VIRTUAL DEMONSTRATOR REQUIREMENTS

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1 EXECUTIVE SUMMARY

The development of fully operative virtual demonstrators is an essential part of work within the EU-LIVE project. The objective of this deliverable is to define the virtual demonstrator requirements regarding use cases, subsystem models included, and interfaces between the models. The advantages of virtual prototyping are, most notably, a reduction of development time and a subsequent reduction of costs. Modern numerical simulations even allow a quantitative assessment of the performance of hardware parts of vehicles. Usually, sophisticated numerical simulations are implemented in domain-specific simulation tools. In order to maximise the impact of the results on the one hand, and to minimise the programming effort of new models on the other hand, it is advantageous to combine several simulators to a so-called co-simulation.

A basic agreement on specific use cases or simulation scenarios is an essential requirement prior to the modelling process. Based on the experience of all EU-LIVE partners and on user needs (as defined in WP1), we identified a list of use cases for the virtual demonstrators. These 19 use cases will assess the EU-LIVE virtual demonstrators regarding consumption, safety, drivability, performance, and emissions.

Using this list of use cases, we deduced the list of required subsystem models clustered to functional groups. This model structure does not necessarily reflect the hierarchical structure of a real car assembly. Making use of the resulting hierarchical model structure, we will be able to use the simulations in a more time-efficient way during the system optimisation: the – typically already existing – coarse models on a higher hierarchical level can be used already at the beginning of the simulation phase. Subsequently, models with a higher level of detail will be created as well as integrated in an iterative process later on.

While it is common practice to assemble existing models without prior specifications on the interfaces, EU-LIVE proposes a different strategy. Using a top-down approach, the interfaces between simulation models are defined before the models themselves are created or existing models are adapted accordingly. Therefore, the consistency of the subsystem models is guaranteed at any time.

This deliverable provides the requirements for the implementation of the EU-LIVE virtual demonstrators. Using the defined simulation scenarios, a list of required subsystem models is deduced. Finally, we describe the interfaces of each simulation model for all use cases.

Keywords: virtual demonstrators, modelling, co-simulation

2 OBJECTIVES

2.1 Objectives of the virtual demonstrators within EU-LIVE

The usage of computer simulations and their combination to virtual demonstrators is an essential part of the development process within the EU-LIVE concept. Since virtual demonstrators should support the development of the real demonstrators, it is mandatory to define use cases and applications of the simulations. As a consequence, the assessment of the performance of the virtual demonstrators will be possible. This first part of the present deliverable is a prerequisite to the following requirements definitions.

According to the project proposal [1], the EU-LIVE virtual demonstrators should be implemented in a modular way, similar to the real demonstrators. Therefore, single subsystem models can be exchanged easily such that testing of different subsystem concepts can be performed efficiently. Additionally, some subsystem models may relate to each other in a hierarchical way, i.e. some of them may be grouped together such that they share common interfaces. The deduction of the subsystem model structure from the virtual demonstrator use cases is the second part in defining the requirements.

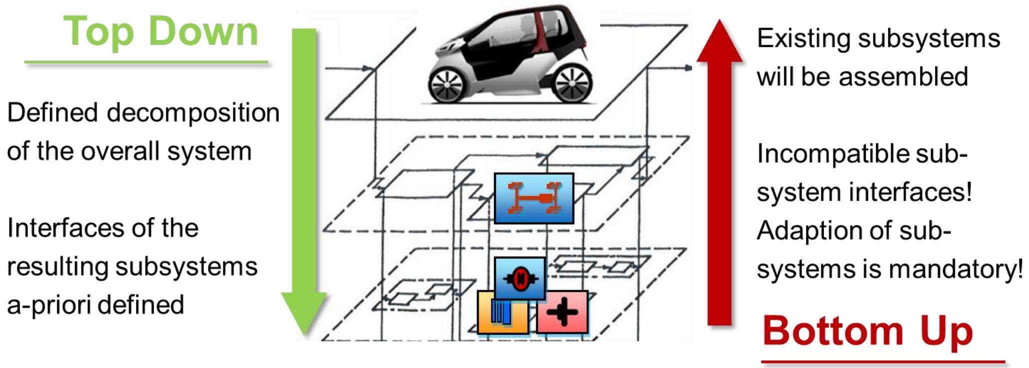

Figure 1: Comparison of "top-down" and "bottom-up" approaches

While it is common practise in virtual prototyping of vehicles to assemble existing component and subsystem models starting from the highest Level of Detail (LOD), EU-LIVE proposes a completely different approach: before assembling subsystem models, the interfaces between them are defined and the models are adapted accordingly. This so-called "top-down" approach (see Figure 1) enables us to perform simulations already during early project phases by using coarser models (e.g. lookup tables). Therefore, fundamental design decisions can be made by means of qualitative analyses of the simulation results. With progressing development time, the models become more and more detailed and hence the results of the simulations can be assessed more and more quantitatively (see Figure 2). However, it is essential to define the interfaces of the subsystem models before assembling them in order to ensure their compatibility. Therefore, the interface specifications form the third compulsory part of this deliverable.

Deliverable 3.1 [2] will give more details on the simulation models themselves.

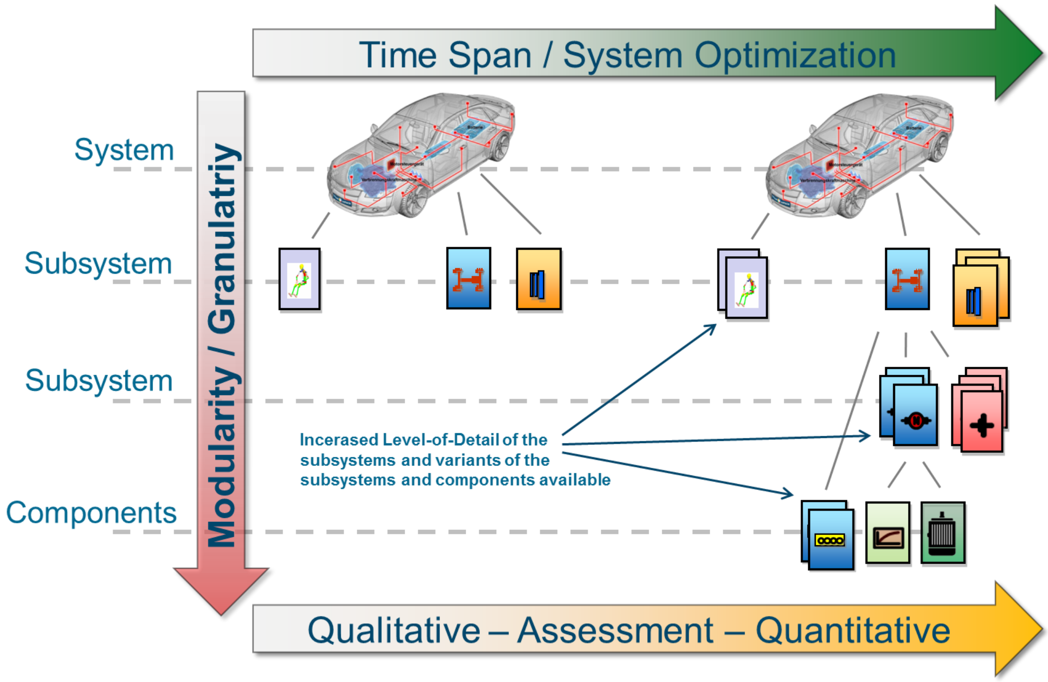

Figure 2: Advantages of a top-down approach during system optimisation phase

2.2 Objectives of co-simulation

In the past few decades, many specific simulation tools have been established in the automotive industry. However, these tools typically specialise on individual areas of expertise. There is very limited support for a heterogeneous simulation environment. The goal of “co-simulation” is to overcome this limitation and to merge the challenges from different areas. Common co-simulation platforms are often limited to a single area of expertise (e.g. the design of a thermal management system with a heterogeneous tool landscape). Such platforms typically address problems from a very specific, restricted dynamic range, which means that the different models exhibit similar dynamic behaviour.

