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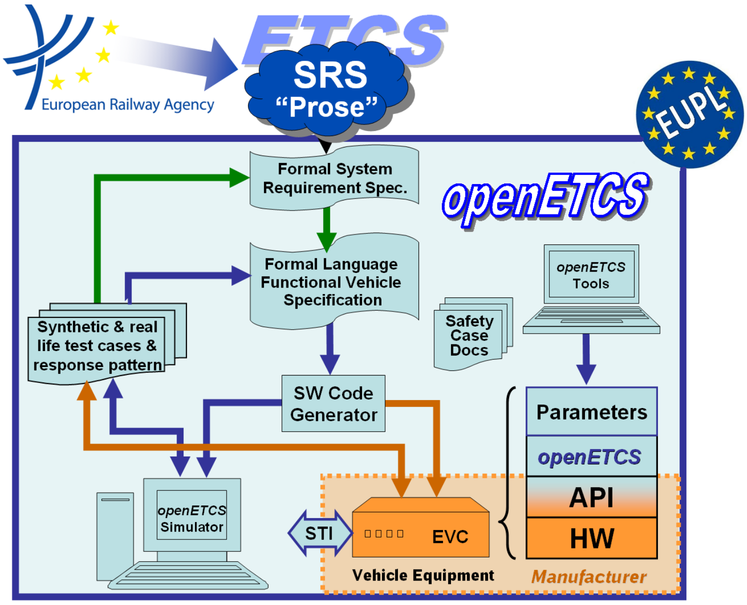
Work-Package 7: “Toolchain”

Event-B Model of Subset 026, Section 4.6

Matthias Güdemann

May 2013



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Model Description

Prepared for openETCS@ITEA2 Project

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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.

For a short introduction on Event-B and the usage of Rodin with models on github see `https://github.com/openETCS/model-evaluation/blob/master/model/B-Systerel/Event_B/rodin-projects-github.pdf?raw=true`

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

Table 1. Glossary

1 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.

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

2 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.

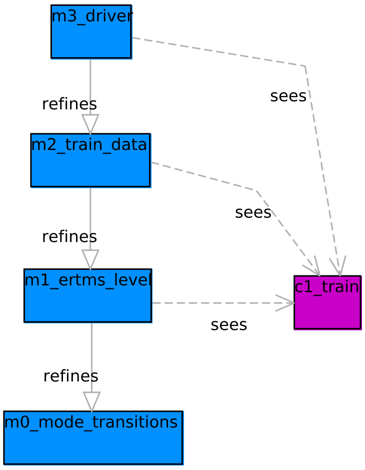

Figure 1. Machine Refinements and Contexts

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.

3 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.

4 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.

4.1 Machine 0 - Mode Transitions

The first machine *m*0 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.

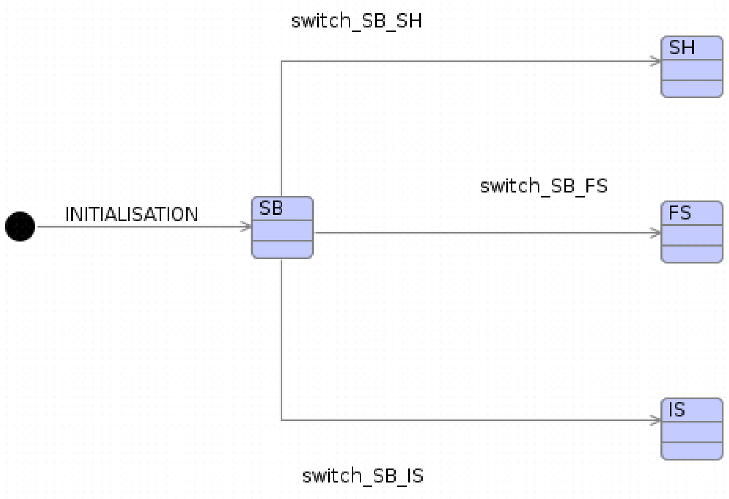

Figure 2. Statemachine for Machine 0

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.

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].

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

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` : $SB := TRUE$
`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

4.2 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

4.3 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.

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

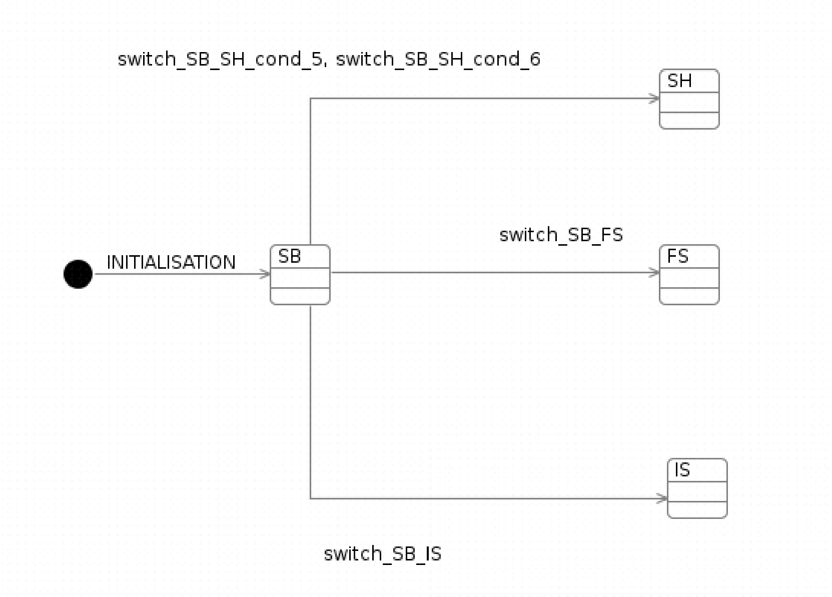

Figure 3. Statemachine for Machine 1

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
```

4.4 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 ≙
    when
            grd1 : MA_SSP_gradient_data = FALSE
    then
            act1 : MA_SSP_gradient_data := TRUE
    end
Event  remove_MA_SSP_gradient_data ≙
    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
```

4.5 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 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.

