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Passenger cars — Simulation model classification —

Part 1:
Vehicle dynamics

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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.

Introduction

This document was developed in response to worldwide demand for standardization of simulation models and their requirements in specific application and driving manoeuvres as use cases. During development and test of road vehicles the question arises, which models should to be used and how good simulation models have to be for performing certain applications with related driving manoeuvers. Without standardization, it is common practice that experts in different organizations develop their own methods and processes to answer this question. When it comes to comparability and model exchange between project partners, obstacles occur. Today, either the requirements for simulation models have to be elaborately created and coordinated by experts, or there are major uncertainties in implementation and quality.

The main purpose of this standard is to provide a framework that enables a systematic assignment of certain application, driving manoeuvres to required 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 application is the responsibility of the user or other regulations and standards. The standard contains recommendations in the sense of an appropriate simulation quality in terms of performance tests. The standard thus enables the user to specify the requirements for the models with reference to the standard. The standard thus also creates the basis for model recommendations relevant to vehicle dynamics with regard to Advanced Driver Assistance Systems and Automated Driving (ADAS/AD).

Passenger cars — Simulation model classification —

Part 1: Vehicle dynamics

1 Scope

This document establishes a standard for the classification and application of modular simulation models with regard to vehicle dynamics in context of global vehicle without human driver. With the created framework a systematics was created, defining how the requirements of simulation models can be defined for certain application and driving manoeuvres. Thus, allowing to specify the requirements for simulation models for necessary applications and driving manoeuvres in a standardized way.

For this purpose, the proposed framework systematically divides the vehicle model into model classes and all model classes into different model types, corresponding to different model characteristics and common modelling methods. The vehicle dynamics manoeuvres were additionally structured and clustered. One can assign the manoeuvers to the model classes and model types using an allocation and requirement table. The standard 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 or may be determined by other regulations and standards. The standard contains recommendations for selectable model characteristics in terms of adequate simulation quality with respect to performance tests and associated application patterns. With regard to functional testing, the recommendations can be adapted accordingly.

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 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

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:

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

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

3.1
Simulation model
calculation of the system state variables from equations in a mathematical model describing a vehicle or vehicle sub-systems; 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) or models to supplement or complete the simulation loop.

3.2
Model class
mathematical model from the vehicle or vehicle sub-systems

3.3
Model designation number
different gradations of model types and depths with associated model characteristics, represented effects and minimal model inputs and outputs

3.4
Steady state model (physical models)
A steady state model is a model, which represents the definitions of steady state equilibrium mentioned in ISO 8855 and therefore steady state. The model has to represent 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 (physical models)
In addition to the steady state model, a first order model is capable of representing the transient behaviour. The model is usually mathematically described by a differential equation with a first order lag force element such as PT1 behaviour with a first order.

3.6
Second order model (physical models)
A second order model is defined by a second order force element such as PT2 behaviour with second order. 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 unit under test (UuT) with full-function controller into the simulation model as a controller model

3.8
Software-in-the-Loop
SiL
Testing method in which the controller is integrated UuT with complete controller functionality into the simulation model as a controller software function from the ECU

3.9
Processor-in-the-Loop
PiL
Testing method in which the controller with processor emulation is integrated into the simulation model

3.10
ECU-in-the-Loop
HiL
This is a hardware-in-the-loop test method in which the controller are integrated into the simulation model as a real ECU. In this document it refers to controller primarily.

3.11
Open-loop control
An open-loop controller influences a system's behaviour without a feedback loop for example based on maps and is an electric device.

3.12
Principal logic closed-loop controller
A closed-loop controller influences a physical system's behaviour with a feedback loop. For principal logic, the controller is implemented in a fundamental way – e.g. with a PID controller – to demonstrate the control logic.

3.13
Full-function controller (MiL/SiL)
For full-function (MiL/SiL), the controller is implemented as the full-function, but just regarding the function control algorithm. The controller is either realized in MiL or SiL.

3.14
Full-function ECU (SiL/HiL)
For full-function ECU (SiL/HiL), the controller is implemented as the full-function ECU with the whole software e.g. with function architecture such as Autosar for connecting the ECU to the vehicle on-board network and not just the function control algorithm. The controller is either realized virtually via emulation in SiL mode or physically in HiL mode.

3.15
eBooster
An eBooster is a electric brake booster – comprising a control unit, actuator and transmission device – which has the ability to boost the brake force applied by the driver and to build up pressure autonomously without driver actuation[20].

