Control unit simulation of EOBD functions as essential element of a testing and approval process

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Abstract

When a motor vehicle is tested, a reliable and verifiable result is essential both for the test institution concerned and for the customer. One element of the statutory general inspection is the emissions test. On vehicles that were first registered in 2006 or later, this is conducted, subject to restrictions, purely electronically by means of the OBD (On Board Diagnostic) interface. The testing organizations attach supreme importance to the operating safety, reliability and function of the tools used for this test by the different manufacturers. To this end, an automated test environment has been developed that provides the hardware and software needed to monitor a formal testing and approval process. Apart from the specific user software, database support and other tools, an essential software component is an editable control unit simulation that is compliant with relevant standards.

Two separate modules are presented for this purpose. Firstly, the partial control unit simulation of actual vehicles. These are based on an analysis of statistics, such as the distribution of bus systems, protocol coverage, etc., and from specifications contained in standards and guidelines. The second module represents a visualized and fully editable control unit simulation. Beside the obligatory basic functions such as the coverage of diagnostic modes $01-09, the user is also able to make use of specific functions for testing and examining. The key words here include oxygen sensor test, request and response timing, readiness code (RDC) functions, etc. These functions implement the communications elements specified in the relevant standards and they also offer the possibility of specifically checking and testing according to the user concerned.

1 Introduction

Greater complexity, starting with increased networking, means that the automotive industry and its suppliers are having to deal with new challenges. The associated functions have also continually increased in recent years with respect to diagnostic questions. The issue of communications between the vehicle and the tester is becoming ever more important, especially with respect to the European On Board Diagnostic (EOBD) requirements. In accordance with the stipulations of OBDII legislation, OBD data have been employed on vehicles with spark-ignition engine since production year 2001, and on vehicles with diesel engine since 2004. For vehicles which were first registered in or after 2006, the emissions test (which forms part of the statutory general inspection) is performed purely electronically if parameters such as the so-called readiness codes (RDC) and the fault memory entries satisfy certain specifications. The on-board data for the emissions test are read off by the tester with service modes $01 and $03, as defined in the "International Standard Organization" (ISO) standard ISO 15031-5 [01]. Mode $09 is used to record additional vehicle data such as the vehicle identification number (VIN).

Because these results are obtained using testing equipment from different manufacturers, the result is of supreme priority for the organization performing the test. The acceptance and testing of these tools before their widespread usage require a process of structured examination and subsequent approval. Here, the objective is to illustrate the options and to formulate and shape the process transparently from the very beginning. The basis for this is the availability of an intelligent test environment [02]. The approval test covers, amongst others, scenarios such as programming the system with faults and processes. It has been shown that the extensive specifications contained in standards, especially in ISO 15031, grant degrees of freedom in implementation for the manufacturers of "OBD tools". Here, it must be ensured that the tool works with different vehicles in the field and also with niche models. It must be possible to explicitly test and visualize variants and specific characteristics. Further EU specifications with respect to EOBD and the requirements of the "Environment Protection Agency" (EPA) [03] and of the "California Air Resources Board" (CARB) [04] with respect to the statutory general inspection and OBD functions also have to be covered. Moreover, the stipulations contained in ISO 15031 and of the Guidelines for Statutory General Inspection Equipment [05] issued by the German Federal Ministry for Transport, Construction and Urban Development (BMVBS) also have to be taken into account. The permissible bus systems and protocols are taken from ISO 15031, Part 4. Figure 1.1 illustrates these hierarchically.

