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Event-B Model of Subset 026, Section 4.6

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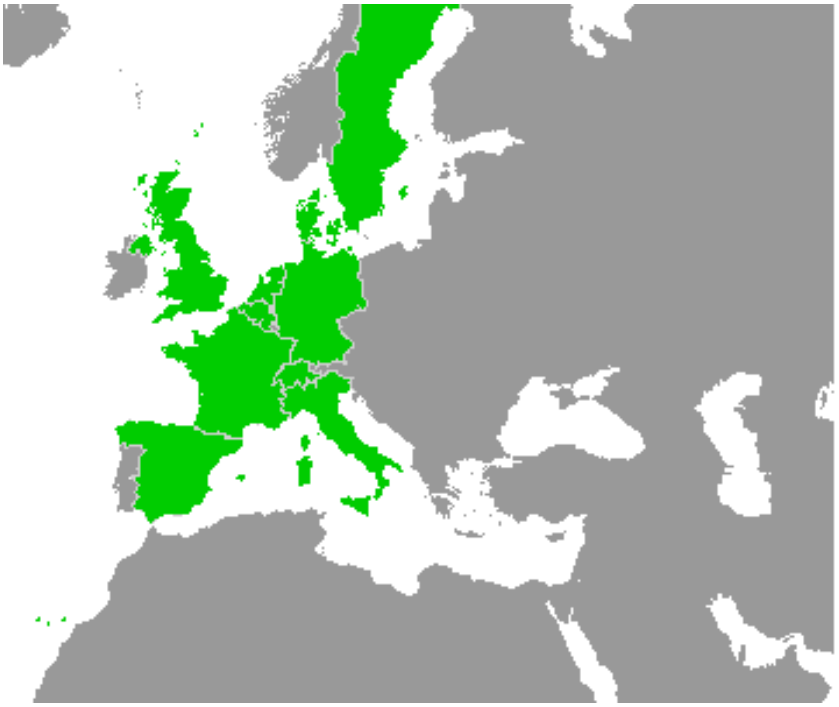

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Model Description

Prepared for ITEA2 openETCS consortium
Europa

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Tables

This document describes a formal model of the requirements of section 4.6 of the subset 026 of the ETCS specification 3.3.0 **?**. This section describes the transition table between the different train modes. This includes the transition conditions and their respective priorities.

The model is expressed in the formal language Event-B **?** and developed within the Rodin tool **?**. This formalism allows an iterative modeling approach. In general, one starts with a very abstract description of the basic functionality and step-wise adds additional details until the desired level of accuracy of the model is reached. Rodin provides the necessary proof support to ensure the correctness of the refined behavior.

In this document we present an Event-B model of the transitions from stand-by to shunting, from stand-by to full supervision and from stand-by to isolation. The transition table is expressed as a graphical model of a state machine which is automatically translated into Event-B code.

SB	stand-by
FS	full supervision
IS	isolation
SH	shunting
MA	movement authority
SRS	system requirements specification

Table 1. Glossary

1 Short Introduction to Event-B

The formal language Event-B is based on a set-theoretic approach. It is a variant of the B language, with a focus on system level modeling **?**. An Event-B model is separated into a static and a dynamic part.

The dynamic part of an Event-B model describes abstract state machines. The state is represented by a set of state variables. A transition from one state to another is represented by parametrized events which assign new values to the state variables. Event-B allows unbounded state spaces. They are constrained by invariants expressed in first order logic with equality which must be fulfilled in any case. The initial state is created by a special initialization event.

The static part of an Event-B model is represented by contexts. These consist of carrier sets, constants and axioms. The type system of a model is described by means of carrier sets and constraints expressed by axioms.

Event-B is not only comprised of descriptions of abstract state machines and contexts, but also includes a development approach. This approach consists of iterative refinement of the machines until the desired level of detail is reached. In the Rodin tool, proof obligations are automatically created which ensure correct refinement.

Together with the machine invariants, the proof obligations for the refinement are formally proven, creating proof trees. To accomplish this, there are different options: many proof obligations can be discharged by automated provers (e.g., AtelierB, NewPP, Rodin's SMT-plugin), but as the underlying logic is in general undecidable, it is sometimes necessary to use the interactive proof support of Rodin.