4 Model designation numbers

Each model class may consist of a physical system including hydraulics and pneumatics and a controller.

NOTE This segmentation can be extended to sensor and actuator.

4.1 Physical system

The model of a physical system shall have a model designation number out of Table 1 according to the definitions in Chapter 3. The force element characteristic changes 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 number are valid for all vehicle sub-systems from chapter 5.1 except the suspension model because its designation number 1 and 2 lack body masses. Nevertheless, the suspension model designation numbers are reasonably adapted.

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

4.2 Controller

The controller model shall have a model designation number out of Table 2 according to the definitions in Chapter 3. The model characteristics increases from level 0 – no model – to level 4 – 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 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 complied target code of the software. 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. 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 with hardware related software, communication and diagnosis.

Table 2 — Model characteristic and designation number of a controller

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: Software-in-the-Loop (SiL) – Application + Base Software	3.1
Target software: Processor-in-the-Loop (PiL)	3.2
Target ECU: Hardware ECU (HiL)	4

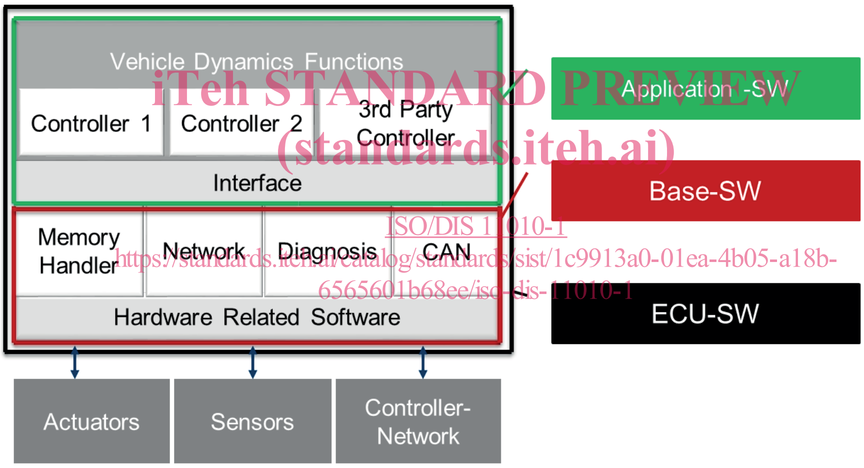


Figure 1 — Subsets of a controller

Note Though it is possible to calculate the time response of communication by high level control models only, low level models might be enabled by empirical latency time delays. E.g. also the performance of a closed-loop controller (Level 2) might be significantly influenced by the latency time of sensor signals.

Compared to the model designation number of the physical system (see chapter 4.1), the designation number of the controller is not mainly influenced by the driving manoeuvre, but by the scope of the investigation. In pre-development 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 as sample.

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

Table 3 *(continued)*

Type of investigation	Controller designation number
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