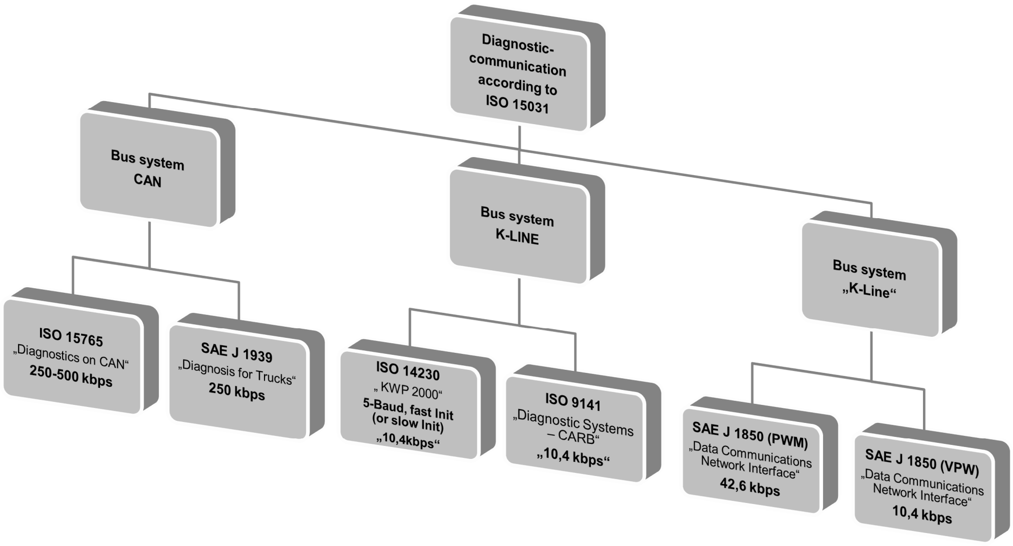

Fig. 1.1: Bus systems and protocols according to ISO 15031 [01]

Essentially, two steps are necessary for systematic testing and for deriving from this a process for approving equipment for the statutory general inspection, for example pursuant to the Guidelines for Statutory General Inspection Equipment in conjunction with the EOBD requirements:

- Testing with selected static simulations of vehicle control unit functions
- Testing with fully editable control unit (ECU) network simulators

2. Test environment

The basis for each simulation and for each test is the connection to the medium being tested (for this application, this is either the vehicle or an external tester). Here, a fully automated test environment is available, the so-called Universal Interface Tester (univ. IT / univ. SST) [02]. This allows diagnostic questions to be answered using hardware and software. To this end, a database-supported relay matrix is employed, housing more than 150 relays and various circuits, power supply components, a µC evaluation board and a multi-channel diagnosis interface. The modular, expandable structure of the basic software and of the analysis and test modules is the basis for universal usage. All relevant and possible scenarios can thus be implemented and covered. Application examples are the systematic analysis and troubleshooting between a vehicle and a tester, and freely configurable and reproducible tests, including a conformance test or control unit network simulation. Figure 2.1 shows the univ. IT with the related laptop for the implemented applications.

Fig. 2.1: Test environment with main user interface (univ. IT / univ. SST)

Four operating modes form the basis for analysis and for the applications based on this. These are structured as follows:

- Scenario I: Analysis
  Analysis is necessary both when troubleshooting and when testing. Special modules are of relevance here, for example an implemented oscilloscope or analysis tools for bus data, data consistency and timing. If the analysis is used as the basis for subsequent testing, tools such as a CAN (Controller Area Network) analysis database are available which make it possible to evaluate a communications section (trace), to filter it, prepare it and thus to decipher and visualize the related useful content.

- Scenario II: Stimulation
  Stimulation is very close to testing. Here, messages / data are actively fed into a relevant bus system, or even several bus systems. In the case of a tester, appropriate messages are sent (requests) and the responses are evaluated. This also implements functions such as active output testing. In conjunction with testing and approval applications, analysis modules are also employed which perform defined tests and evaluations of the behavior and of the sample.

- Scenario III: Simulation
  During simulation of control units or of a network of control units, requests from testers are responded to appropriately. During implementation, a whole series of fringe conditions has to be taken into account, depending on the requirements and the area of application of the simulation. For manufacturer-specific applications, these are, for example, specifications contained in transport protocols such as counters or timing parameters. For OBD functions, these include specifications

contained in standards and guidelines. In conjunction with the analysis, this operating scenario is the main part of this paper.

- Scenario IV: Manipulation (simulation and stimulation)
  Acting as a manipulator, operation is a link between stimulation and simulation. This application can lead to solutions for several different questions. Besides examinations of error tolerance in communications, the deliberate impingement, e.g. of behavior that is not compliant with standards, is cited as an example. It must be noted that various complex gateway functions between the vehicle and the external tool are necessary to do this and that accordingly, an automated physical separation of the bus system with connected relays is essential.