However, the development of modern, mechatronic systems requires a much broader approach. The interactions between sub-systems from different areas have to be taken into account through a suitable interconnection of the parts. The coupling of existing (specific) simulation programs (and the models implemented therein) from different areas of expertise represents a promising approach for the simulation of the complete system (see Figure 3).

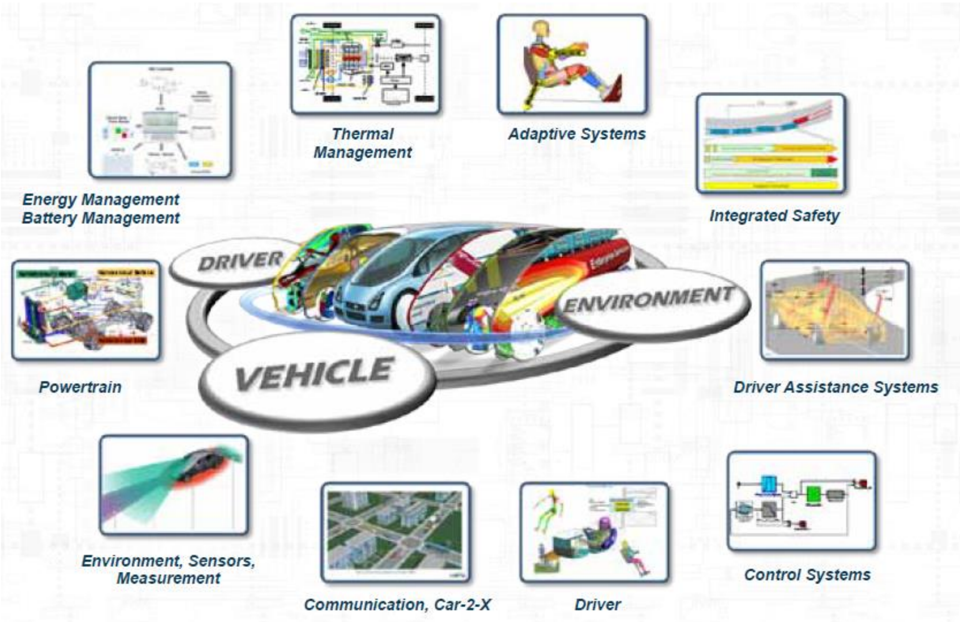

Figure 3: Examples of domains and models that can be connected via a co-simulation platform

With the introduction of co-simulation in the development process the task of developing complex mechatronic systems can be solved in a very efficient way. For example, the integration of Finite Element Methods (FEM) is supported for applications in the field of "Integral Safety". Another example is the integration of electrical and thermal components into existing drivetrain concepts in the field of "alternative drives", such as hybrid or electric vehicles. In all of these considerations the vehicle itself is not the exclusive focus, but rather the interactions with the vehicle's environment and the influence of the real driver are taken into account.

The task of a co-simulation platform is to take the complex interactions of the various simulation models in a suitable and correct way into account. The platform has to enable the precise co-working of different simulation tools (see Figure 4).

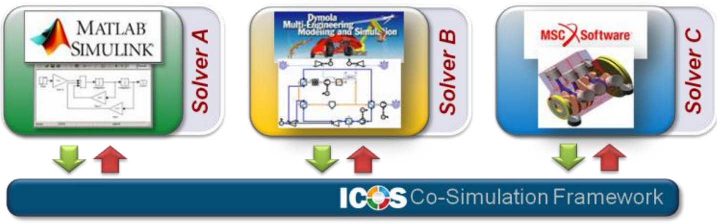

Figure 4: Co-simulation platform for the integration of various simulation tools

Only the verified interaction of numerous models (and therefore also simulated components) enables a realistic virtual concept design and validation of the overall system consisting of vehicle, driver and environment.

Some important considerations should to be taken into account when simulation tools from various development areas have to be coupled:

- Only minor adaptions in the simulation models, i.e. only input / output / controller blocks for the co-simulation should be added.
- No changes in the solver settings, i.e. the settings defined by the model designer should be used.
- The simulation models use their specific solvers and simulation step-sizes.
- The communication intervals between the co-simulation platform and the simulation tools are autonomous and adaptable.
- The co-simulation platform can remotely control the simulation tools.
- Interfacing of subsystems has to be supported, which enables a fast subsystem integration.

Within EU-LIVE, we will use the software Model.CONNECT™, which makes use of the co-simulation platform ICOS (Independent CO-Simulation, see [3]). It fulfills all the aforementioned requirements.

Although ICOS supports a large number of different simulation tools, we aim to use FMI [1] as standard for incorporating models to the co-simulation. FMI allows the definition of model interfaces in a standardized way. Moreover, it provides the possibility to include the compiled implementation of models. This means that models can safely be exchanged between partners without disclosure of the details of the model. The implementation of models using FMI will be subject of the deliverable 3.1 [2].

[1] FMI stands for “Functional Mock-up Interface” and was introduced in [4].

3 DESCRIPTION OF WORK

The work of this deliverable consists of the three following parts:

> Definition of use cases and simulation scenarios of the virtual demonstrators,
> Deduction of the required subsystem models including the LOD, and
> Specifications of the interfaces of the subsystem models for interconnection.

Following the modular approach of the simulations (see [1]), single models should be easily exchangeable. This means that the virtual demonstrators shall additionally support the variation of models. An example for different model variants is the different concepts for the design of the L6e vehicle that will be defined in D4.3 [5]. Figure 5 shows the overall workflow for the deduction of subsystem models including the LOD used for this deliverable.