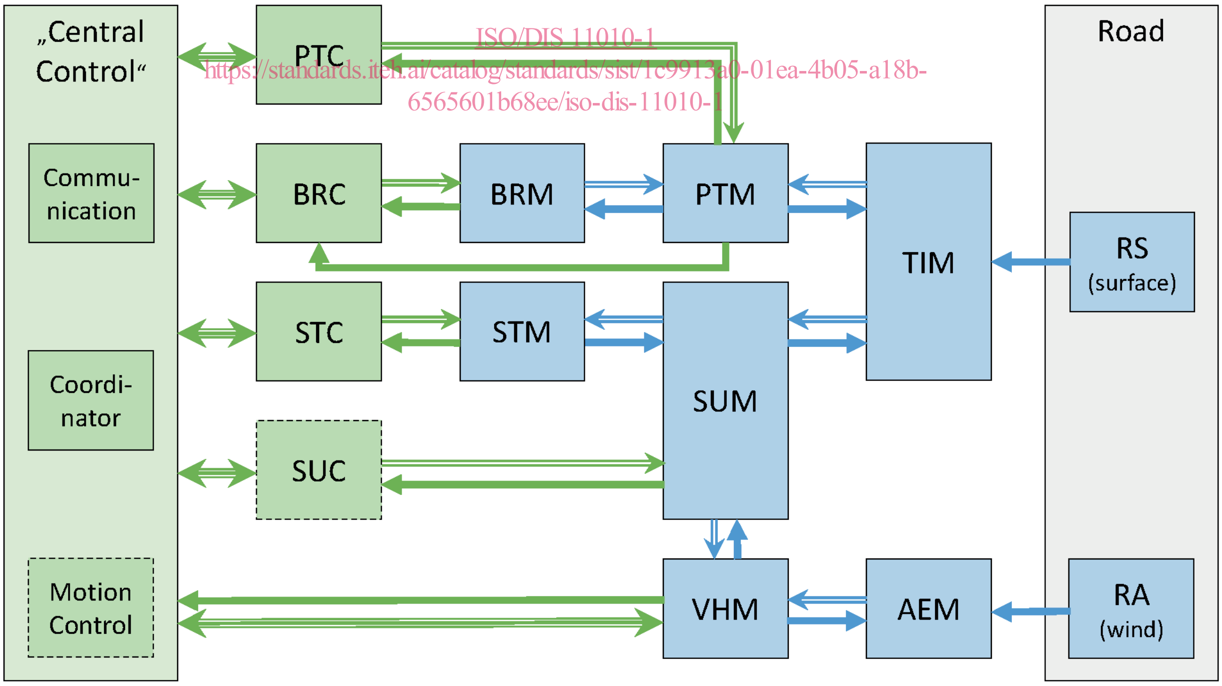
5 Model classes

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 Tire (TI) and the Road with Road Surface (RS) and Road Wind (RA). Some model classes consist only of a physical system XXM, other as combination of a physical system XXM and a control system XXC. The models refer to common vehicle systems as they are used in passenger cars today. The user can create model prototypes of future systems accordingly.

Independent from the above-mentioned structure of the models, a controller is not necessarily mapped to a single ECU. A ECU will likely hold more than one single controller. In addition, a controller algorithm might be distributed over multiple ECU. This is of important role especially for higher model designation numbers, where base software or other properties of the ECUs must be considered.

NOTE There might be differing allocations and interfaces defined in chapter 5. In this standard, the axial rotation of wheels is calculated in the powertrain (PTM) and is passed to the Tire (TIM) and Brake (BRM).



Key

⟺	signalbus (bidirectional)	⇒	actor	⇒	forces
		→	sensor	→	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 track planning is necessary as well as a track control. The path 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 standard.

NOTE The “central controller” might be partitioned to separate control unit(s) or be 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 resp. numbers shall replace the placeholders in angle brackets. For the <ModelClass> the specified abbreviation shall be used. The syntax looks like 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” with the architecture in Figure 3 is actually targeted to describe the modelling of 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 3.

The designation numbers for class Vehicle does not follow exactly the classification as descripted 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 splitted sprung mass, unsprung mass, rigid bodies and lock-up table for suspension

VHM3: Multi-Body Model splitted sprung mass, unsprung mass, multi-body suspension

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

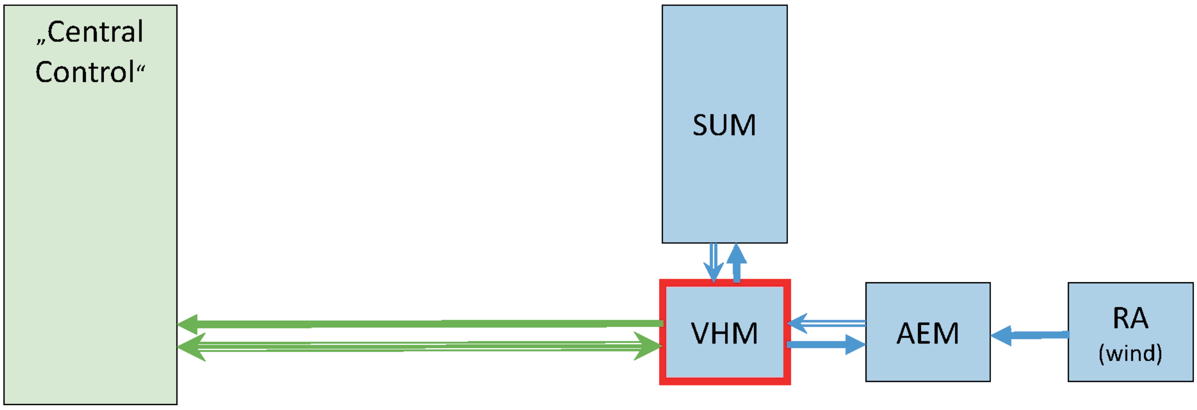


Figure 3 — Vehicle architecture