Figure 2.2 graphically illustrates the respective modes according to application, with the related modules and applications.

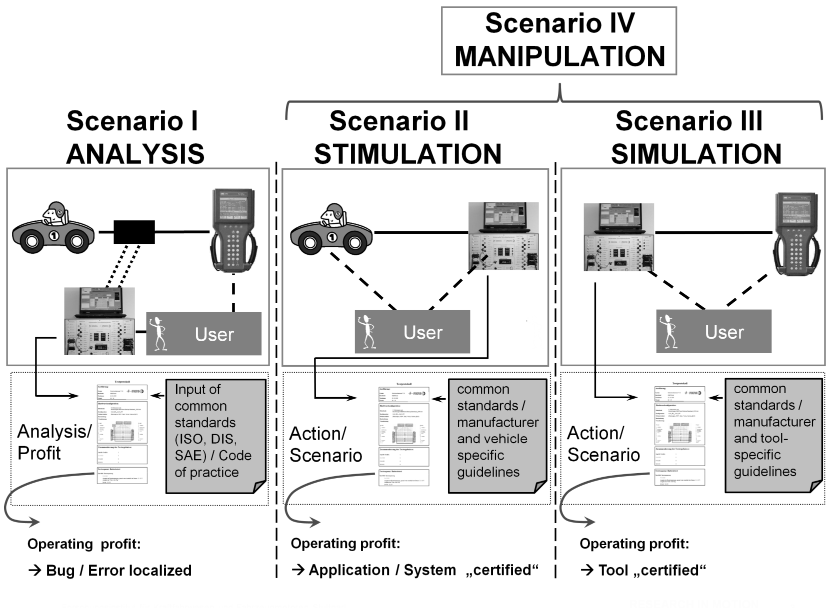

Fig. 2.2: Application scenarios with the univ. SST

3 Simulation application

Every tester accesses the vehicle and its bus system via the diagnosis interface, which is standardized in accordance with ISO 15031. To be mentioned here are new concepts such as remote diagnosis [06] or TeleService [07]. These make it possible to access the vehicle using a mobile phone connection (UMTS), although these vehicle still need the diagnosis interface in the vehicle in order to comply with current legislation. Here, the vehicle is connected to the tester either directly or via a communications module that is similar to an interface and which establishes the connection, e.g. using Bluetooth or a radio connection.

A strict difference is made according to the background against which the analysis or test is performed. In the event of errors or of a breakdown in communications between the vehicle and the tester (possibly even while the connection is being established), the procedure and the motivation will be different from that employed for the acceptance or approval of a tester. Using a heuristic approach (trial & error) based on random tests with different vehicles, the probability of achieving a qualitatively reliable statement with respect to function and the required range of functions, is rather small. It would thus be dubious to justify a function guarantee on this basis.

A requirements list therefore has to be defined for the individual test steps and content. Besides the pure communication and the exchange of data, other influencing factors such as, for example, the tester excitation process during the build-up of communications via the K/L line, the respective potential level during communication or the timing parameter also have to be observed and checked. A transparent, verifiable and reproducible result is another requirement for processing in conjunction with the simulation application and test environment.

Given an abstract consideration, there are several different possible solutions. If factors such as the ratio of cost to complexity and benefit are fed into a neutral evaluation matrix, it can be seen that two main modules have to be specifically implemented. These are based on the available test environment. Besides depictions of real vehicle ECUs, which are selected on the basis of a statistical evaluation, a fully editable simulation application is available which makes all variants and variations possible on the basis of the standard. The necessary individual steps are explained in more detail in the respective subsections. Here, the focus is on the application with its structure and possibilities, not on the practical testing process or how to perform it.

3.1 Structure of user interface

The structure is integrated into the modular structure of the available test environment. Available features are used such as the editable database. Every test focuses on reproducibility based on specified processes. The user chooses the test scenario and monitors the processes in conjunction with the outputs from the tester. Approvals cannot be automated because every reading on the tester has to be read off either on the display or on a laptop. Here, the guided interaction between the user, the vehicle and the tester are essential. At the same time, this also creates a further test category, the so-called user guidance for each tester.

