OverNight Testing – The Fully Automated Simulation Environment for Evaluation of Car Concepts ONT

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Abstract. In this paper, a short introduction of the full vehicle simulation environment OverNight Testing (ONT) is given. This environment was developed in cooperation of Dr. Ing. h.c. F. Porsche AG with the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS) [1]. The main application area is in the concept development for the assessment of overall vehicle concepts. The distinctive features of the simulation environment are a strong configurability and the high degree of automation and modularization.

A process has been defined for the evaluation of a car concept, starting with the integration of new model components continuing with the creation of a new vehicle configuration, over the simulation using various manoeuvres up to the presentation of results. The advantage of the presented simulation tool is the ability to handle a huge number of variaties of a vehicle concept automatically and create evaluation results quickly by using the toolkit principle.

Introduction

The number of vehicle derivatives is increasing in the automotive industry for years. With the introduction of platforms and the toolkit principle these variants must stay manageable [2]. A large number of variants for each car concept need to be evaluated within a short time.

Hence it is the goal to use full vehicle simulation models with the same modular structure as the toolkit principles to make the diversity and complexity controllable [3]. The vehicle model should be divided into modules that can be replaced and are reusable. A very important additional constraint is, that the amount and detail of information in the early phase of the vehicle development process are low [4].

The models of the vehicle components with different levels of detail are combined to a complete full vehicle model. In the course of the project the simple models can be easily replaced by more complex and larger models. A clearly defined and structured evaluation process is essential to make the high number of evaluations manageable [5]. With the help of a developed domain ontology [6] the automated linking of the various forms of information, objects and properties is made feasible.

Furthermore, it must be possible to evaluate the vehicle models with a variety of technologies as well was parameter sets and comparing the results. Easy and rapid variations of the components and the parameters of the model are crucial in the concept evaluation. It is of high importance to make the expertise of other disciplines available by using and exchanging models over simulation platform boundaries [7].

Therfore the model boundaries and interfaces need to be cleary defined. A user-friendly interface will be provided to review the results easily and quickly. All data used in the evaluation and the results should be stored to be able to repeat the review and understand the results anytime later.

1 The Simulation Environment OverNight Testing (ONT)

The prototype of the simulation environment ONT implements the above mentioned requirements. The Starting window of ONT is depicted in Figure 1. The tool was created in MATLAB and Simulink and enables a simple and user-friendly simulative evaluation of vehicle concepts.

MATLAB and Simulink was chosen on the one hand due to the possibilities for creating graphical user interfaces, easy implementation and integration of functions for processing data, which are necessary for the pre- and postprocessing of simulations and lastly as the program is widely used for the simulation of vehicle behavior within the company. The user does not need prior experience with MATLAB or Simulink since all functions can be operated via user interfaces.

Figure 1. ONT starting window.

The following is an example for a concept evaluation which will be explained gradually.

1.1 Example for a concept evaluation

In this example, the fictional concept of an electric vehicle with the name *Concept_1* is evaluated. The standard procedure for the review of a vehicle in ONT is shown in Figure 2.

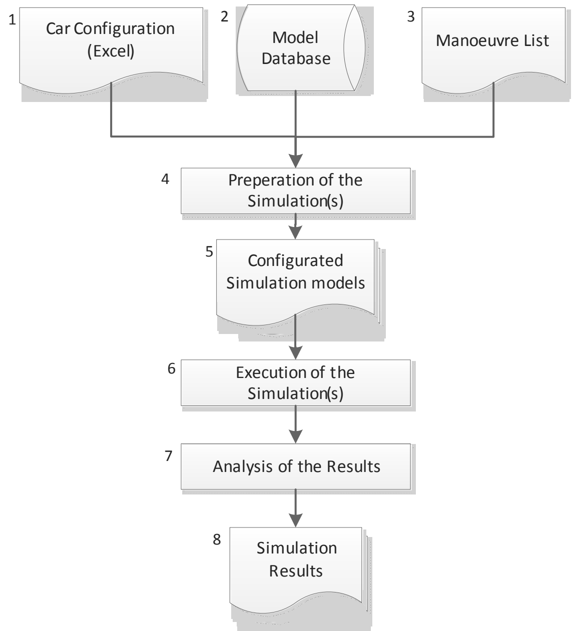

Figure 2. Standard evaluation procedure in ONT.

