structures are the same (see figure 26)

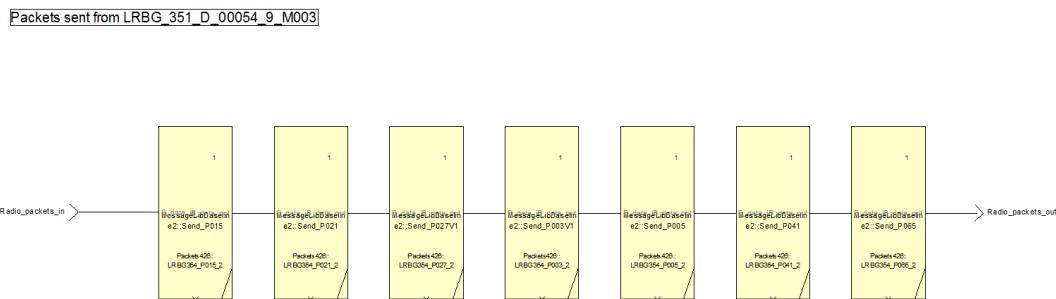


Figure 26. Composing packets for a L2/3 Movement Authority message (view from SCADE model)

5 Implementation of additional user stories

During the remaining period of openETCS, we may extend the track model to reflect additional scenarios. We consider the balise part of the model as stable, as we are on a Level 2 infrastructure. Hence, we simply need to add or derive radio message models consisting of specific combinations of

- Messages and Packets
- Trigger conditions

5.1 Building your own tracks

A detailed HOWTO guide on how to build new test tracks using the provided design templates and libraries will be provided for the final iteration of openETCS.

6 Connecting with existing environments

The dynamic track model is intended to be used as part of the existing testing and validation ecosystem around ETCS. It could also be extended, using the same principles, to reflect national systems, or be used for experiments with new approaches such as ERTMS Regional.

6.1 Subset-076

The Dynamic Track Simulation model relies on a formalisation of Subset-026 chapters 6,7, and 8 provided by the openETCS TrackMessages library. This library provides data structures which are compatible with Subset-076, but require some interfacing work. openETCS WP4 is working on the integration.

6.2 Subset-094

Thanks to the open architecture of openETCS and the openETCS track simulation approach, integration with existing Subset-094 compliant onboard testing systems is feasible. Extension of the openETCS demonstrator to a full Subset-094 implementation may be an interesting topic for future exploitation of the project's results.

7 Closing remarks

We have extended the openETCS approach to exploring the possibilities of formal modelling also on Trackside ETCS infrastructure. The main focus for this iteration was on creating an extensible, modular approach to reflect the dynamic behaviour of trackside train automation installations. We had, to a large extent, to rely on reverse engineering techniques and are aware that the model is far from complete as far as the RBC messages are concerned.

References

- [1] European Rail Agency: *Applicable standards in HS Control-Command and Signalling TSI (2006/860/EC)* ERA/Interoperability/JCP/hpi/2008/208 Version 1.0, 2008
- [2] ERA - UNISIG - EEIG ERTMS USERS GROUP Subset-026 *System Requirements Specification Chapter 6 Management of older System Versions Issue 3.3.0.* 2012.
- [3] ERA - UNISIG - EEIG ERTMS USERS GROUP Subset-026 *System Requirements Specification Chapter 7 ERTMS/ETCS language Issue 3.3.0.* 2012.
- [4] ERA - UNISIG - EEIG ERTMS USERS GROUP Subset-026 *System Requirements Specification Chapter 8 Messages Issue 3.3.0.* 2012.
- [5] ERTMS/ETCS Subset-076 *Test cases, Version 3.1.0.* 2015.
- [6] ERTMS/ETCS Subset-094: *FUNCTIONAL REQUIREMENTS FOR AN ON-BOARD REFERENCE TEST FACILITY, Version 3.0.0.* 2014.
- [7] Rod Muttram, Bombardier: *Delivering the upgraded Amsterdam-Utrecht corridor.* HighSpeed 2008 Amsterdam 6th World Congress on High Speed Rail, 2008.
- [8] Paolo De Cicco, Olivier Levêque, UIC: *ETCS Implementation Handbook.* Paris, 2008.
- [9] ProRail: *Het rijden van ETCS treinen op het trace Amsterdam-Utrecht.* Version 7.0, 2010, German Translation by Shivan Daparoe

- [10] Esterel Technologies: *Methodology Handbook: Efficient Development of Safe Railway Applications Software with EN 50128 Objectives Using SCADE Suite®*. Third Edition (Revision 1), Elancourt, 2012
- [11] S. Besure: *Alstom OpenETCS WP3 contribution: EXTRACT FROM ALSTOM TRB MODEL*. OpenETCS_DNOT_0001 Rel. A, Charleroi 2013