Any external actions, e.g., mode changes by the driver or train level changes are modeled via parametrized events. Only events can modify the variables of a machine. An Event-B model

is on the system level, events are assumed to be called from a software system into which the functional model is embedded. The guards of the events assure that any event can only be called when appropriate.

2 Modeling Strategy

The description of the section 4.6. of the SRS consists of a large table which describes the possible transitions from one mode to another and the necessary preconditions of a transition. The table also specifies different priorities and the relative priorities of the transitions, i.e., to ensure an explicit precedence if more than one condition is enabled.

The model view consists of a state machine representing the current state, external events can trigger the prerequisites for the conditions. Priorities are modeled by negating a condition with a higher priority for a conditions with a lower priority. For example, let q and p be preconditions that can be fulfilled at the same time, q for event *evt_q* and p for event *evt_p*. Let q have a higher priority than p. In Event-B this precedence can be modeled by using q as condition for *evt_q*, and $\neg q \wedge p$ for evt_p, i.e., the preconditions for the two events cannot be fulfilled at the same time.

The state machine itself is modeled using the iUML statemachine plugin [1] which allows graphical modeling of state machines. The model start with the basic possibilities for the transitions between the modes. The conditions are iteratively refined and external events added to the model.

3 Model Overview

Figure 1 shows the model overview. The left column shows the different state machines and the right column the context. An arrow from one machine to another represents a refinement relation, an arrow from a machine to a context represents a sees relation.

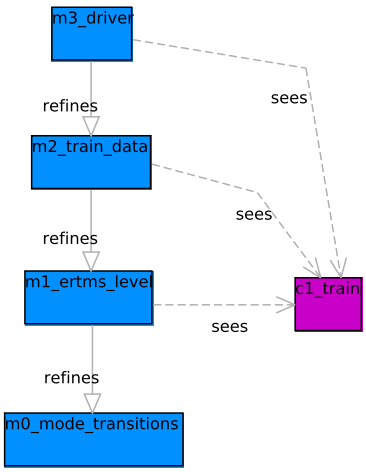

Figure 1. Machine Refinements and Contexts

The model starts with the principal possibilities for the transitions from mode SB to FS, SB to IS and SB to SH. This is realized in the machine $m0$. The refinement in $m1$ implements the dependency on the train behavior and ETCS levels which are introduced in the context $c1$. The refined machine $m2$ allows for storing abstract train data and gradient information for a movement authority. The refinement in $m3$ finally introduces the external driver who can trigger events.

[1] `http://wiki.event-b.org/index.php/Event-B_Statemachines`

4 Model Benefits

The Event-B model in Rodin has some interesting properties which are highlighted here. Some stem from the fact that Rodin is well integrated into the Eclipse platform which renders many useful plugins available, both those explicitly developed for integration with Rodin, but also other without Rodin in mind. Other interesting properties stem from the fact that Rodin and Event-B provide an extensive proof support for properties.

- **Refinement** The Event-B approach allows iterative development based on refinement. This allows starting modeling with a very abstract machine and then step-wise adding more detailed behavior. Rodin generates all the necessary proof obligations which are required to assure correct refinement.
- **Requirements Tracing** Rodin provides an extensible EMF model, therefore it is easily possible to trace requirements using the requirements modeling framework of Eclipse (RMF) via the ProR plugin. This allows the usage of requirement documents in the OMG standardized Requirements Interchange Format (ReqIF).
- **Model Animation** The Event-B model can be animated via different plugins, e.g., ProB or AnimB. This allows the simulation of the model, by clicking on the activated events and tracking the resulting state of the variables. This technique allows to examine the run-time behavior of the model, e.g., for testing purposes. There is also ongoing development for a model-based testing plugin in Rodin, which will allow storing and replaying of event sequences.
- **Graphical Modeling** Rodin supports graphical modeling via its plugin mechanism. The iUML statemachine plugin allows for graphical state machine modeling and animation via ProB. The graphical model is automatically translated into the Event-B language.

5 Detailed Model Description

This section describes the formal model in more detail. For each refinement the new state variables are introduced and their meaning is explained. The machines are not fully presented, only the relevant changes done in the refinement.