3.2 Non-editable simulators

The non-editable (static) simulators concept focuses on being able to reproducibly formulate an approach with a statistically verified number and coverage, a reflection of real vehicles that are actually on the market. The underlying selection is derived from the 2010 registration statistics of the German Federal Motor Transport Authority (KBA) [08] in conjunction with the stipulations contained in standards and other regulatory provisions. In addition, evaluations based on the vehicles presented to the DEKRA Automobil GmbH organization for the statutory general inspection with emissions test are also included. Here, the statistics are evaluated according to various criteria. Figure 3.1 illustrates examples of registration statistics based on the respective manufacturer. Besides the absolute number of registrations, the percentage of the total number for each manufacturer is also shown. Further splits can be defined at will by grouping (SUV, compact class, middle class, …). The essential market share of the major carmakers such as Volkswagen, Mercedes Benz, Opel, BMW and Audi is striking in the evaluation illustrated.

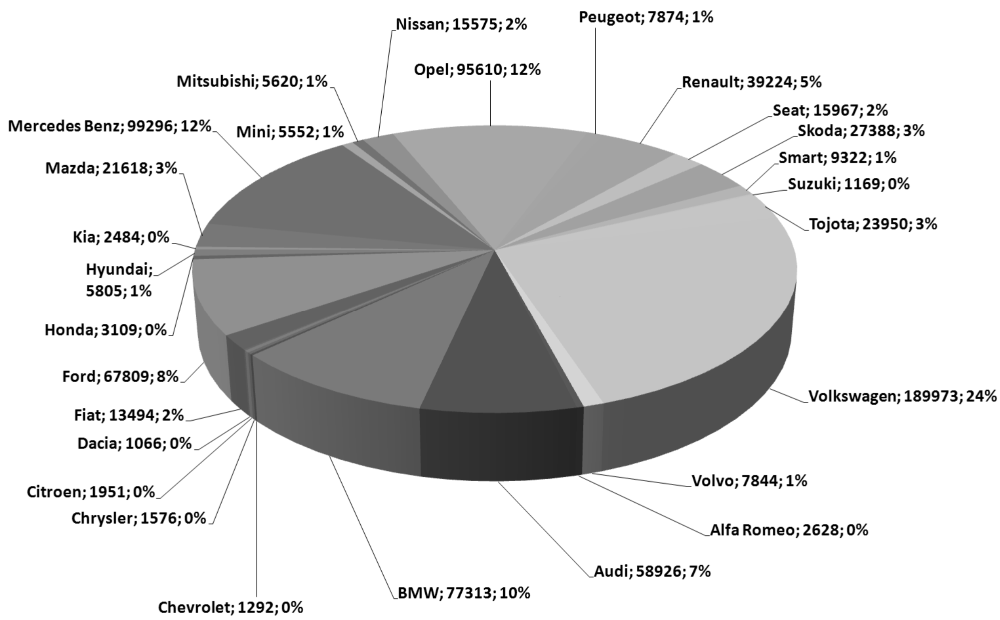

Fig. 3.1: Evaluation of registration statistics according to manufacturer

In particular for the selection of vehicles, which are implemented as a representative proportion in the form of ECU simulations, statements are needed about the distribution of the bus systems and their transport protocols. The KBA is unable to supply data about these questions. Similarly, no information about this is available from the manufacturers so each assignment has to be analyzed, either with the protocol analysis module on the vehicle (univ. IT) or with an OBD tool. In conjunction with the KBA data, this information makes it possible to identify the permissible bus systems (see Fig. 3.2, left) and their related protocols. Using the K/L line as an example, the split is illustrated in the right-hand diagram. It should be noted that the data are generated on the basis of the available vehicles. In other words, vehicles that are listed in the KBA but which were not available are neutrally evaluated with "unknown".