In order to evaluate a vehicle concept with the simulation tool ONT the name of the components must be stored in an Excel file (1) in a predefined hierarchical structure. The information in the Excel file is imported and can be seen in extracts in Figure 3.

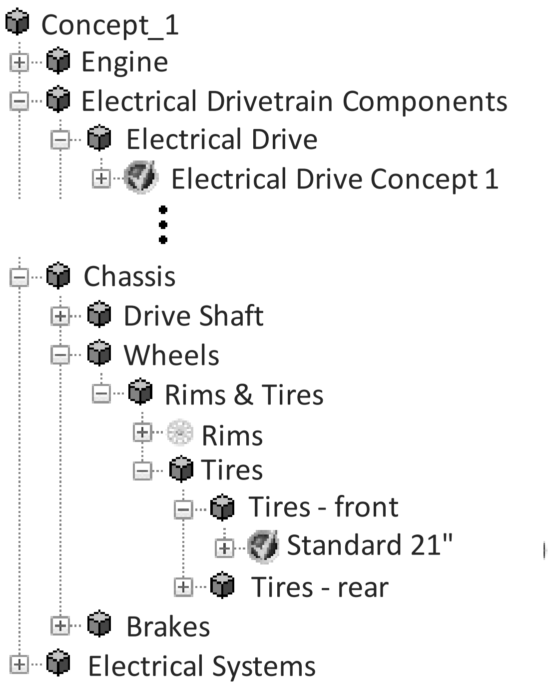

Figure 3. Extract from the tree view of the vehicle configuration in ONT.

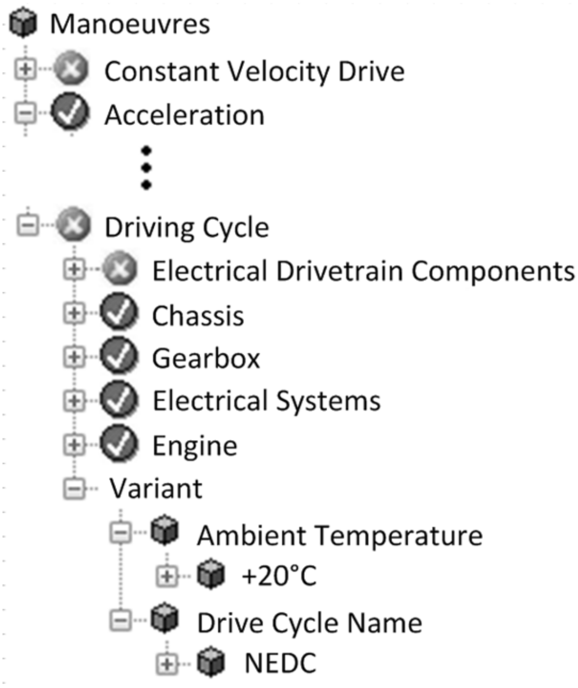

Figure 4. Example of a manveuer tree view with its requirements and variants

Once a component is marked with a cross the manoeuvre cannot be simulated. The requirements on the manoeuvres are described in more detail in section 2.6.

In this example only one manoeuvre can be simulated due to the available vehicle data and manoeuvre request. The two manoeuvres, driving cycle and constant travel, cannot be selected because the requirements to the electric drive components are not met. For example this can be the case if the efficiency of the electrical motor is unknown. An assertion of consumption would be very inaccurate and would not meet the underlying requirements.

From the vehicle definition (2) and the list of manoeuvres (3) fully configured vehicle models are generated automatically with the help of a database in which all the models and parameters are stored (5).

Subsequently, the simulations can be carried out (6). A small status window provides an overview of the current status. The simulation model is hidden from the user in the background.

Not only the information about the components of the vehicle has to be defined, also the simulation-scenarios (in this paper called manoeuvres) have to be considered. Therefor a list (3) can be prepared consisting of pre-defined manoeuvres. It is possible to simulate e.g. different types of acceleration, drives with constant velocity, elasticity, driving cycles and circuits. Boundary conditions and requirements, like ambient temperature, SOC values and speed limits are given by the user.