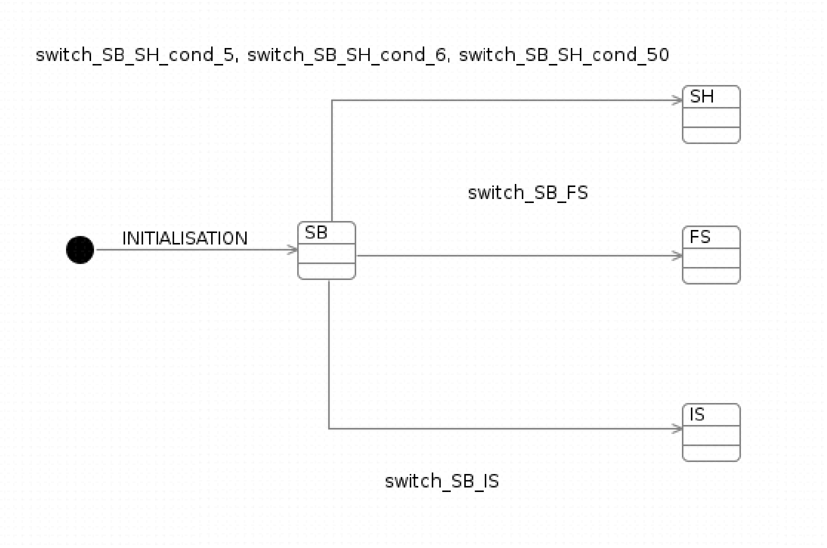
switch_SB_SH_cond_5, switch_SB_SH_cond_6, switch_SB_SH_cond_50
SH
switch_SB_FS
INITIALISATION
SB
FS
IS
switch_SB_IS

Figure 4. Statemachine for Machine 3

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., $([5] \vee [6] \vee [50]) \wedge [10] \neq FALSE$. 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

$driver\_select\_shunting$
$driver\_request\_shunting$
$driver\_ack\_shunting$
$display\_shunting\_ack$
$shunting\_granted\_RBC$
$driver\_isolates\_ETCS$
$specific\_mode\_profile$

EVENTS
Event *change_specific_mode_profile* $\widehat{=}$
any

l_flag

```
      where
            grd1 : l_flag ∈ BOOL
      then
            act1 : specific_mode_profile := l_flag
      end
Event  driver_isolates_ETCS ≙
      when
            grd1 : driver_isolates_ETCS = FALSE
      then
            act1 : driver_isolates_ETCS := TRUE
      end
Event  driver_select_shunting ≙
      when
            grd1 : current_level ∈ {NTC, L0, L1}
      then
            act1 : driver_select_shunting := TRUE
      end
Event  driver_request_shunting ≙
      when
            grd1 : current_level ∈ {L2, L3}
      then
            act1 : driver_request_shunting := TRUE
      end
Event  display_shunting_ack ≙
                              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 ≙
      when
            grd1 : display_shunting_ack = TRUE
      then
            act1 : driver_ack_shunting := TRUE
      end
Event  switch_SB_SH_cond_5 ≙
extends  switch_SB_SH_cond_5
      when
            isin_SB : SB = TRUE
            grd2 : current_level ∈ {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  $switch\_SB\_SH\_cond\_6 \mathrel{\widehat{=}}$
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  $switch\_SB\_SH\_cond\_50 \mathrel{\widehat{=}}$
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  $switch\_SB\_FS \mathrel{\widehat{=}}$
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  $switch\_SB\_IS \mathrel{\widehat{=}}$
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

4.6 Machine 4 - Hypothesis

This machine refinement adds some functional details which are not present in the information about the 3 modeled transitions and which prevent the proof of mutual exclusion of the transitions (see previous note). There was a discussion about topic on the wiki on github for the model-evaluation project within openETCS.

This refinement does not change the state machine of course, it only changes the guards of the transitions. For this, there are three new Boolean variables: *SSP_data*, *MA_data* and *gradient_data*.

The change specific mode profile event is split into two, to prevent the non-deterministic removal of a specific mode profile in SB mode. The *driver_selects_shunting* event can only be executed if there is no *MA_data* available, the same holds for *driver_requests_shunting*. The events *display_shunting_ack* and *driver_ack_shunting* both now require the absence of *MA_data* and the presence of *specific_mode_profile*. New valid train data can only be stored if there is no shunting selected, to acknowledge or granted by the RBC. ERTMS level changes or train behavior changes are only possible if there is no *MA_data* available. The general variable *MA_SSP_gradient_data* is refined by the three new variables.

Together this allows to proof the mutual exclusion of the transitions, as captured in the invariants *inv3*, *inv4* and *inv5*.

MACHINE m4_hypothesis

REFINES m3_driver

SEES c1_train

VARIABLES

MA_data

SSP_data

$gradient\_data$

INVARIANTS

inv1 : $MA\_data \in BOOL$

inv2 : $SSP\_data \in BOOL$

inv3 : $gradient\_data \in BOOL$

inv4 : $SB = TRUE \Rightarrow$
$\neg((current\_level \in \{NTC, L0, L1\} \land current\_behavior = standstill \land driver\_select\_shunting = TRUE)$
$\land\ (MA\_SSP\_gradient\_data = TRUE \land valid\_train\_data = TRUE \land specific\_mode\_profile = FALSE))$