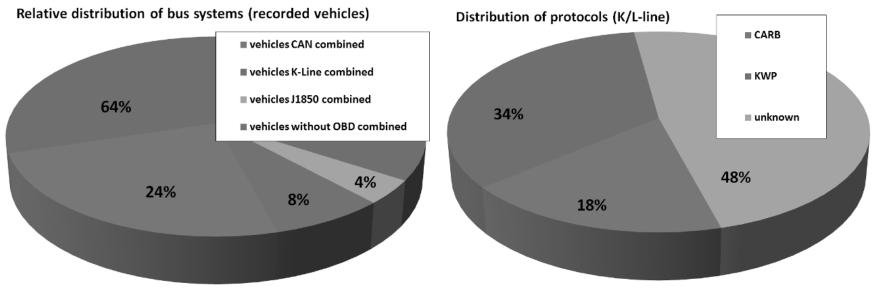

Fig. 3.2: Statistical evaluation based on data from KBA & DEKRA

Another fringe condition arises from the fact that the bus system and protocol may be changed by manufacturers on a single model, even during the life cycle of a model. As a rule, a change is made from K line to CAN, but protocol changes, e.g. from CARB transport protocol [09] to KWP2000 [10] (Keyword Protocol) are not uncommon. The influencing factor for the selected bus system is fed into the following formula in conjunction with a weighting table:

$$Numb. = CAN\left(\sum_{i=SPC}^{EPC} \frac{n.o.C}{Years} \times (Factor)\right) + K\_Line\left(\sum_{i=SPC}^{EPC} \frac{n.o.K}{Years} \times (1 - Factor)\right)$$

Numb.	Number of vehicle
n. o. C	Number of vehicles with bus system CAN
n. o. K	Number of vehicles with bus system K-line
CAN	bus system
K_Line	K-line bus system
SPC	Start of production cycle
EPC	End of production cycle
Years	Period considered in years ('EPC' minus 'SPC')
Factor	Weighting (0…1) based on probability in [%]

The weighting table provides a percentage probability for the corresponding bus system based on the year. These factors are reasoned by the analysis of various manufacturers who are active on the market. As a rule, only a CAN is fitted for diagnosis on vehicles manufactured in or after 2010. This is because this has now become mandatory for certification / approval for vehicle models that are exported to the USA. Numerous random checks on vehicles in the field have confirmed this assumption. The factors are illustrated in Table 3.1.

Table 3.1: Weighting of distribution of bus systems according to date of first registration

Year of first registration	K line	CAN
before 2003	100%	0%

2003	95%	5%
2004	90%	10%
2005	75%	25%
2006	50%	50%
2007	40%	60%
2008	30%	70%
2009	20%	80%
2010	10%	90%
after 2010	0%	100%

On the basis of the evaluated data available, a selection of vehicles can be defined that covers every variant approved to the standard. An adequately high coverage of the so-called volume models is thus assured. The additional series of niche models created as ECU simulation, covers special cases such as configurations with transmission control unit and/or with several engine control units, or even with specific oxygen sensor arrangements.

For these models, each diagnosis communication trace was recorded on the basis of existing modules and elements of the univ. IT, with a defined schematic between the vehicle and one or more certified OBD general inspection testers. This generates a trace which can be used to create a semi-automated simulation in conjunction with Excel VBA applications and a basic function of the diagnosis software [11] used, as illustrated in Figure 3.3.

