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# Passenger cars — Simulation model classification —

## Part 1: Vehicle dynamics

*Voitures particulières — Classification des modèles de simulation —*

*Partie 1: Dynamique du véhicule*



Reference number
ISO 11010-1:2022(E)

# Contents

Page

# Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

A list of all parts in the ISO 11010 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

This document has been developed in response to worldwide demand for the standardization of simulation models and their requirements for use in specific applications and driving manoeuvres. During the development and testing of road vehicles questions arise around which simulation models should be applied and how well matched they need to be for performing certain applications with related driving manoeuvres. In the absence of standards it is common practice that experts in different organizations develop their own methods and processes as response to these questions. This causes obstacles when it comes to comparability and model exchange between project partners. Currently, unless the requirements for simulation models undergo extensive elaboration and coordination among the experts involved, there will be major uncertainty with their implementation and quality.

The main purpose of this document is to provide a framework that enables a systematic assignment of certain applications and driving manoeuvres to suitable simulation models and their elements and characteristics. This document classifies the simulation models into certain model classes, their designation number and related elements, characteristics and common modelling method. Assigning models to classes related to specific applications is the responsibility of the user or other regulations and standards. This document contains recommendations in the sense of an appropriate simulation quality in terms of performance tests, thus enabling the user to specify the requirements for the models with reference to this document. This document thus also creates the basis for model recommendations relevant to vehicle dynamics with regard to advanced driver assistance systems and automated driving (ADAS/AD)[19].

# Passenger cars — Simulation model classification —

# Part 1:
# Vehicle dynamics

## 1 Scope

A systematic framework has been created that facilitates the definition of the requirements of simulation models for certain applications and driving manoeuvres in a standardized manner.

For this purpose, the proposed framework systematically divides the vehicle model into model classes and all model classes into different model types, corresponding to various model characteristics and common modelling methods. The vehicle dynamics manoeuvres have been additionally structured and clustered. Manoeuvres can be assigned to model classes and model types using an allocation and requirements table. This document thus also creates the basis for model recommendations relevant to vehicle dynamics with regard to advanced driver assistance systems and automated driving (ADAS/AD).

The application of the framework and the specification of the model requirements are the responsibility of the user. Alternatively, they may be determined by other regulations and standards. This document contains recommendations for selectable model characteristics in terms of adequate simulation quality with respect to performance tests and associated application patterns. The recommendations can be adapted accordingly to be applied to functional testing.



## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3833, *Road vehicles — Types — Terms and definitions*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3833 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

**3.1**
**simulation model**
mathematical model for the calculation of the system state variables based on equations describing a vehicle or vehicle sub-system

Note 1 to entry: The vehicle's environment is only modelled as far as required, i.e. friction of the road surface, wind, etc. Models in this context are both, the unit under test (UuT) as well as models to supplement or complete the simulation loop.

**3.2**
**model class**
mathematical model based on the vehicle or vehicle sub-systems

**3.3**
**model designation number**
gradation of model type and depth with associated model characteristics, represented effects and minimal model inputs and outputs

**3.4**
**steady state model**
physical model representing the definitions of steady state equilibrium mentioned in ISO 8855

Note 1 to entry: The model represents the transfer function between model input and output for steady-state equilibrium. The model is not capable of representing the correct time behaviour. Effects caused through small changes in time may be neglected. The model is usually mathematically described by a gain.

**3.5**
**first order model**
model, in addition to the *steady state model* (3.4), capable of representing the transient behaviour

Note 1 to entry: The physical model is usually described mathematically by a differential equation with a first order lag force element such as PT1 behaviour with a first order.

**3.6**
**second order model**
model defined by a second order force element such as PT2 behaviour with second order

Note 1 to entry: Due to its conjunct complex poles, a time variant input results in an oscillatory output.



**3.7**
**model-in-the-loop**
**MiL**
testing method in which the controller is integrated as a unit under test (UuT) with a *full-function controller* (3.12) into the *simulation model* (3.1) as a controller model



**3.8**
**software-in-the-loop**
**SiL**
testing method whereby the controller is integrated as a UuT with complete controller functionality as application software from the ECU into the *simulation model* (3.1)

Note 1 to entry: See Figure 1.

**3.9**
**processor-in-the-loop**
**PiL**
testing method whereby the controller together with processor emulation is integrated as UuT into the *simulation model* (3.1)

**3.10**
**open-loop control**
controller that influences a system's behaviour without a feedback loop, for example based on maps

**3.11**
**principal logic closed-loop controller**
controller that influences a system's behaviour with a feedback loop

Note 1 to entry: For principal logic, the controller is implemented in a simplified form, for example, with a PID controller, to demonstrate the control logic.