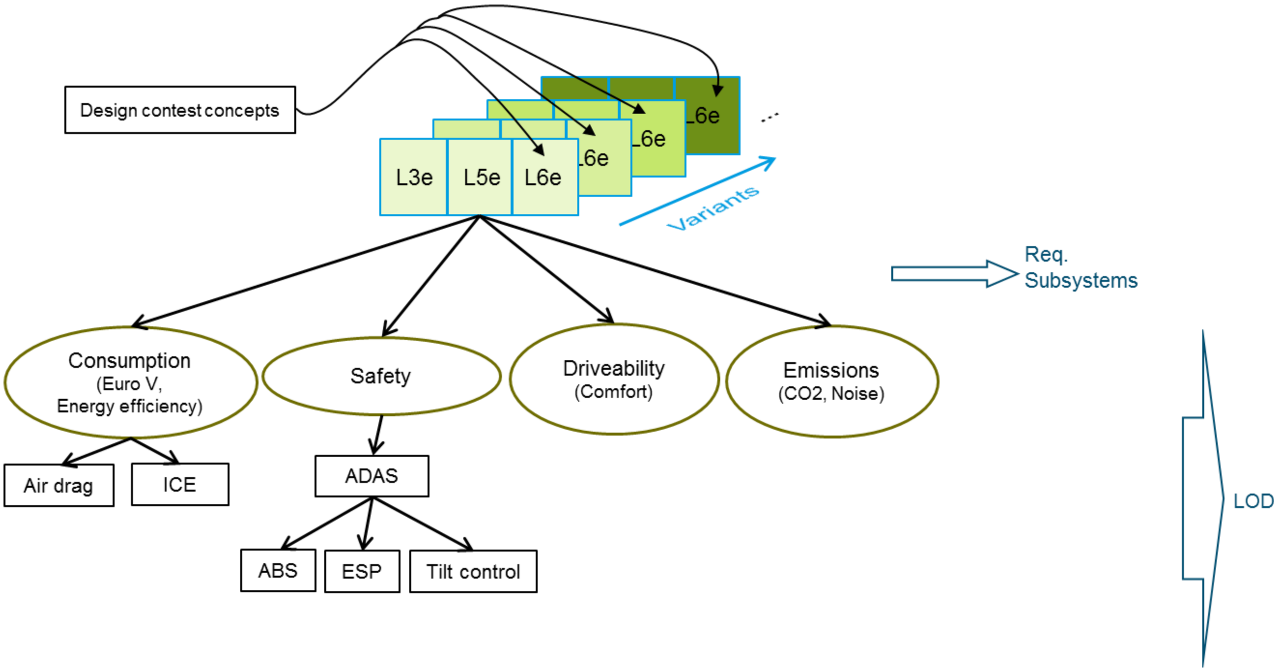

Figure 5: Workflow for establishing the list of required subsystem models

3.1 Use cases for the virtual demonstrators

The objectives of the virtual demonstrator as defined in the project proposal [1] are:

> Provide a testing environment for different components of the subsystems,
> Implement the components/subsystems in a modular way,
> Establish a hierarchical model structure.

In addition to these overall requirements, we define several use cases of the virtual demonstrators. On the one hand, the results of these concrete simulation scenarios will assist in the development process of the real demonstrators. On the other hand, simulations will provide a means for the assessment of the performance of the EU-LIVE demonstrators within specific situations.

In a first step, we proposed the following high-level groups of use cases (see Figure 5) following the overall objectives defined in the project proposal (see [1]):

> Consumption
> Safety
> Drivability
> Emissions

For each group, we came up with more dedicated use cases. In the next step, we surveyed all EU-LIVE partners about their priorities regarding virtual demonstrator use cases. They were asked to rate the scenarios on a scale from 0 (not relevant) to 3 (very important) and to add new use cases or even groups of use cases. Additionally, the partners could specify the vehicle type (L3e, L5e, or L6e) which should be considered for each use case. In order to cover all powertrain types, we allowed a further distinction into conventional (ICE only), hybrid, and fully electric configuration.

Together with the survey about use cases, we also asked the partners to rate the priorities for the exchange of single models or parameter variations. We defined a first list of subsystems and the partners could again select on a scale from 0 (not relevant) to 3 (very important) their opinion for each subsystem model to be varied. The same distinctions as before (vehicle type, powertrain type) were allowed.

We received questionnaires from the EU-LIVE partners. Figure 12 (see Appendix) shows the computed mean values of the survey results for the use cases, whereas Figure 13 (see Appendix) shows the mean values for the model variations.

Apart from the partner survey, we aimed to integrate results of deliverable 1.2 [6] to the list of use cases. However, only a few of the user needs are suitable for the EU-LIVE virtual demonstrators because we focus on the overall system development and a dynamic system analysis. We added the following use cases:

- Performance evaluation of the air condition (A/C) system
- Driving dynamics in a parking situation
- Stop-and-go autonomous driving
- Contribution of the power consumption of an elaborate entertainment or infotainment system to the overall consumption

Using these results, we were able to establish a list of simulation scenarios. In order to facilitate the assessment of the virtual demonstrator against the use cases, we formulated them as questions. Table 1 lists the virtual demonstrator use cases. Apart from the name and the description, each item has a unique ID, and is subscribed to certain vehicle types (L3e, L5e, L6e).

ID	Name	Description / Content / Verification	L3e	L5e	L6e
	Consumption				
C_01	Euro V	Is the Euro V standard fulfilled (yes/no)	x	x	x
C_02	Air drag	How does the air drag affect consumption (quantitative)	x	x	x
C_03	Traffic	How do different traffic conditions affect consumption (quantitative)	x	x	x
C_04	Infotainment	How does the power consumption of an elaborate infotainment system affect the overall consumption (quantitative)	x	x	x
	Safety				
S_01	ABS	How does ABS affect vehicle safety (quantitative)	x	x	x
S_02	Moose test	What is the vehicle's behaviour in case of a suddenly appearing obstacle (quantitative)		x	x
S_03	Failure mode	What is the vehicle's behaviour if the limp home/failure mode is active (quantitative)		x	x
S_04	NCAP (front)	What would be the effects in case of a front impact (as defined in EURO NCAP) (quantitative)		x	x
S_05	NCAP (side)	What would be the effects in case of a side impact (as defined in EURO NCAP) (quantitative)		x	x

ID	Name	Description / Content / Verification	L3e	L5e	L6e
	Drivability				
D_01	A/C performance	What is the demisting performance of the A/C system (quantitative)		x	x
D_02	Steering effort	How large is the steering effort (quantitative)		x	x
D_03	Start behaviour	What are the characteristics of driving the vehicle right after starting (e.g. lower performance) (quantitative)	x	x	x
D_04	Switch ICE-IWM	Does the switching between ICE and IWM influence the drivability (e.g. due to loss of momentum) (quantitative)	x	x	x
	Performance				
P_01	Peak velocity	What is the highest achievable velocity (quantitative)	x	x	x
P_02	Peak acceleration	What is the highest achievable acceleration (quantitative)	x	x	x
P_03	Take-off capability	Is it likely that the vehicle takes off and if so under which conditions (quantitative)	x	x	x
P_04	Roll on acceleration	What is the average acceleration in a normal roll-on situation (quantitative)	x	x	x
P_05	Hill start	What is the performance (acceleration) in case of starting on a hill (quantitative)	x	x	x
	Emissions				
E_01	CO2	What is the (maximum, average, continuous) CO2 emission of the engine (quantitative)	x	x	x

Table 1: List of virtual demonstrator use cases

3.2 Required subsystem models

Using the list of virtual demonstrator use cases (Table 1), we were able to establish a first draft for the list of required subsystem models. We discussed the models in this draft version with those EU-LIVE partners who have experience in the specific fields and who will provide the models. Table 2 shows the final list, which already contains the feedback we received from the partners. The field “Level” shows the rank of a model within the hierarchical structure, ranging from 1 (highest level) to 4 (lowest level present). The field “equal” applies if the model/parameter is independent on the vehicle architecture, otherwise there can be different models/parameters for each architecture. The type of a subsystem model can be either a full physical model or a simple value or parameter. The field “Responsible Partner” lists the EU-LIVE partner that will provide the component model, hence this field makes only sense on the lowest level within each subsystem. The representatives of all these partners contributed to this deliverable.