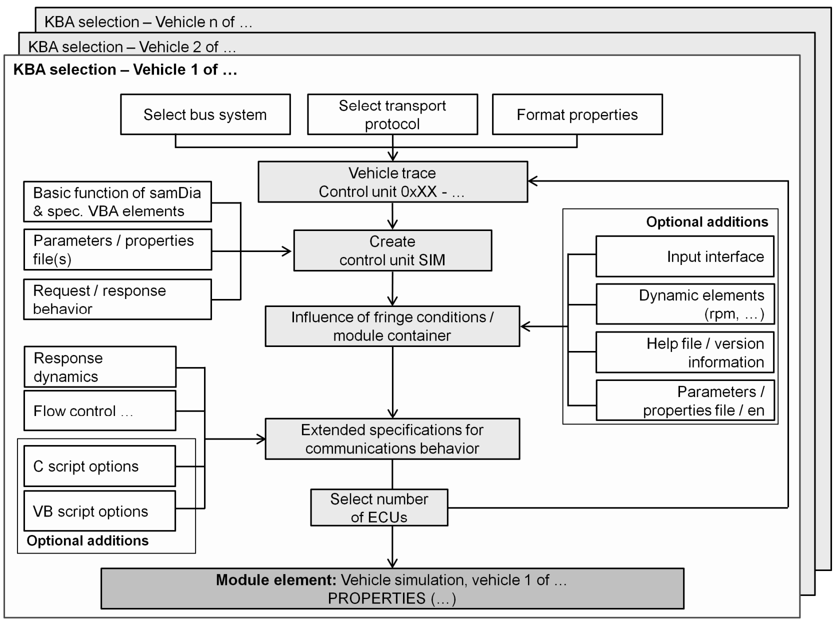

Fig. 3.3: Process for simulating a selection of real vehicles

The draft schematic specifies the centrally illustrated process, if necessary with a loop for several control units. In turn, the element "Create control unit SIM" contains further sub-processes, for example the formation of message pairs (response to request). The illustrated optional additions are also elements whose complexity and extent are illustrated in a simplified form as these are not central and pivotal elements.

3.3 Editable simulators

The second element of the simulation functions are the fully editable simulations of control unit functions that are relevant to OBD. These satisfy the requirement of illustrating all possible scenarios, both permissible and impermissible ones. The structure and the user interface are structured in to systems and subsystems, similar to a Simulink model. The Graphic User Interface (GUI) is structured into four domains in the main application. The top left section is where the bus system and the transport protocol are selected. To the right of this are the controls and the connection to the assistance feature. The bottom part is split into the main functions and the special functions. The main functions cover diagnosis modes $01-09. The special functions are based on the communications elements specified in the relevant standards and they also make specific checks and tests possible according to the user concerned. Besides the full coverage of the basic functions, the specific application scenario makes it possible to test processes relevant for specific manufacturers. Moreover, there is also the option of subjecting processes relevant to the statutory general inspection to optimized tests. Figure 3.4 provides an overview of the user interface with the associated menus.

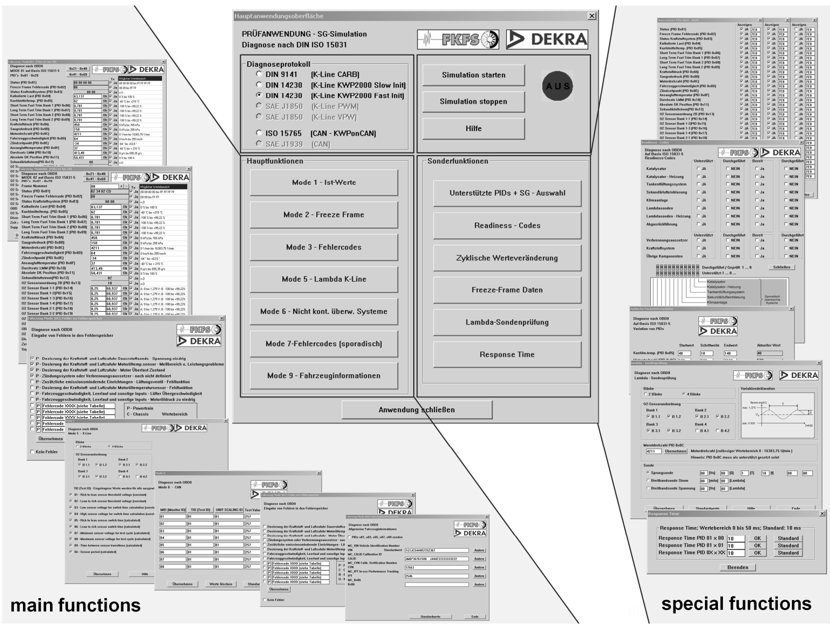

Fig. 3.4: User interface – editable EOBD simulation functions

The elements used consist of a Visual Basic programming for the GUI, a C script for controlling the so-called block sequencer and various specifications, communication parameters and messages. Implementation is based on the diagnosis software samDia with the HSX interface from the company samtec [11]. Integration in the existing test environment is illustrated in a simplified form in Figure 3.5, like the interaction of the simulation application with the test environment and the user. Here, the modular structure, the extensibility for future applications and the links between the simulation elements are taken into account for the systematics of implementation.