The modes and transitions between the modes are modeled graphically using the iUML statemachine plugin. In this notation, transitions are labeled with events, i.e., the transitions are active if the preconditions of the respective events are fulfilled.

In the graphical model, it is possible to have multiple events triggering a transition, the semantics of this is the disjunction of the conditions, i.e., any single event can trigger the transition.

5.1 Machine 0 - Mode Transitions

The first machine $m0$ implements the transition possibilities for the states *SB*, *SH*, *FS* and *IS*. It is shown in Figure 2. The transition labels represent events of the Event-B machine. The initial state is *SB*, this is represented by the *INITIALISATION* event from the UML initial state.

The state machine is translated into Event-B code. Every state is represented as a Boolean variable. An invariant ensures that there is always only a single variable with the value “TRUE”, i.e., the state machine is always in exactly one state.

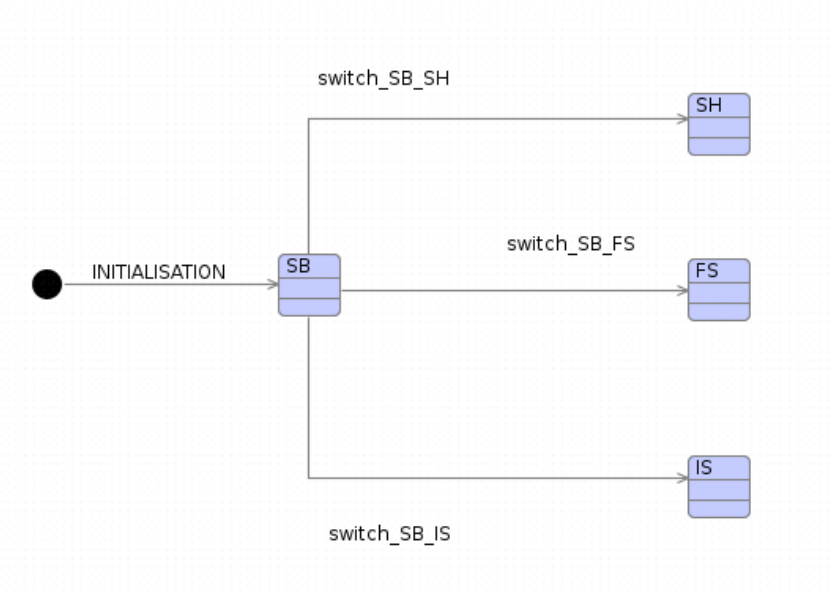

Figure 2. Statemachine for Machine 0

A transition will use these Boolean variables to analyze whether its source state is active. A state change is encoded by changing the values of the variables corresponding to the source and target state of the transition. For more details on the possible encoding see [2].

Implemented Requirements

- §4.6.2 transition from *SB* to *SH*
- §4.6.2 transition from *SB* to *FS*
- §4.6.2 transition from *SB* to *IS*

VARIABLES

SB
SH
FS
IS

INVARIANTS

typeof_SB : $SB \in BOOL$
typeof_SH : $SH \in BOOL$
typeof_FS : $FS \in BOOL$
typeof_IS : $IS \in BOOL$
distinct_states_in_mode_changes1 : $partition(\{TRUE\}, \{SB\} \cap \{TRUE\}, \{SH\} \cap \{TRUE\}, \{FS\} \cap \{TRUE\}, \{IS\} \cap \{TRUE\})$

EVENTS

Initialisation

begin

init_IS : $IS := FALSE$
init_SB : $SB := TRUE$

[2] http://wiki.event-b.org/index.php/Event-B_Statemachines

init_SH : $SH := FALSE$
init_FS : $FS := FALSE$

end

Event *switch_SB_SH* $\widehat{=}$

when

isin_SB : $SB = TRUE$

then

enter_SH : $SH := TRUE$
leave_SB : $SB := FALSE$

end

Event *switch_SB_FS* $\widehat{=}$

when

isin_SB : $SB = TRUE$

then

enter_FS : $FS := TRUE$
leave_SB : $SB := FALSE$

end

Event *switch_SB_IS* $\widehat{=}$

when

isin_SB : $SB = TRUE$

then

enter_IS : $IS := TRUE$
leave_SB : $SB := FALSE$

end

END

5.2 Context 1 - Train

The first context introduces the notion of the different ETCS levels. It also introduces a very abstract notion of the behavior of a train, either moving or at standstill. At this model level, more detailed information is not necessary.