In Figure 4 an extract of the tree view of the manoeuvre is shown. The manoeuvres have requirements on each component of the full vehicle model that are fully automated verified.

These requirements are shown in the same hierarchy as the vehicle structure in a tree view beneath every manoeuvre. If a requirement is met a check mark shows up. If it is not met the components and its higher-level category is flagged with a cross.

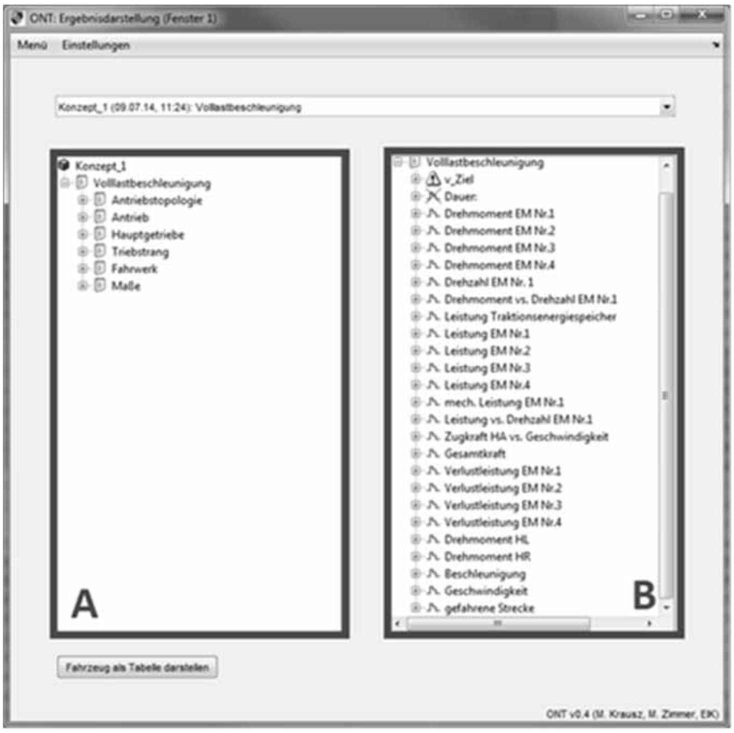

Figure 5. The results window in ONT.

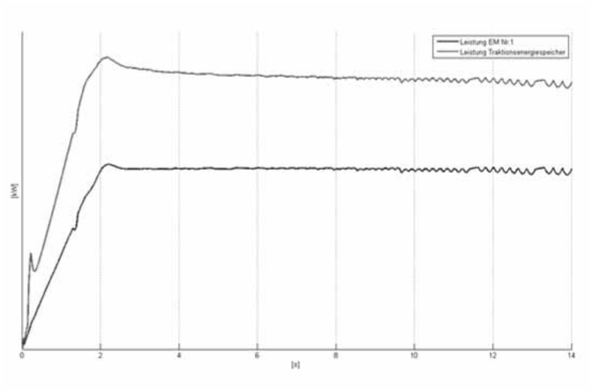

Figure 6. Example for a combined result diagram.

After the simulation, an automated evaluation of the simulation results is optionally performed (7). To view the simulation results, the presentation of results can be opened. In addition to the current former performed simulation results (8) can be viewed anytime. The content of the window, which is shown in Figure 5, is fully configurable.

Besides of the vehicle configuration (A) signals from list (B) can be selected and illustrated in different diagrams. An example of displaying multiple signals in one diagram is shown in Figure 6. The set of shown signals can be configured for each manoeuvre by the user. The signals can be combined in plots and be exported to Excel files for further use.

2 The Vehicle Structure

The mentioned Excel file (see section 2.1) is the underlying hierarchical structure in ONT and will be discussed in more detail in the following. This structure is used throughout the company to list the components integrated in the vehicle. In addition to a folder-based database, in which the models and parameter files are stored, the structure is found again in the signals of the simulation model.

The full vehicle model has a central signal bus which is divided into the same levels. This only serves to structure the variety of signals in a reasonable and continuous way and has no properties of a real communication bus. By reusing this system, models and sets of parameters can be easily found and stored in the file system. Furthermore parts of the full vehicle model and selected individual signals of partial models from the signal bus can be located easily.