ID	Level	Name	Type	L3e	L5e	L6e	equal	Responsible Partner
B	**1**	**Battery**						
B1	2	Electrical model	Physical model	x	x	x		SDI
B2	2	Thermal model	Physical model	x	x	x		SDI
P	**1**	**Powertrain**						
P1	2	In-Wheel-Motor (IWM)	Physical model	x	x	x		
P1_1	3	Mechanical model (input: electric/control, output: torque)	Physical model	x	x	x		Brembo
P1_2	3	Thermal model	Physical model	x	x	x		Elaphe
P1_2_1	4	Interior of the thermal model (air flow)	Physical model	x	x	x		Elaphe
P2	2	Internal Combustion Engine (ICE)	Physical model	x	x	x		
P2_1	3	Mechanical model (input: control, output: torque)	Physical model	x	x	x		PSCO
P2_2	3	Emission model	Physical model	x	x	x		PSCO
P2_3	3	Thermal model	Physical model	x	x	x		PSCO
P3	2	Transmission (gear ratios)	Physical model	x	x	x		IFPEN
B	**1**	**Braking system**	Physical model	x	x	x		Brembo
Ch	**1**	**Chassis/Structure**						
Ch1	2	CFD model for aerodynamics	Value/Parameter	x	x	x		FKA
Ch2	2	CAD model	Physical model	x	x	x		PSA
Ch3	2	MBS	Physical model	x	x	x		VIF
Ch4	2	Additional electric power						

ID	Level	Name	Type	L3e	L5e	L6e	equal	Responsible Partner
		consumption						
Ch4_1	3	Power consumption of HVAC	Value/Parameter		x	x		VIF
Ch4_2	3	Power consumption of infotainment	Value/Parameter	x	x	x		VIF
Ctrl	**1**	**Control**						
Ctrl1	2	ADAS	Physical model					
Ctrl1_1	3	ABS	Physical model	x	x	x		VIF
Ctrl1_2	3	Tilt control	Physical model	x	x			PSA
Ctrl2	2	Operations strategy	Physical model	x	x	x		Conti
E	**1**	**Environment**						
E1	2	Exterior temperature	Value/Parameter				x	VIF
E2	2	Traffic	Value/Parameter				x	VIF
E3	2	Properties of obstacle	Value/Parameter				x	VIF
E4	2	Steepness of the road	Value/Parameter				x	VIF
C	**1**	**Cooling System**						
C1	2	Air cooling	Physical model	x	x			VIF
C2	2	Liquid Cooling	Physical model		x	x		VIF
Dr	**1**	**Driver**	Physical model	x	x	x		VIF

Table 2: List of required subsystem models

Figure 6 shows a tree-like visualisation of the subsystem model structure. We want to emphasise that the structure of the subsystem models does not necessarily correspond to the physical structure of real components and subsystems.

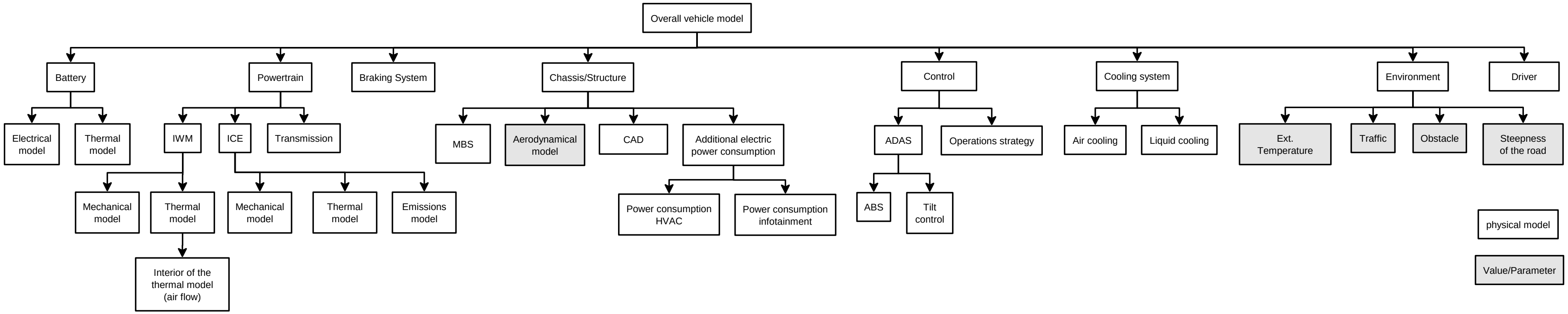

Figure 6: Hierarchical visualisation of the subsystem model structure

3.3 Model interfaces

It is essential to define the interfaces between subsystem models before assembling the virtual demonstrators in terms of a so-called Top-Down approach (see Figure 1). This step guarantees the interfacing consistency of the EU-LIVE virtual demonstrators. By the term “interfaces”, we mean the specifications of the information that is exchangeable between two or more models, i.e. the inputs and outputs of each model. This information can either be a physical quantity, or a dimensionless number (e.g. in the case of control signals). Therefore, we require the definition of the following properties for each interface:

> Name
> Dimension
> Physical unit
> Direction of the flow of information

Since only quantities of the same dimension and physical unit can be exchanged, we define interfaces within each domain. Additionally, this approach enhances the clearness of the visualisations. Within this project, we restrict ourselves to the following domains:

> Electric
> Mechanical
> Thermal
> Control

Additional domains are possible (e.g. hydraulic/hydrodynamic), however, we do not use them for the interface definitions for reasons of better visibility[2]. Since the EU-LIVE virtual demonstrators will be used mainly for dynamic analyses (see section 3.1), it will be sufficient to use only the results of CAD and CFD modelling for most of the use cases. Consequently, models such as CAD model of the chassis (Ch2) or CFD models (Ch1) are not displayed in the following sections, except if their inputs or outputs contribute to co-simulations. This has no effect on the overall hierarchical approach because it is still possible to perform e.g. CFD simulations for different LODs. Finally, the multi body simulation (MBS, Ch3) is mainly a stand-alone model where other models (e.g. assumptions on tyres) will be directly incorporated. The inputs to the MBS are again geometric data, as well as material properties. Nevertheless, control systems (e.g. models in the group Ctrl) can interact with the MBS.