SETS

train_behavior
ERTMS_level

CONSTANTS

L0
L1
L2
L3
NTC
standstill
moving

AXIOMS

axm1 : $partition(train\_behavior, \{standstill\}, \{moving\})$
axm2 : $partition(ERTMS\_level, \{NTC, L0, L1, L2, L3\})$

END

5.3 Machine 1 - ERTMS Level

The first refined machine uses the ETCS levels with the state variable *current_level* and the current train behavior with the state variable *current_behavior*. The ETCS level *NTC* is the initial level and the initial behavior is *standstill*. These variables are modified by their corresponding *change_*-events.

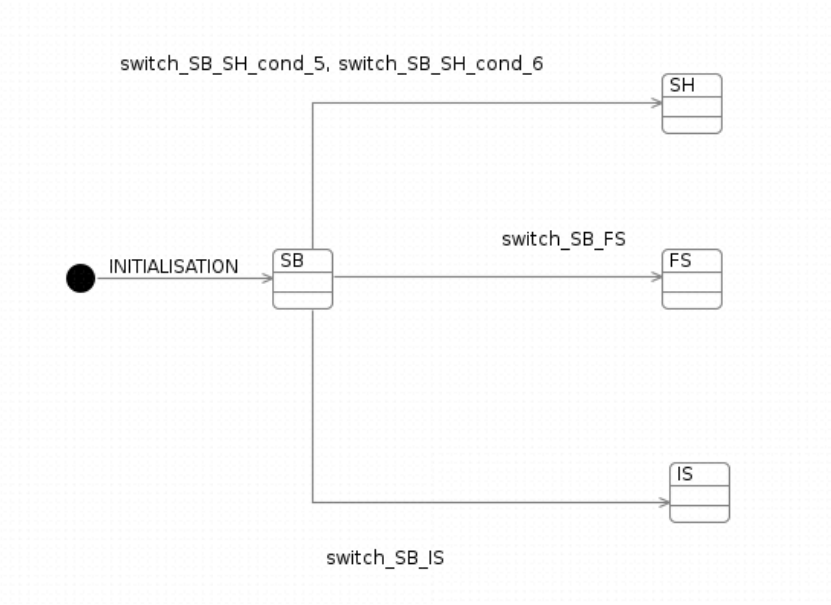

Figure 3. Statemachine for Machine 1

The level and the behavior are used to refine the transition from *SB* to *SH* into two different cases, dependent on the current ETCS level. This is shown in the transition label in Figure 3.

REFINES m0_mode_transitions
SEES c1_train
VARIABLES

current_level
current_behavior

INVARIANTS

inv1 : $current\_level \in ERTMS\_level$
inv2 : $current\_behavior \in train\_behavior$

EVENTS
Initialisation
extended
begin

act1 : $current\_level := NTC$
act2 : $current\_behavior := standstill$

end
Event *change_level* $\widehat{=}$
any

l_level

where

grd1 : $l\_level \in ERTMS\_level$

then

act1 : $current\_level := l\_level$

end

Event *change_behavior* $\widehat{=}$

any

$l\_behavior$

where

grd1 : $l\_behavior \in train\_behavior$

then

act1 : $current\_behavior := l\_behavior$

end

Event *switch_SB_SH_cond_5* $\widehat{=}$

extends *switch_SB_SH*

when

isin_SB : $SB = TRUE$
grd2 : $current\_level \in \{NTC, L0, L1\}$
grd1 : $current\_behavior = standstill$

then

enter_SH : $SH := TRUE$
leave_SB : $SB := FALSE$

end

Event *switch_SB_SH_cond_6* $\widehat{=}$

extends *switch_SB_SH*

when

isin_SB : $SB = TRUE$
grd1 : $current\_behavior = standstill$
grd2 : $current\_level \in \{L2, L3\}$

then

enter_SH : $SH := TRUE$
leave_SB : $SB := FALSE$

end

END

5.4 Machine 2 - Train Data

The second machine refinement adds the notion of valid train data and movement authority gradient data. The validity of these two different kinds of data is represented by the Boolean variables *valid_train_data* and *MA_SSP_gradient_data*. Both variables can be modified by two events; one that stores valid data and one that deletes, i.e., invalidates the stored data.