Figure 7 is an example to see where the traction energy storage is arranged in the vehicle hierarchy.

2.1 The full vehicle model

The full vehicle model in ONT consists of a variety of components which are represented by different detailed models depending on the manoeuvres to be simulated. Simulations in ONT are always forward simulations. The model at the highest level is shown in Figure 8. All blocks have the full vehicle bus as input. The output of each block is a bus with the aggregated signals of its subcomponents. In section 2.4 the exact buildup of the models is discussed in more detail.

The powertrain of the full vehicle model consists of one or more engines/electric motors, clutch, transmission, power divider, differentials, drive shafts, brakes, wheels and tires. In addition to the physical mapping of components controls and regulations of the systems are also modeled, if necessary. In case of an electrified powertrain the high-voltage aspects are represented by electric drives, power electronics, a traction battery and a charging unit. Through this a very good reproduction of the longitudinal dynamics can be achieved for combustion-engined as well as electrified vehicles.

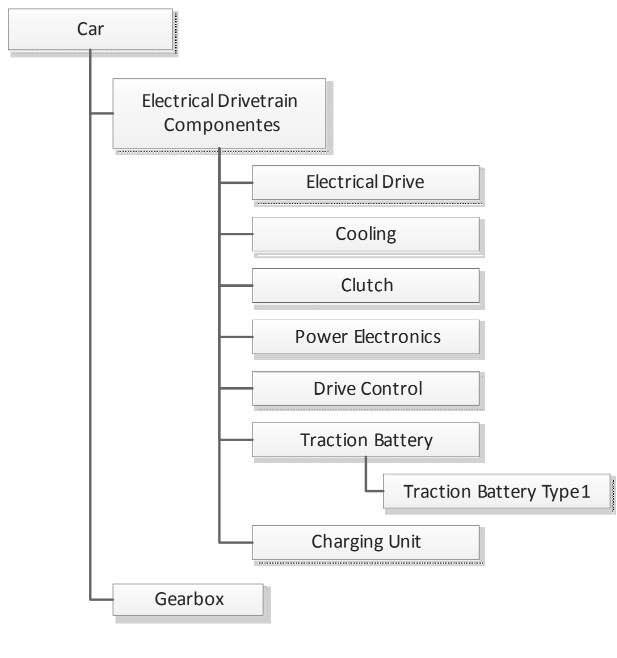

Figure 7. Extract of the tree view of the vehicle hierarchy.

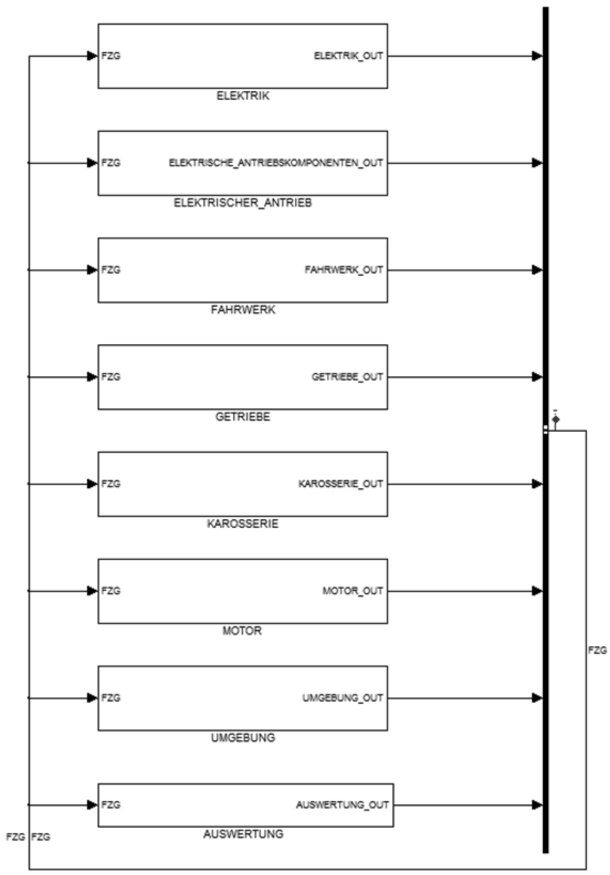

Figure 8. The full vehicle simulation model in Simulink.