**3.12**
**full-function controller**
controller that is implemented with complete functionality, but with operation restricted to the function control algorithm under test

Note 1 to entry: The controller is realized as either *MiL* (3.7) or *SiL* (3.8).

**3.13**
**ECU-in-the-loop**
test method whereby the controller is integrated as a UuT into the *simulation model* (3.1) as a real ECU (Figure 1)

Note 1 to entry: In this document it refers primarily to the controller. The controller is typically implemented in hardware-in-the-loop (HiL).

**3.14**
**full-function virtual ECU**
**vECU**
controller that is implemented as a UuT with the whole ECU software with application and base software (Figure 1)

Note 1 to entry: The controller is realized virtually via emulation in SiL mode. Full-function architecture means software modules such as AUTOSAR connect the virtual ECU to the vehicle's communication network.

**3.15**
**electric brake booster**
brake booster that has the ability to amplify the braking force applied by the driver through electrical actuation and autonomously build up pressure without driver actuation

Note 1 to entry: Electric brake boosters consist of a control unit, electric actuator and transmission device [20].



# 4 Model designation numbers

## 4.1 General

Each model class may consist of a physical system, including hydraulics and pneumatics, and a controller. This segmentation can be extended to sensor and actuator.

## 4.2 Physical system

The model of a physical system shall have a model designation number from Table 1, according to the definitions in Clause 3. The force element characteristic ranges from level 0 – no model – to level 3 – second order model and within the sub-designation levels 1.x to 3.x. If a model requires a deeper sub-categorization, the dot notation and a second digit starting from 1 shall be used.

NOTE The model designation numbers are valid for all vehicle sub-systems from 5.1 except the suspension model, since its designation numbers 1 and 2 lack body masses. Nevertheless, the suspension model designation numbers are adapted reasonably.

**Table 1 — Model characteristic and designation number of a physical system**

| Force element characteristic | Model designation number |
|---|---|
| None | 0 |
| Steady state model | 1 |
| First order model | 2 |
| Second order model | 3 |

## 4.3 Controller

The controller model shall have a model designation number from Table 2 according to the definitions in Clause 3. The model characteristics range from level 0 – no model – to level 4 – ECU-in-the-loop (HiL). For level 2 and 3, a deeper subcategorization “3.x” is used.

The subcategorization “.x” of level 2 and 3 defines the range of subsets of the target software (see Figure 1), being included in the test bench. This depends on the scope of investigation, mostly in the context of model-based testing. While level 1 and 2.1 controller models contain a simplified principal logic, level 2.2 models map the target function (MiL) – that is the original control structure function and application. Model level 2.3 (SiL) is based on the compiled target code of the application software (see Figure 1). A level 3.1 model is restricted to the application software (e.g. implementation of control functions and application parameter) as well as the base software such as a virtual ECU (vECU). A level 3.2 model additionally includes the emulation of the processor and the software is compiled for the target processor. Model 4 is the typical HiL as ECU-in-the-loop with hardware-specific software, communication and diagnosis.

**Table 2 — Model characteristic and designation number of controllers**

| Description | Model designation number |
|---|---|
| None | 0 |
| Open-loop control | 1 |
| Principal logic closed-loop controller | 2.1 |
| Target function: model-in-the-loop (MiL) – application software model only | 2.2 |
| Target software: software-in-the-loop (SiL) – application software only | 2.3 |
| Target software: full-function virtual ECU (vECU) – application + base software | 3.1 |
| Target software: processor-in-the-loop (PiL) | 3.2 |
| Target ECU: ECU-in-the-loop (HiL) | 4 |



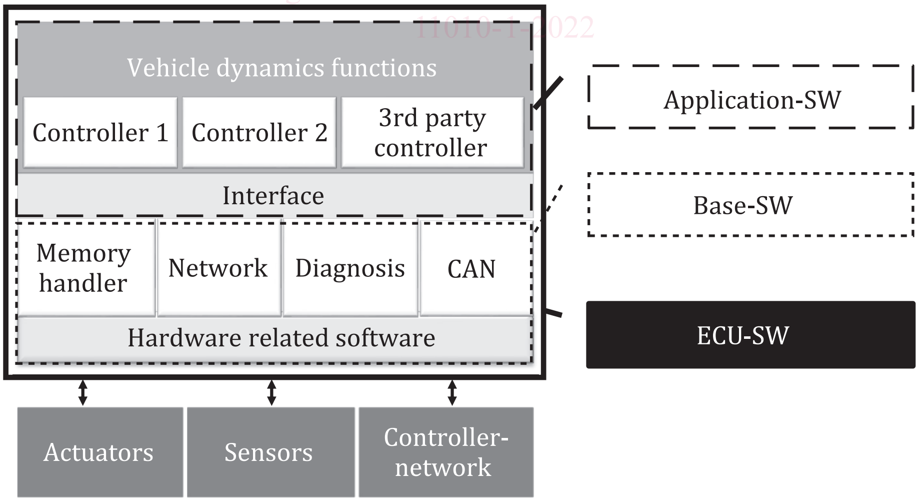



**Figure 1 — Subsets of a controller**

Figure 1 illustrates a typical software architecture of a real or virtual control unit in reference to Table 2 with the levels: application software, base software and interfaces to actuators, sensors and network.