When using physical models, usually so-called back-effects have to be considered (see e.g. [7]). This means that – if a physical conservation law applies - the flow of a physical quantity in one direction requires an opposed flow of a related quantity. This is valid within all domains, e.g. a transmission of electric energy requires the coupling of both electric voltage and electric current. Mechatronic systems design [7] or similar textbooks list several approaches for the definition of exchange quantities, e.g. that the product of the two exchanged quantities always has the dimension of power. Therefore, we require the EU-LIVE virtual demonstrator interface specifications to follow this approach whenever possible.

Subsections 3.3.1 to 3.3.5 graphically illustrate the interfaces between the subsystem models for each group of use cases (indicated by their IDs). The grouping is slightly different from the one used in section 3.1 because it reflects the technical dependencies between models and not the topical relations between the use cases.

Finally, subsection 3.3.6 shows the complete list of interfaces of all subsystem models.

3.3.1 Required interfaces for driving dynamics simulations

Applicable for the use cases S_04, D_02, D_03, D_04, P_01, P_02, P_03, P_04, and P_05.

The largest part of the planned driving dynamics simulations will be performed within Task 4.1.7 with the stand-alone MBS. However, some of the use cases introduced in section 3.1 need the integration of the MBS with other subsystem models. Figure 7 depicts the functional dependencies between the models of the subsystems. Interface specifications are required in each available domain (i.e. on each horizontal layer). We use the same graphical representation of interfaces for the Figures Figure 8 amd Figure 10.

[2] The CFD simulations will not exchange hydrodynamic data anyway because their outputs are values of air drag (mechanical domain) and heat exchange (thermal domain).

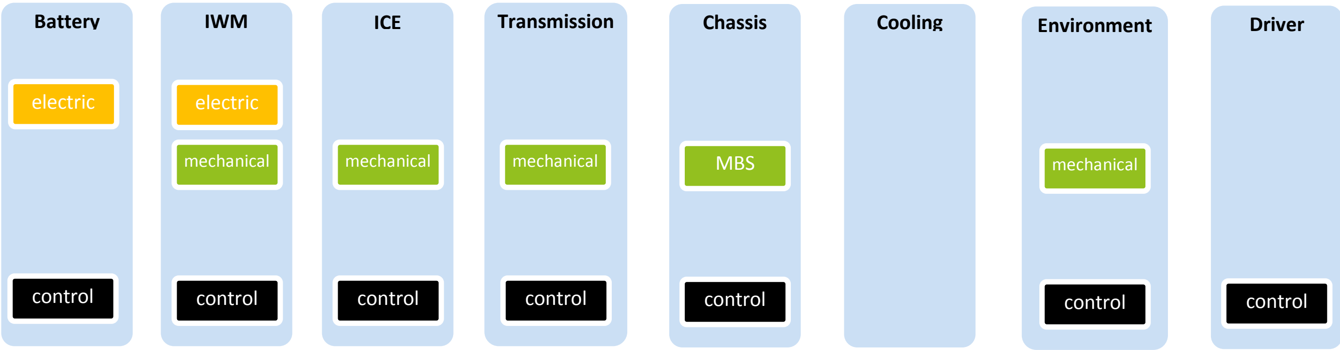

Figure 7: Subsystem models involved in the driving dynamics simulations and their interfaces

3.3.2 Required interfaces for ADAS evaluation simulations

Applicable for the use cases S_02 and S_05.

Figure 8 shows the models required for ADAS evaluation simulations.

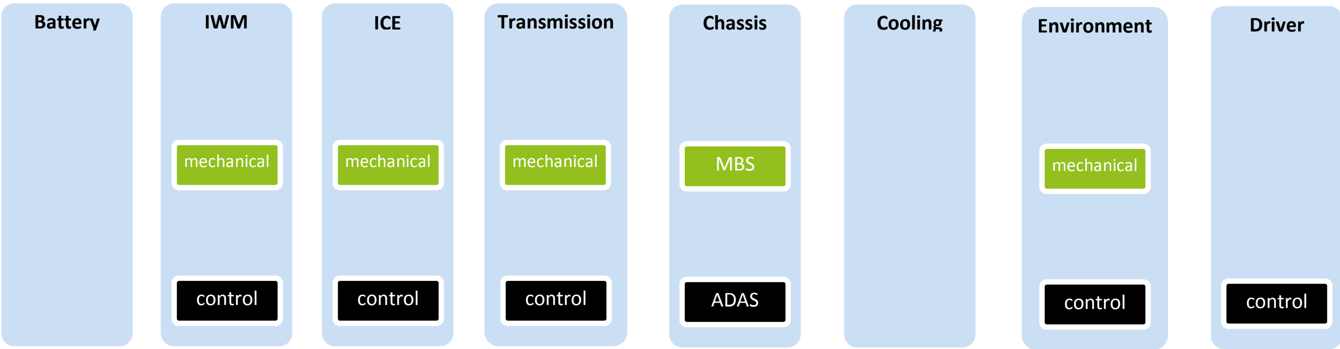

Figure 8: Subsystem models involved in the simulations evaluating ADAS systems and their interfaces

3.3.3 Required interfaces for consumption/emissions simulations

Applicable for the use cases C_01, C_02, C_03, C_04, D_01, and E_01.

The vehicle's consumption/emissions depend mostly on the ICE. However, due to the hybrid powertrain, the IWM, the transmission, and the control strategies strongly influence the ICE consumption. Additionally, we will investigate the contribution of large electric consumer loads (cooling system, air condition, infotainment systems) to the overall consumption. Within this group of simulations, we will also evaluate the performance of a liquid cooling system. Figure 9 depicts the involved subsystem models and their interfaces.

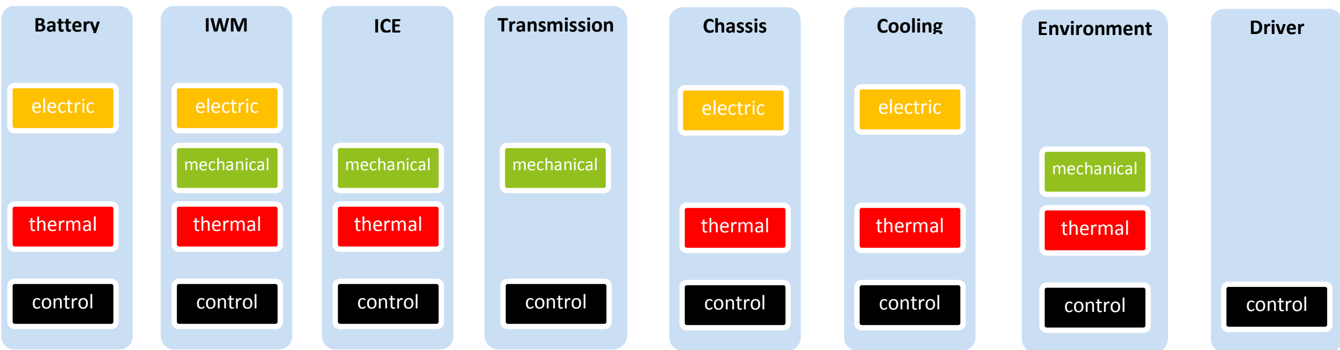

Figure 9: Subsystem models involved in the consumption/emissions simulations and their interfaces

3.3.4 Required interfaces for aerodynamic simulations

Applicable for the use case C_02.