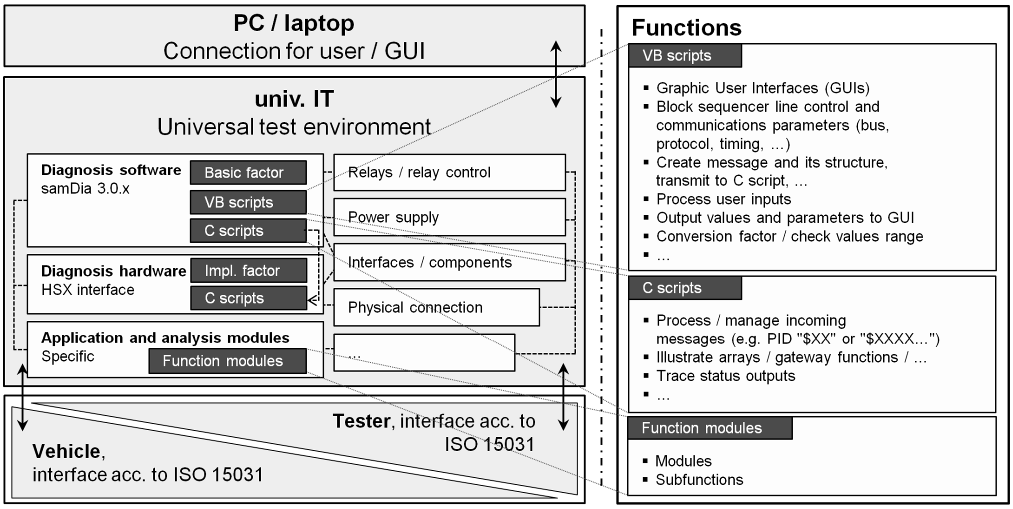

Fig. 3.5: Structure and integration – univ. IT

A modular structure of the simulation application is not possible without links between the individual elements, similar to diagnosis mode. One example here is the diagnosis service PID $01 from mode $01. The four data bytes in the message contain three items of information: the status of the malfunction indicator lamp (MIL), the status of the diagnostic trouble code (DTC) entered in mode $03 and the readiness status (RDC). Figure 3.6 shows the definitions specified according to the standard. In addition, CAN messages must be dynamically generated and varied according to the selection. Here, the arrangement and definition of the oxygen sensors installed in the vehicle act as an example. The installation status is generally needed to diagnostically test the bistable sensor signals. This is stored either in PID $13 or in PID $1D. According to the defined positions, the individual sensor values can be generated and periodically transmitted on this basis. Another example is the simulation of entries in the fault memory (mode $03, DTC). Here, the message length depends on the number of faults.