NOTE The performance of a closed-loop controller can be significantly influenced by the time latency of sensor signals.

Compared to the model designation number of the physical system (see 4.2), the designation number of the controller is not mainly influenced by the driving manoeuvre, but by the scope of the investigation. In predevelopment stage, a simple principal logic might be sufficient to evaluate the overall vehicle behaviour; for functional development and safeguarding, the original function should be used. Some exemplary types of investigation concerning the choice of the controller designation number are given in Table 3.

**Table 3 — Examples for the selection of controller designation number**

| Type of investigation | Controller designation number |
|---|---|
| Preliminary design physical system | 0/1/2.1 |
| Functional development (preliminary design) | 2.2/2.3 |
| Homologation | 2.3/3.1/4 |
| Safeguarding of software implementation | 2.3/3.1 |
| Safeguarding of function including operation system | 3.1/3.2/4 |
| Systematic functional safeguarding in spite of a lack of a virtual controller model | 4 |

# 5 Model classes

## 5.1 General

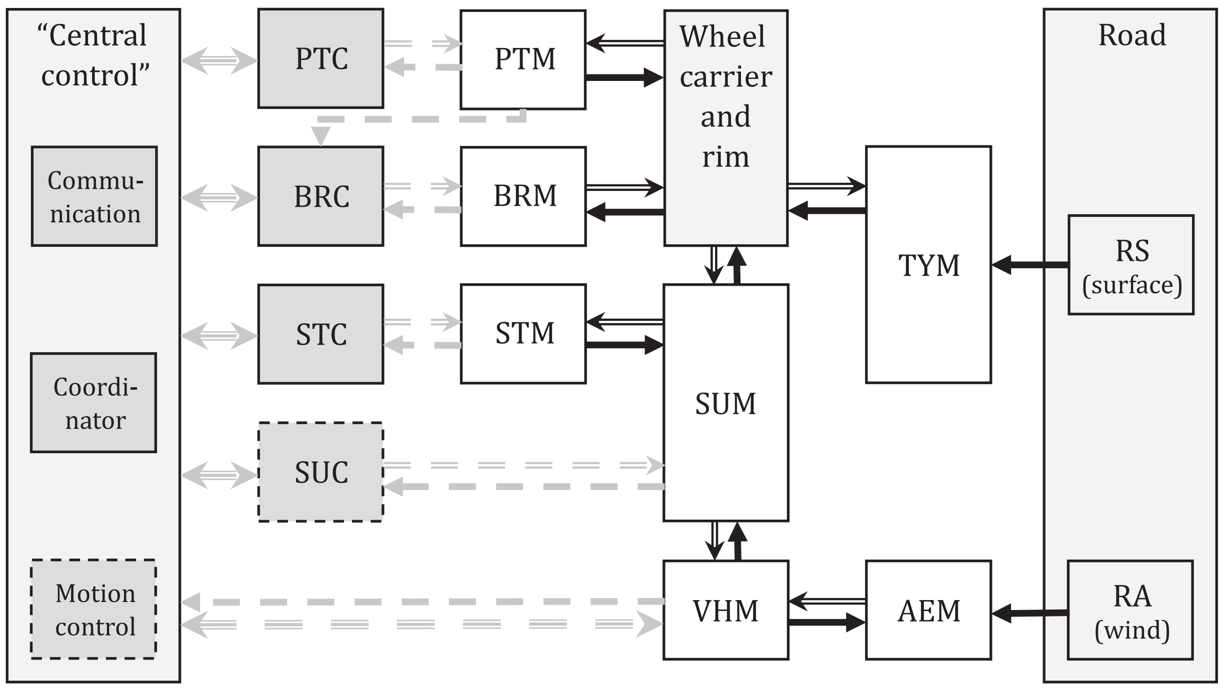


The vehicle model is structured in the following model classes according to Figure 2: vehicle / body (VH), powertrain (PT), brake (BR), steering (ST), suspension (SU), aerodynamics (AE) and tyre (TY) and the road with road surface (RS) and road wind (RA). Some model classes consist only of a physical system XXM, others as combination of a physical system XXM and a control system XXC. The models refer to common vehicle systems as currently used in passenger cars. The user can create model prototypes of future systems accordingly.