Aerodynamic CFD simulations will provide not only input data for mechanical simulations (e.g. air drag values), but also for the thermal modelling. Since we wish to assess the performance of pure air cooling, all models producing heat (battery, IWM, ICE) will contribute. Figure 10 shows the required models and their interfaces.

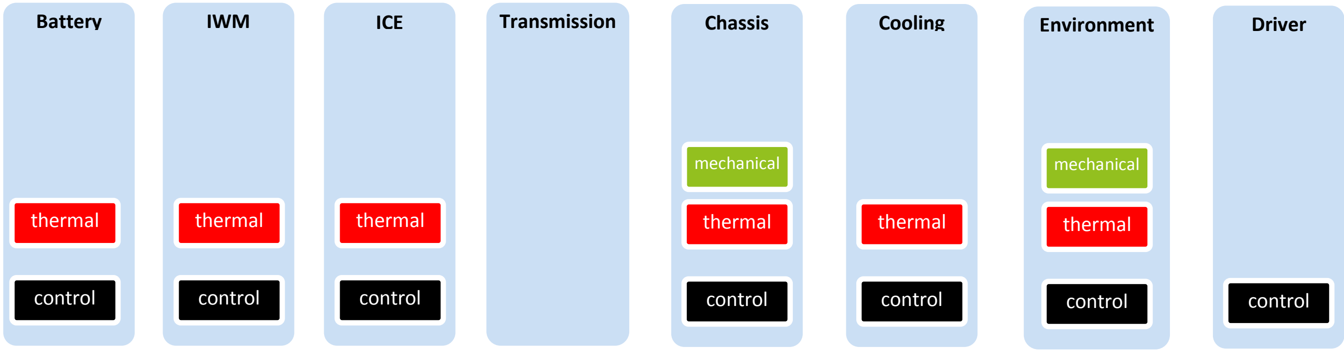

Figure 10: Subsystem models involved in the aerodynamical simulations and their interfaces

3.3.5 Required interfaces for NCAP crash test simulations

Applicable for the use cases S_06 and S_07.

The crash test simulations will be performed on a stand-alone basis. We will simulate the deformation of the chassis after an impact with defined velocity and angle towards a standardised obstacle. Figure 11 shows the involved models and their interfaces.

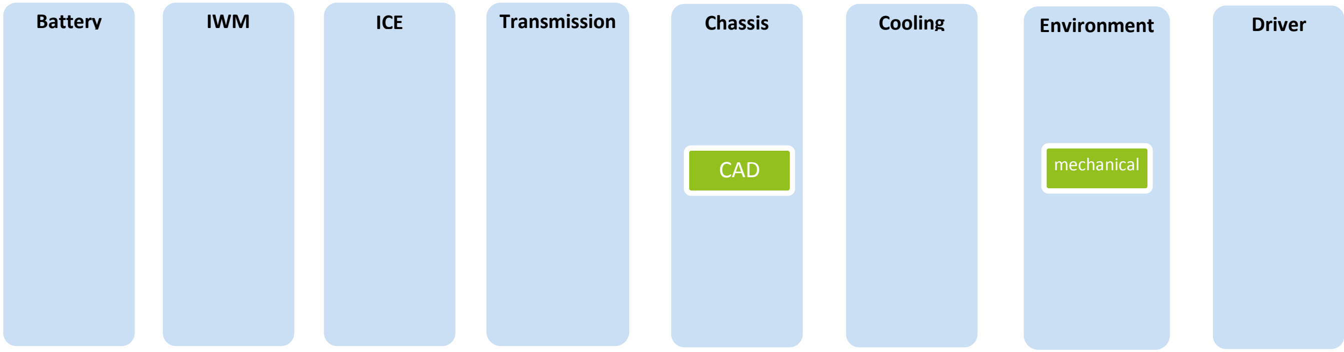

Figure 11: Subsystem models involved in the NCAP crash test simulations and their interfaces

3.3.6 Interfaces of each subsystem model

This section gives the detailed interface specifications of the subsystem models. Since some of the models already exist, their interfaces are very detailed due to the practical experience in their usage. The model interfaces were specified by the partners responsible for the models (compare with Table 2). Table 3 shows the full list of interfaces together with the respective specifications. The models and their IDs are the same as in Table 2.

Model ID	Model Name	Domain	Name	Dimension	Unit	In/Out
B	**Battery**	Electric	Power	power	kW	In
		Electric	Cell parameter (resistance)	resistance	Ohm	In

Model ID	Model Name	Domain	Name	Dimension	Unit	In/Out
		Electric	Cell parameter (capacity)	charge	Ah	In
		Electric	Power Loss	power	W	Out
		Electric	System Current	current	A	Out
		Electric	System Voltage	voltage	V	Out
		Thermal	Heat capacity	specific heat capacity	J/(K*kg)	In
		Thermal	Heat conductivity	thermal conductivity	W(m*K)	In
		Thermal	Cell/System temperature	temperature	°C	Out
		Control	Time	time	s	In
		Control	SoC (State of Charge)	-	%	Out
P1_1	**IWM (mech.)**	Mechanical	Brake pedal force	force	N	In
		Mechanical	Brake level force	force	N	In
		Mechanical	IWM torque	torque	Nm	In
		Mechanical	ICE torque	torque	Nm	In
		Mechanical	Torque at wheel (ground)	torque	Nm	Out
		Mechanical	Brake pedal travel	distance	m	Out
		Mechanical	Brake level travel	distance	m	Out
		Control	Brake pressure command (incl. ABS)	-	-	In
P1_2	**IWM (thermal)**	Mechanical	Mech. design of the IWM	length	mm	In
		Mechanical	Mech. design of the rim	length	mm	In
		Mechanical	Peak motor torque	torque	Nm	Out
		Mechanical	Continuous motor torque	torque	Nm	Out
		Thermal	Heat capacity of the motor's housing	specific heat capacity	J/(K*kg)	In
		Thermal	Heat convection coefficient of the motor's housing	thermal conductivity	W(m*K)	In
		Thermal	Temperature on outer stator surface	temperature	°C	Out
		Other	CFD airflow	-	-	In