2.2 The Models oft the Car Components

Every component used in the full vehicle simulation is filed in the same way. A component can be modelled in different ways and therefore be represented by different models. Simple models are used, if there is only little information about the system available. Over time the amount of information is increasing and therefore more complex models can be used. These more complex models need more data to be parameterized.

The level of detail for every variant of the model needs to be defined in five categories. These categories are: mechanics, electrics, thermodynamics, chemistry, and logic. The range reaches from 0 (not modelled) to 10 (reality). In Table 1 an example is shown. It is the excerpt for the definition of the level of detail for the component traction battery.

LoD	Electrics	Thermodynamics
0	Not modelled	Not modelled
1	Simple Resistore	0-dim. System
2	Simple Energy Storage	0-dim. Cell
3	Temp. Dep. Resistor	1-dim System
…		
10 H	iL-Battery	HiL-Battery

Table 1. Example for the definition of the level of detail for the model *traction battery*

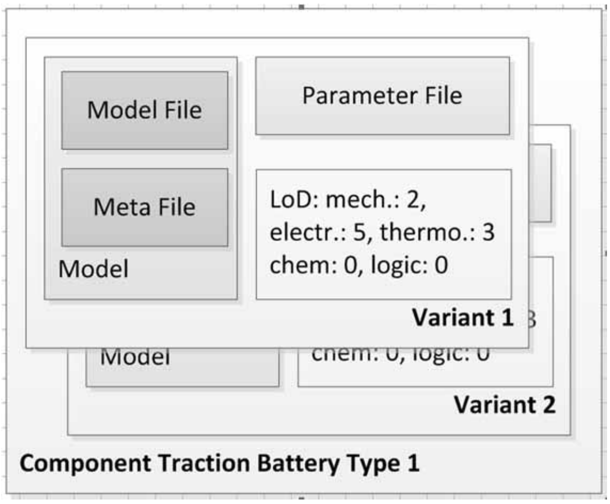

Figure 9. The component *traction battery type 1* with its different parts.

A model variant consists of different parts: The parameter set, the model file itself, and a metafile with additional information about the model. In this metafile in- and output signals, parameters of the model and other information as author of the model, date of creation, restrictions of the model etc. are definied.

In Figure 9 the different parts of the component traction battery type 1 are shown. One extract for the developed domain ontology is shown in Listing 1, which is defined in XML-format.

```
<name>…</name> (model name)
… (additional informations)
<inputs> (list of all input signals)
      <element>
      </element>
…
</inputs>
<outputs> (list of all output signals)
      <element>
      </element>
…
</outputs>
<parameters> (list of all model parameters)
</parameters>
```

Listing 1 Metafile structure for the simulation model of a component

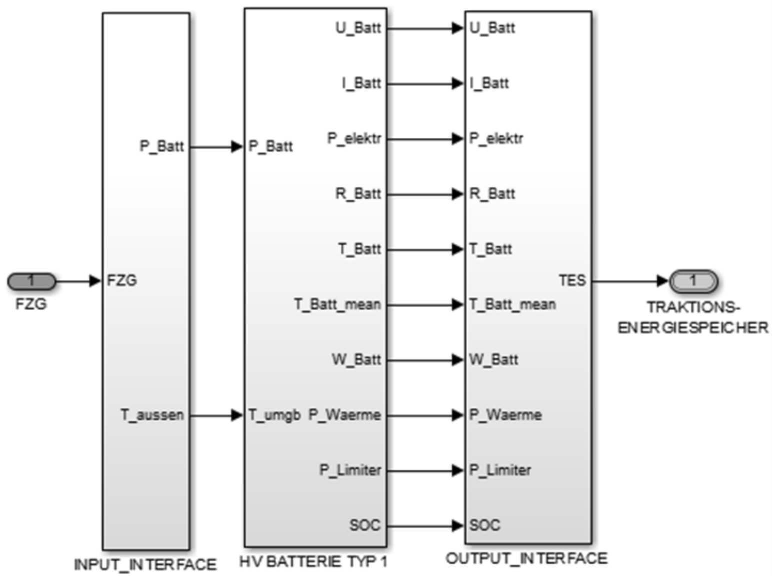

Figure 10. The model *traction battery type 1* with its input and output interfaces.