Having valid MA and train data is the precondition for the transition from *SB* to *FS*. This transition is refined by guard strengthening.

REFINES m1_ertms_level
SEES c1_train
VARIABLES

valid_train_data

MA_SSP_gradient_data

INVARIANTS

inv1 : $valid\_train\_data \in BOOL$

inv2 : $MA\_SSP\_gradient\_data \in BOOL$

EVENTS

Event *store_valid_train_data* $\widehat{=}$

when

grd1 : $valid\_train\_data = FALSE$

then

act1 : $valid\_train\_data := TRUE$

end

Event *remove_valid_train_data* $\widehat{=}$

when

grd1 : $valid\_train\_data = TRUE$

then

act1 : $valid\_train\_data := FALSE$

end

Event *store_MA_SSP_gradient_data* $\widehat{=}$

when

grd1 : $MA\_SSP\_gradient\_data = FALSE$

then

act1 : $MA\_SSP\_gradient\_data := TRUE$

end

Event *remove_MA_SSP_gradient_data* $\widehat{=}$

when

grd1 : $MA\_SSP\_gradient\_data = TRUE$

then

act1 : $MA\_SSP\_gradient\_data := FALSE$

end

extends *switch_SB_FS*

when

isin_SB : $SB = TRUE$

grd1 : $MA\_SSP\_gradient\_data = TRUE$

grd2 : $valid\_train\_data = TRUE$

then

enter_FS : $FS := TRUE$

leave_SB : $SB := FALSE$

end

END

5.5 Machine 3 - Driver

The next machine refinement adds the behavior of the driver and some abstract behavior of the RBC to the model, as well as the notion of a specific mode profile.

In this machine the transition from *SB* to *SH* is refined to a third possibility, the switch from *SB* to *FS* is refined with the required conditions of the driver and mode profile data and the high

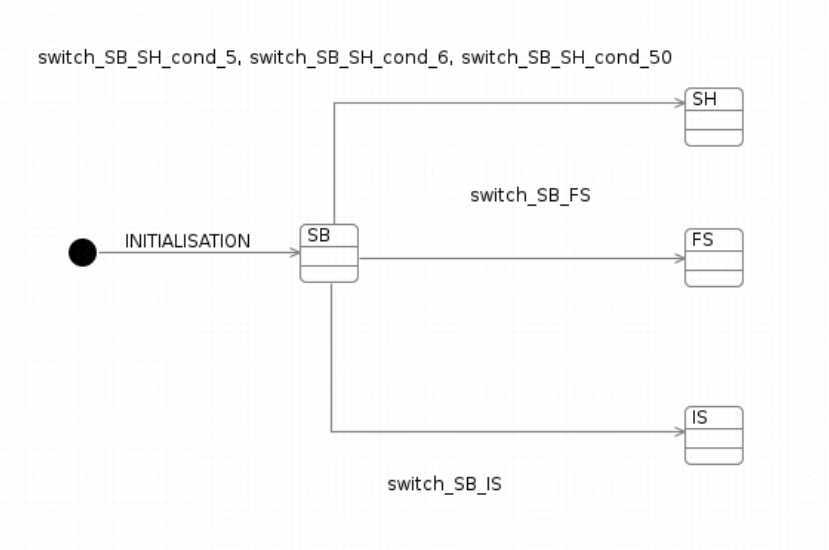

Figure 4. Statemachine for Machine 3

priority of the transition from *SB* to *IS* is taken into account. Figure 4 shows the corresponding state machine.

The RBC can grant a shunting request and display the information to acknowledge shunting. This is represented by the Boolean state variables *shunting_granted_RBC* and *display_shunting_ack*. The driver can isolate the ETCS system, he can manually select shunting, execute a shunting request and acknowledge when the train switches to shunting. This is represented by the Boolean state variables *driver_select_shunting*, *driver_request_shunting*, *driver_ack_shunting* and *driver_isolates_ETCS*.

These variables are set as active by events representing the respective actions by the RBC or the driver. Events which have one of these actions as precondition will reset the events, e.g., displaying the shunting acknowledge (*display_shunting_ok*) needs a previous request as precondition and will reset the variable *driver_request_shunting* when it is executed.