Model ID	Model Name	Domain	Name	Dimension	Unit	In/Out
P2_1	**ICE**	Mechanical	Torque request	torque	Nm	In
		Mechanical	Engine speed	rotational speed	rpm	In
		Mechanical	Torque delivered	torque	Nm	Out
		Mechanical	Power delivered	power	kW	Out
		Mechanical	Engine speed	rotational speed	rpm	Out
		Other	SFC	fuel consumption/power	g/(kW*h)	Out
		Other	Pressure drop (cooling liq.)	pressure	Pa	Out
		Thermal	Heat transfer to liquid cooling	heat flux	kW	Out
		Thermal	ICE exterior wall temperature	temperature	K	Out
		Thermal	Exhaust muffler wall temperature	temperature	K	Out
P3	**Transmission**	Mechanical	Engine torque	torque	Nm	In
		Mechanical	Wheel speed	rotational speed	rpm	In
		Mechanical	Engine speed	rotational speed	rpm	Out
		Mechanical	Wheel torque	torque	Nm	Out
		Control	Actuator 1	-	-	In
		Control	Actuator 2	-	-	In
	Transmission Control	Mechanical	Speed_1/Input shaft speed	rotational speed	rpm	In
		Mechanical	Speed_2 / Intermediate shaft speed	rotational speed	rpm	In
		Mechanical	Speed_3 / Output shaft speed	rotational speed	rpm	In
		Mechanical	Engine_Speed / ICE speed	rotational speed	rpm	In
		Mechanical	Engine_Torque / Estimated ICE torque	torque	Nm	In
		Mechanical	Engine_Torque_sp / ICE torque setpoint	torque	Nm	In
		Mechanical	Motor_Speed / Electric Motor speed	rotational speed	rpm	In

Model ID	Model Name	Domain	Name	Dimension	Unit	In/Out
		Mechanical	Motor_Torque / Estimated electric motor torque	torque	Nm	In
		Mechanical	Motor_Torque_sp / electric motor torque setpoint	torque	Nm	In
		Mechanical	Engine speed limitation	rotational speed	rpm	Out
		Control	Trans_mode_sp / requested transmission mode (gear ratio)	-	-	In
		Control	Trans_state / transmission state (engaged, gear change, fault,…)	-	-	Out
		Control	Trans_mode / Current transmission mode (gear ratio)	-	-	Out
		Control	Actuator 1 / GearBox Act 1	-	-	Out
		Control	Actuator 2 / GearBox Act 2	-	-	Out
Ch1	**CFD Model for Aerodynamics**	Other	CAD data	-	-	In
		Mechanical	Drag coefficient c_w	-	-	Out
Ch2_2	**CAD Model**	Other	CAD data	-	-	Out
Ctrl2	**Operations strategy**	Control	Twist grip accelerator / Degree of activation of accelerator	-	%	In
		Control	Brake Light switch / Brake activation	-	-	In
		Thermal	ICE's Engine temperature	temperature	°C	In
		Control	ICE's mode / Engine operating states (e.g. idle speed,…)	-	-	In
		Control	ICE's diagnosis / engine diagnosis	-	-	In
		Mechanical	ICE's Torque limitation / Maximum torque that ICE could provide	torque	Nm	In
		Mechanical	ICE's actual torque / actual torque provided by ICE	torque	Nm	In

Model ID	Model Name	Domain	Name	Dimension	Unit	In/Out
		Control	Diagnosis from transmission	-	-	In
		Mechanical	Engine speed @ ICE	rotational speed	rpm	In
		Mechanical	Engine speed @ IWM	rotational speed	rpm	In
		Mechanical	IWM's torque limitation / Maximum torque that IWM could provide	torque	rpm	In
		Mechanical	IWM's actual torque / actual torque provided by IWM	torque	rpm	In
		Electric	Battery voltage limitation	voltage	V	In
		Electric	Battery current limitation	current	A	In
		Control	Battery state of charge	-	%	In
		Control	Battery diagnosis	-	-	In
		Mechanical	Torque setpoint ICE	torque	Nm	Out
		Mechanical	Torque setpoint IWM	torque	Nm	Out
		Control	Actuator 1 / GearBox Act 1	-	-	Out
		Control	Gear setpoint	-	-	Out
		Control	Actual gear	-	-	Out
		Control	Actuator 2 / GearBox Act 2	-	-	Out
C1	**Air Cooling**	Other	CAD data	-	-	In
		Thermal	Heat flux on the surface	heat flux	W	In
		Thermal	Temperature on the surface	temperature	°C	Out
C2	**Liquid Cooling**					
		Thermal	Temperature	temperature	°C	Out
		Other	Mass flow	mass/time	kg/s	In
		Other	Pressure loss	pressure	Pa	In
Dr	**Driver**	Control	Twist grip accelerator / Degree of activation of accelerator	-	%	Out
		Control	Degree of activation of brake	-	%	Out
		Control	Degree of steering	-	-	Out

Model ID	Model Name	Domain	Name	Dimension	Unit	In/Out
		Mechanical	Vehicle speed	speed	km/h	In

Table 3: List of the interface specifications

4 DISSEMINATION, EXPLOITATION AND STANDARDISATION

This deliverable will be published on EU-LIVE's website.

The results of this deliverable define the prerequisites for the whole WP3 "Virtual demonstrators". Especially the definition of the model interfaces forms the basis of the following development of the simulation models.

The usage of a Top-Down system specification combined with a hierarchical model structure is, in our opinion, the most innovative part of this work. Consequently, further research can be based on the results published in this deliverable. This means that we plan the publication of this work or parts of it within scientific journals and in scientific conferences.

To the best of our knowledge, FMI has never been used before in such a comprehensive way in L-category industry.

Moreover, we intend the usage of a modular and hierarchical modelling strategy within future scientific and industrial projects. We believe that especially the saving of time during the optimisation phase due to this modelling approach could generate impact in industrial applications.

5 INTEROPERABILITY

Since we will implement the EU-LIVE virtual demonstrators for the vehicle categories L3e, L5e, and L6e, we have to consider the interoperability of the simulation models. However, due to the modular structure of the EU-LIVE concept, the overall simulation structure (see Figure 6) remains the same, regardless of the vehicle type. Nevertheless, some models have to be implemented differently depending on the vehicle type. Their re-integration is anyway feasible because the model interfaces are defined a priori due to the innovative top-down approach. The largest part of subsystem models though alter via model parameters. This is the preferred approach because it allows even an easier model variation.

To summarise, the EU-LIVE virtual demonstrators will be implemented using full interoperability between the vehicle concepts. This is only feasible due to the modular and hierarchical structure of the simulation models.

6 CONCLUSION

The main objective of this deliverable is to define the requirements for implementing the EU-LIVE virtual demonstrators. The virtual demonstrators will produce output that is essential for the development and optimisation of the real demonstrators. While virtual prototyping already is common practise in the automotive industry, EU-LIVE extends this approach to the L-category industry.

Before modelling, it is important to agree on a set of simulation scenarios and purposes of the virtual demonstrators. We combined the opinions and expertise of the EU-LIVE partners with possible user needs in order to generate this set. A total of 19 use cases (or simulation scenarios) will govern the implementation of the simulations.

Using this list, we were able to deduce a list of required simulation models. Due to the usage of a ground-breaking hierarchical model structure, this list already includes several Levels-of-Detail, depending on the purpose of each subsystem model. Furthermore, this highly innovative modelling approach supports the future testing and optimisation phase of the demonstrators because existing coarse models can be assembled already at the beginning.

In order to ensure the consistency of the overall simulation assembly it is indispensable to specify the interfaces of the simulation models already within this deliverable. This so-called top down approach facilitates the continuous optimisation of models because the model interfaces do not change.