The simulation model of each component possesses always an input and an output interface. As an example the model of the traction battery type 1 is shown in Figure 10.

The *Input Interface* selects from the full vehicle signal bus all signals, which are definied in the metafile. In this signal bus all signals from every car component model are available. The model output signals are collected in the *Output Interface* block and aggregated in a component-specific signal bus.

With the input and the ouput interfaces models from other departments or suppliers can be integrated easily. To integrate new models only the interfaces need to be adapted and the main model can be remain in its original state.

2.3 The integration of a new component into ONT

A procedure is defined to integrate new compontents or variants of new models into the simultation environment ONT, which is shown in Figure 11.

This process uses different methods of verification and validation [8] that are not focus of this paper and therefore not further explained.

To start the process the new component needs to be defined as shown in section 2.2 with a model file, parameter file, and metafile. In the first step the interfaces of the model are compared with the definitions in the metafile. Beside the correct dimensions and naming the existence of required input signals in the full vehicle signal bus is checked.

Also the parameters of the model are compared to the definitions in the metafile and the additional information of the metafile like solver settings is reviewed. After the formal test procedures the model is installed into a virtual model test bed for the next steps.

This test bed is providing all necessery input signals to run the test and is observing the model behaviour by logging all outputs of the model.

The first step on the test bed is a short test of executability. Afterwards predefined verification tests are run. These verification tests are specifically defined for each component and can consist of simple input-output test and more complex combinded test scenarios. An example for a simple scenario for the traction battery model is to discharge and charge the battery. Another example is to check the model behaviour while the attempt to discharge the battery below 0% SoC (State of Charge).

After all tests are executed the results are saved in a test protocol and added to the component model. The component model is filed to a component library if all tests were passed successfully. Now the component can be used in ONT.

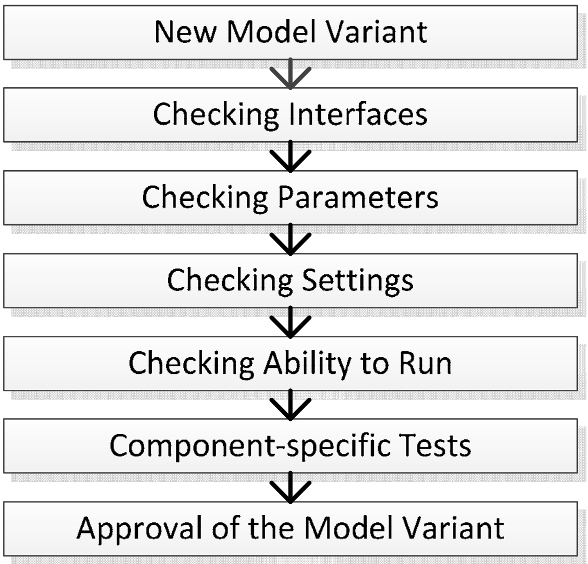

Figure 11. Procedure for the integration of new components in ONT

3 Manoeuvres and their Requirements on the Model

The manoeuvres for the simulation with the full vehicle model are predefined. They can be divided into two main groups:

1. Manoeuvres with time- or distance-based velocity and height profile
2. Event-triggered manoeuvres

The first group of manoeuvres provides a route profile that is traced by a digital driver. As soon as the profile reaches its end the simulation is finished. Examples for this type of manoeuvres are driving cycles, longitudinal driving on a race track, hill climbing, simple accelerations and decelerations.

The second group of manoeuvres depend on events. There is no static profile given, the requested velocity is dynamic.

Examples for this type of manoeuvres are driving until the traction battery is empty, repeated acceleration to a given speed and instant deceleration after reaching it.

The manoeuvres are filed in a database and can be combined with a graphical user interface to a list. Most of the manoeuvres are equipped with some tunable paramters like ambient temperature or starting/finishing speed. Besides the parameters, all manoeuvres have requirements on the level of detail of every component model.