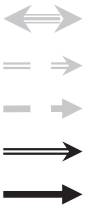


Independently of the above-mentioned structure of the models, a controller is not necessarily mapped to a single ECU. An ECU will likely host more than one single controller. In addition, a controller algorithm might be distributed over multiple ECU. This is of importance especially for higher model designation numbers, where base software or other properties of the ECUs shall be considered.

NOTE It is possible that there are differing allocations and interfaces defined in Clause 5. In this document, the axial rotation of wheels is calculated in the powertrain (PTM) and is passed to the tyre (TYM) and brake (BRM).




**Key**



signalbus (bidirectional)

actor

sensor

forces

kinematics



**Figure 2 — Top-level model architecture**

The control systems XXC are specific for their components XXM. Sometimes a "central controller" coordinates the component-specific controller. For ADAS a sensor-based environment detection and trajectory planning is necessary as well as a trajectory control. Trajectory control generates target values for the component-specific controllers: in longitudinal direction for the powertrain (PTC) and brake (BRC) and in the lateral direction for the steering (STC). Due to the fact that the "central controller" is very specific to the manufacturer it is not classified in this document.

NOTE The "central controller" can be partitioned into separate control unit(s) or added to the control unit of the specific controller(s).

The capital letters in parenthesis are the model classes' abbreviations. The selected designation number of a model class shall be written in the following syntax:

<ModelClass>M<MechanicalSystemDesignationNumber >

<ModelClass>C<ControllerDesignationNumber>

The actual names and numbers shall replace the placeholders in angled brackets. For the <ModelClass> the specified abbreviation shall be used. The syntax resembles that in the following examples:

STM2

PTM2 PTC4

BRM2.1 BRC3.1

NOTE This can be extended to sensor and actuator via the syntax:

<ModelClass>S<SensorDesignationNumber>

<ModelClass>A<ActuatorDesignationNumber>

## 5.2 Vehicle/body

The model class vehicle (VH), with the architecture in Figure 3, is actually targeted to describe the modelling of the vehicle body. However, depending on the designation number, it is possible that the vehicle body is not isolated from the whole vehicle model. The higher the designation number, the better the vehicle body can be isolated.

The model class vehicle (VH) shall have a designation number of the physical system (VHM) in accordance with Table 4.

The designation numbers for class vehicle does not follow exactly the classification as described in Table 1. Here the principle "best practice" applies. Thus, the models are clustered into three groups:

VHM1: one body model;

VHM2: multi-body model split sprung mass, unsprung mass, rigid bodies and look-up table for suspension;

VHM3: multi-body model split sprung mass, unsprung mass, multi-body suspension.

In the group VHM1 the tyre is combined with the vehicle, while in the groups VHM2 and VHM3, the vehicle body can be isolated from suspension and tyre. As an example, the widely used single-track model belongs to VHM1, and VHM3 has the 3D-vehicle body model with local stiffness/stiffness matrix within its scope.



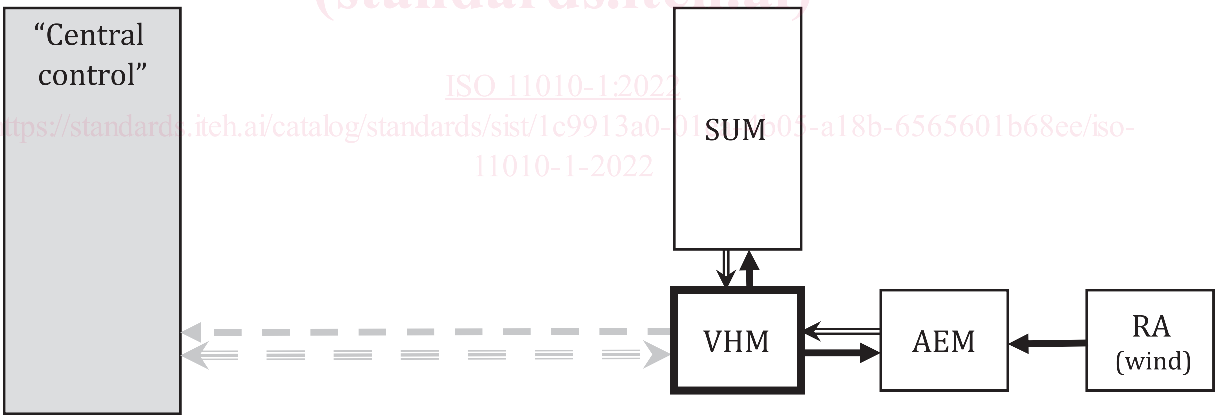



**Figure 3 — Vehicle architecture**