Implemented Requirements

- §4.6.2 condition [5]
- §4.6.2 condition [6]
- §4.6.2 condition [10]
- §4.6.2 condition [50]
- priority of *SB* to *IS* over *SB* to *SH* and *SB* to *FS*

NOTE: The invariant, that the preconditions of the transitions with the same priorities are mutually exclusive, does not hold, i.e., $([5] \vee [6] \vee [50]) \wedge [10] \neq FALSE$. Either this is an error in the specification or there is an underlying functional dependency which is not captured if these 3 transitions are modeled in isolation.

REFINES m2_train_data
SEES c1_train

VARIABLES

driver_select_shunting
driver_request_shunting
driver_ack_shunting
display_shunting_ack
shunting_granted_RBC
driver_isolates_ETCS
specific_mode_profile

INVARIANTS

inv1 : $driver\_select\_shunting \in BOOL$
inv2 : $driver\_request\_shunting \in BOOL$
inv3 : $driver\_ack\_shunting \in BOOL$
inv4 : $display\_shunting\_ack \in BOOL$
inv5 : $shunting\_granted\_RBC \in BOOL$
inv6 : $driver\_isolates\_ETCS \in BOOL$
inv7 : $SB = TRUE \Rightarrow$
$\neg((current\_level \in \{NTC, L0, L1\} \wedge current\_behavior = standstill \wedge driver\_select\_shunting = TRUE)$
$\wedge (MA\_SSP\_gradient\_data = TRUE \wedge valid\_train\_data = TRUE \wedge specific\_mode\_profile = TRUE))$
not cond5 and cond10
inv8 : $SB = TRUE \Rightarrow$
$\neg((current\_behavior = standstill \wedge current\_level \in \{L2, L3\})$
$\wedge (MA\_SSP\_gradient\_data = TRUE \wedge valid\_train\_data = TRUE \wedge specific\_mode\_profile = TRUE))$
not cond6 and cond10
inv9 : $SB = TRUE \Rightarrow$
$\neg((display\_shunting\_ack = TRUE \wedge driver\_ack\_shunting = TRUE)$
$\wedge (MA\_SSP\_gradient\_data = TRUE \wedge valid\_train\_data = TRUE \wedge specific\_mode\_profile = TRUE))$
not cond50 and cond10
inv10 : $specific\_mode\_profile \in BOOL$

EVENTS

Initialisation

extended

begin

init_IS : $IS := FALSE$
init_SB : $SB := TRUE$
init_SH : $SH := FALSE$
init_FS : $FS := FALSE$
act1 : $current\_level := NTC$
act2 : $current\_behavior := standstill$
act3 : $valid\_train\_data := FALSE$
act4 : $MA\_SSP\_gradient\_data := FALSE$
act7 : $driver\_ack\_shunting := FALSE$
act9 : $shunting\_granted\_RBC := FALSE$
act6 : $driver\_request\_shunting := FALSE$
act10 : $driver\_isolates\_ETCS := FALSE$
act5 : $driver\_select\_shunting := FALSE$
act11 : $specific\_mode\_profile := FALSE$

act8 : $display\_shunting\_ack := FALSE$

end

Event *change_specific_mode_profile* $\widehat{=}$

any

l_flag

where

grd1 : $l\_flag \in BOOL$

then

act1 : $specific\_mode\_profile := l\_flag$

end

Event *driver_isolates_ETCS* $\widehat{=}$

when

grd1 : $driver\_isolates\_ETCS = FALSE$

then

act1 : $driver\_isolates\_ETCS := TRUE$

end

Event *driver_select_shunting* $\widehat{=}$

when

grd1 : $current\_level \in \{NTC, L0, L1\}$

then

act1 : $driver\_select\_shunting := TRUE$

end

Event *driver_request_shunting* $\widehat{=}$

when

grd1 : $current\_level \in \{L2, L3\}$

then

act1 : $driver\_request\_shunting := TRUE$

end

Event *display_shunting_ack* $\widehat{=}$

train acknowledges shunting -> specific mode required?