In Section 2.2 the concept of the level of detail for models was introduced. It is used for the preparation of the simulation model. The full vehicle simulation model with all its component models is defined with the information about the manoeuvre and the components of the car concept. To make this possible the concept of manoeuvre requirements are developed. Every manoeuvre defines requirements for each model component of the full vehicle model. These requirements are formulated in level of details in five different categories.

The requirements on the level of detail are mimal requirements that need to be met by each used component model. If none of the available model variants of one single component can fullfill a requirement the manoeuvre cannot be simulated for this vehicle. The idea is to allow simulations only if enough information are available to get trustworthy results.

For each manoeuver a list is definied and saved as a XML-file. This list contains the requirements for every single component specified with the level of detail in five categories. An example for such a manoeuvre requirement list is shown in Figure 12. In this manoeuvre the car drives at constant longitudinal velocity. The aim of the simulation is to calculate the energy consumption. At this manoeuvre the behaviour of the traction battery is important, as this is the energy storage in the car.

On the other side the charging unit of the high voltage system has no influence on the result of the simulation besides its weight and physical size. Therefore the model of the charging unit is not required for this manoeuvre. All required levels of detail are set to zero. With this list of requirements for each model component on the one side and the car configurations on the other side the specific full vehicle model can be defined for each manoeuvre. In this way the most suitable models are used for every simulation.

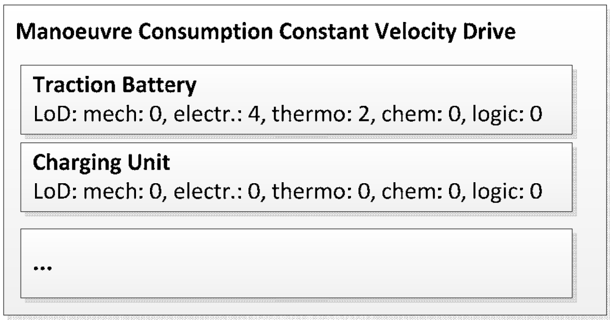

Figure 12. Examplary manuever requirements from the manuever „consumption constant velocity drive"

4 Conclusion and Future Work

The simulation environment ONT is used in the early phase of concept development. A large number of concept variants can be evaluated with it rapidly. This supports the project leaders to make fast and correct decisions. ONT could be used as a simulation platform in all parts of the R&D department, where simulations in many fields e.g. vehicle dynamics are needed.

The structure of ONT follows a standardized and widespread hierarchical system. It is highly configurable and automated. The full vehicle simulation model offers a model architecture, where component models can be included easily. A multidisciplinary project is run in the company to evaluate the benefit of ONT in the R&D department. The results of the evaluation will be shown in future publications.

References

[1] M. Zimmer. *Entwicklung eines durchgängigen Simulationsprozesses zur Effizienzsteigerung und Reifegraderhöhung von Konzeptbewertungen in der Frühen Phase der Produktentstehung*, Dissertation Universität Stuttgart, in publication, 2014

[2] M. Schmieder, S. Thomas. *Plattformstrategien und Modularisierung in der Automobilentwicklung*, Shaker, Aachen, 2005

[3] S. Bewersdorff, J. Pfau. *Beherrschung der Variantenvielfalt durch prozesssichere Simulation*, ATZ Oktober 2011, Volume 113, Issue 10, Springer, Wiesbaden, 774-779

[4] M. Zimmer, M. Krausz, H.-C. Reuss. *OverNightTesting – Ein Simulationsprozess zur Konzeptbewertung in der Frühen Phase*, 7. Grazer Symposium Virtuelles Fahrzeug, 2014

[5] B. Verworn. *Management der frühen Innovationsphasen*, Springer, Heidelberg, 2007

[6] R. Busse, et. al. *Was bedeutet eigentlich Ontologie?*, Informatik Spektrum 37/4 2014, Springer, Heidelberg, 2014

[7] U. Seiffert. *Virtuelle Produktentstehung für Fahrzeug und Antrieb im Kfz*, Vieweg + Teubner, Wiesbaden, 2008

[8] R. G. Sargent. *Verification and Validation of Simulation Models*, Proceedings of the 2003 Winter Simulation Conference, Volume 1, IEEE, Warrendale, 2003