The results of this deliverable are essential for the modelling of the subsystems and the implementation of co-simulations. All deliverables related to the virtual demonstrators, in particular D3.1 [2], D3.2 [8], and D3.3 [9], will rely on the lists of subsystem models and model interfaces.

Due to the highly innovative methods used for this deliverable, its content will serve as fundamental input to scientific publications, such as journal papers or conference presentations. Particularly the hierarchical model structure and the a-priori definition of interfaces could serve as milestones for virtual prototyping and testing in the future.

7 REFERENCES

[1] EU-LIVE Project Proposal, Nr. 653203, 2015-03-19

[2] EU-LIVE Deliverable D3.1 “Description of available subsystem simulation models”, will be delivered until 2016-05-31

[3] ICOS 3.3, Independent Co-Simulation, Virtual Vehicle Research Center, Graz, Austria, information available at http://www.v2c2.at/icos (last accessed: January 2016)

[4] Blochwitz T. et al., Functional Mockup Interface 2.0: The Standard for Tool independent Exchange of Simulation Models, The 9th International Modelica Conference, Munich, Germany, September 2012

[5] EU-LIVE Deliverable D4.3 “Feasibility study on a radically new L6e vehicle concept”, will be delivered until 2016-07-29

[6] EU-LIVE Deliverable D1.2 “Verified user needs (focus groups)”, v1.0, 2015-11-26

[7] Janschek K., Mechatronic systems design: methods, models, concepts., Springer Science & Business Media, 2011

[8] EU-LIVE Deliverable D3.2 “Model library and configuration of the modular simulation”, will be delivered until 2016-07-29

[9] EU-LIVE Deliverable D3.3 “System design and analysis”, will be delivered until 2018-02-28

A. APPENDIX

Virtual Demonstrator Objectives										
Configuration:	PHEV			electric			conventional			
Type:	L3e	L5e	L6e	L3e	L5e	L6e	L3e	L5e	L6e	
Consumption										makes no sense
EURO V verification	2,50	3,00	2,83				2,83	2,83	2,50	new
air drag consideration	1,33	2,33	2,17	1,33	1,33	2,17	1,67	2,17	2,00	low priority
traffic influence analysis	2,33	2,83	2,33	2,33	1,83	2,33	2,50	2,50	2,17	high priority
Safety										
tilt control analysis	0,50	1,67		1,00	0,67		0,50	0,67		
ABS application	2,40	2,80	2,00	3,00	2,20	2,60	2,40	2,20	2,00	
ASC application	1,00	2,20	1,60	1,20	2,00	2,20	0,80	1,80	1,60	
ESP application	0,60	2,60	1,80	1,20	2,00	2,60	0,60	2,00	2,00	
"moose test"	0,40	2,40	2,20	0,80	1,80	2,80	0,40	1,40	2,20	
Limp home/Failure mode										
Front impact (EURO NCAP)										
Side impact (EURO NCAP)										
Drivability										
comfort analysis	2,00	2,40	1,80	2,20	2,20	2,40	2,00	2,20	1,80	
steering effort	1,20	2,20	1,60	1,40	2,00	2,20	1,20	2,00	1,60	
start behaviour	2,00	2,60	2,00	2,00	2,20	2,40	2,00	2,40	2,00	
roll behaviour	1,00	1,40	0,80	1,00	1,20	1,40	0,80	1,20	0,80	
pitch behaviour	1,50	1,50	0,75	1,75	1,25	1,50	1,25	1,25	0,75	
analysis of under/oversteering	1,25	1,50	0,75	1,50	1,25	1,50	1,25	1,25	0,75	
yaw rate analysis	0,80	1,60	0,80	1,00	1,40	1,40	1,00	1,40	0,80	
determination of the peak acceleration	2,67	2,67	2,00	2,50	2,17	2,17	2,67	2,50	2,00	
witching between electric motor and ICE										
ergnonomics and usability										
Emissions										
noise analysis	1,83	2,00	1,83	1,50	1,83	2,00	2,17	2,33	2,00	
CO2 analysis	2,50	2,83	2,67				2,67	2,67	2,50	
Performance (from PSA)										
Maximum speed										
Take-off capability										
Roll-on acceleration										
Hill start										

Figure 12: Detailled results of the survey among partners regarding virtual demonstrator use cases

Virtual Demonstrator Variation									
Configuration:	PHEV			electric			conventional		
Type:	L3e	L5e	L6e	L3e	L5e	L6e	L3e	L5e	L6e
Battery									
size	2,00	2,20	1,80	2,20	1,80	1,60			
cooling	1,80	1,80	1,60	2,40	2,00	1,80			
heating	2,00	2,00	2,00	2,50	2,50	2,50			
type (Li-Ion, …)	1,60	1,80	1,60	1,80	1,60	1,60			
weight									
Capacity									
cell type (Pouch, cylindrical, …)									
e-drive									
size	2,40	2,40	2,20	2,80	2,40	2,60			
cooling	2,00	2,40	2,00	2,60	2,20	2,60			
que transmission ICE to in-wheel									
ICE									
size	2,00	2,20	1,80				2,60	2,20	1,80
cooling	1,60	1,40	1,40				1,60	1,20	1,00
type	1,75	1,75	1,75				1,25	1,25	1,25
Driver									
driver operation characteristics	1,33	2,00	1,67	1,50	1,33	1,67	1,50	1,83	1,50
Transmission									
gear ratios	2,00	2,33	2,00				2,33	2,33	1,83
Chassis/Design									
underhood air flow analysis	1,40	2,20	1,60	2,20	1,80	2,40	1,00	0,80	0,80
aerodynamic drag									
oad condidion (1 or 2 occupants)									
in-wheel air flow analysis									
Tyres									
size/dimension	1,80	1,80	1,60	1,80	1,80	1,80	0,80	0,80	0,60
friction (summer, winter)	1,40	1,20	1,20	1,40	1,20	1,20	1,00	0,80	0,60
Environment									
traffic	1,67	2,00	1,67	1,50	1,00	1,50	1,00	1,00	1,00
temperature	2,00	2,17	2,17	1,83	1,50	2,00	0,83	0,83	0,67
road condition	1,50	1,50	1,17	1,50	0,83	1,17	1,33	0,67	0,67
ADAS									
ABS	2,20	2,20	1,80	2,40	2,00	2,00	2,40	2,00	1,80
ESP	0,80	2,00	1,60	1,00	1,80	2,00	1,00	1,80	1,80
tilt control	0,60	1,00		0,80	0,80		0,80	0,80	
ASC	1,00	1,60	1,20	1,20	1,60	1,20	0,80	1,40	1,20
Intersystems control									

Figure 13: Detailled results of the survey among partners regarding variations of subsystems or parameters

B. ABBREVIATIONS AND DEFINITIONS

Term	Definition
ABS	Anti-lock Braking System
ADAS	Automatic Driving Assistance System
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
ESP	Electronic Stability Control
FMI	Functional Mock-up Interface
ICE	Internal Combustion Engine
IWM	In-Wheel Motor
LOD	Level-Of-Detail
MBS	Multi Body Simulation
NCAP	New Car Assessment Programme