when

grd1 : $driver\_request\_shunting = TRUE$

grd2 : $display\_shunting\_ack = FALSE$

then

act1 : $display\_shunting\_ack := TRUE$

act2 : $driver\_request\_shunting := FALSE$

act3 : $shunting\_granted\_RBC := TRUE$

end

Event *driver_ack_shunting* $\widehat{=}$

when

grd1 : $display\_shunting\_ack = TRUE$

then

act1 : $driver\_ack\_shunting := TRUE$

end

Event *store_valid_train_data* $\widehat{=}$

extends *store_valid_train_data*

when

grd1 : $valid\_train\_data = FALSE$

then

act1 : $valid\_train\_data := TRUE$

end

Event *remove_valid_train_data* $\widehat{=}$
extends *remove_valid_train_data*

when

grd1 : $valid\_train\_data = TRUE$

then

act1 : $valid\_train\_data := FALSE$

end

Event *store_MA_SSP_gradient_data* $\widehat{=}$
extends *store_MA_SSP_gradient_data*

when

grd1 : $MA\_SSP\_gradient\_data = FALSE$

then

act1 : $MA\_SSP\_gradient\_data := TRUE$

end

Event *remove_MA_SSP_gradient_data* $\widehat{=}$
extends *remove_MA_SSP_gradient_data*

when

grd1 : $MA\_SSP\_gradient\_data = TRUE$

then

act1 : $MA\_SSP\_gradient\_data := FALSE$

end

Event *change_level* $\widehat{=}$
extends *change_level*

any

l_level

where

grd1 : $l\_level \in ERTMS\_level$

then

act1 : $current\_level := l\_level$

end

Event *change_behavior* $\widehat{=}$
extends *change_behavior*

any

$l\_behavior$

where

grd1 : $l\_behavior \in train\_behavior$

then

act1 : $current\_behavior := l\_behavior$

end

Event *switch_SB_SH_cond_5* $\widehat{=}$
extends *switch_SB_SH_cond_5*

when

isin_SB : $SB = TRUE$

grd2 : $current\_level \in \{NTC, L0, L1\}$
grd1 : $current\_behavior = standstill$
grd4 : $driver\_isolates\_ETCS = FALSE$
grd3 : $driver\_select\_shunting = TRUE$

then

enter_SH : $SH := TRUE$
leave_SB : $SB := FALSE$
act1 : $driver\_select\_shunting := FALSE$

end

Event *switch_SB_SH_cond_6* $\widehat{=}$
extends *switch_SB_SH_cond_6*

when

isin_SB : $SB = TRUE$
grd1 : $current\_behavior = standstill$
grd2 : $current\_level \in \{L2, L3\}$
grd3 : $driver\_isolates\_ETCS = FALSE$

then

enter_SH : $SH := TRUE$
leave_SB : $SB := FALSE$
act1 : $shunting\_granted\_RBC := FALSE$
act2 : $display\_shunting\_ack := FALSE$

end

Event *switch_SB_SH_cond_50* $\widehat{=}$
extends *switch_SB_SH*

when

isin_SB : $SB = TRUE$
grd2 : $driver\_ack\_shunting = TRUE$
grd1 : $display\_shunting\_ack = TRUE$
grd3 : $driver\_isolates\_ETCS = FALSE$

then

enter_SH : $SH := TRUE$
leave_SB : $SB := FALSE$
act2 : $driver\_ack\_shunting := FALSE$
act1 : $display\_shunting\_ack := FALSE$

end

Event *switch_SB_FS* $\widehat{=}$
extends *switch_SB_FS*

when

isin_SB : $SB = TRUE$
grd1 : $MA\_SSP\_gradient\_data = TRUE$
grd2 : $valid\_train\_data = TRUE$
grd4 : $specific\_mode\_profile = FALSE$
grd3 : $driver\_isolates\_ETCS = FALSE$

then

enter_FS : $FS := TRUE$
leave_SB : $SB := FALSE$

end

Event *switch_SB_IS* $\widehat{=}$
extends *switch_SB_IS*

when

isin_SB : $SB = TRUE$
grd1 : $driver\_isolates\_ETCS = TRUE$

then

enter_IS : $IS := TRUE$
leave_SB : $SB := FALSE$
act1 : $driver\_isolates\_ETCS := FALSE$

end

END