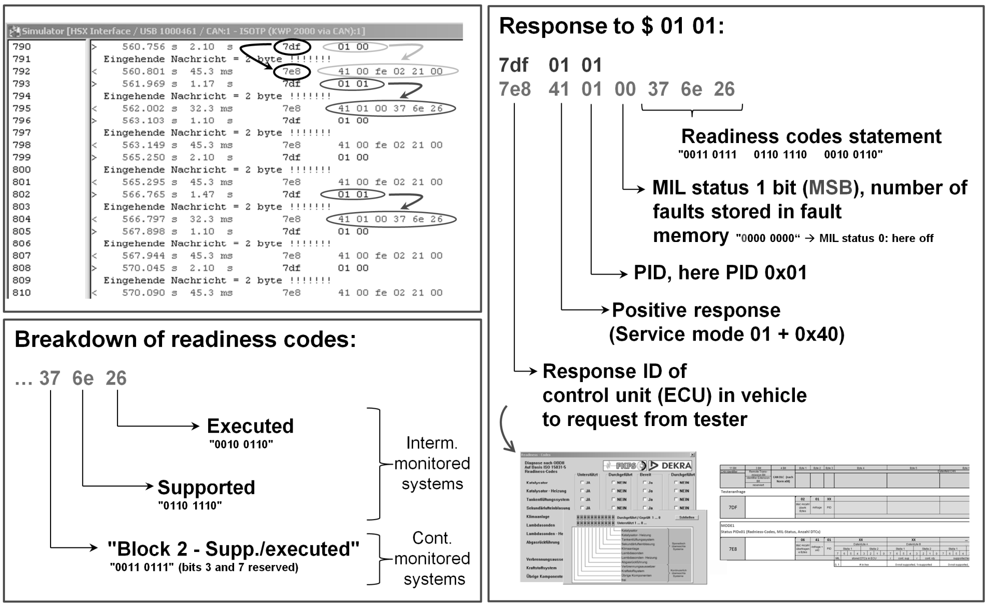

Fig. 3.6: Definition of MODE $01, PID $01 [01] / CAN ISO TP (ISO 15765 [12])

Protocol-specific properties are to be taken into account and implemented, providing the useful data to be transmitted exceeds the size of a message (e.g. also flow control).

4. Testing and approval process

The testing and approval process as such is the synthesis of defined processes with the specifications contained in the standards and other regulatory provisions, plus the interaction of the tools created (modules). There are presented in detail in the above subsections as static and editable simulators.

To start with, the objective is to ensure the correct wiring. This can have the added effect of restricting fault sources, should faults or communications problems occur at the start of a test. Assuming the test environment is correctly incorporated as an element of the testing and approval process, the essential part will follow. This is where the test is conducted with a series of individual examinations and tests. During the test and at the end, the aim is to record and document the results gained.

Figure 4.1 shows the selected subdivision in four steps. The modules of the univ. IT are available and are implemented in all four steps. To visualize the specific applications and test specifications on the basis of the process, the third step (specific applications according to process specifications) is illustrated as being divided into the two main processes. The respective lower levels for the first order are derived from the individual process steps.

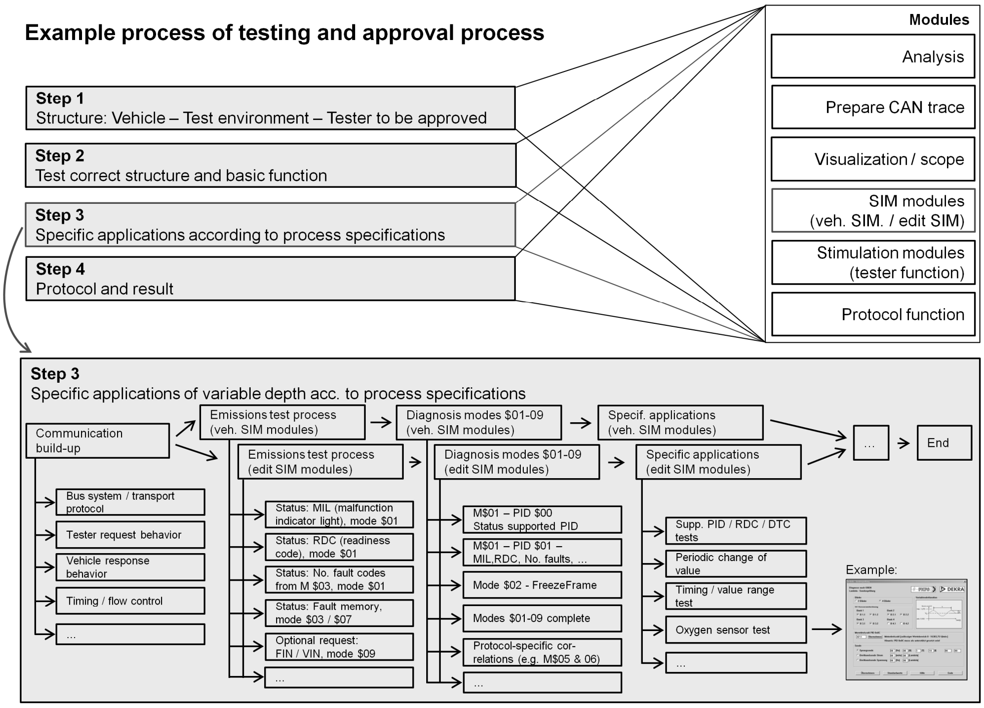

Fig. 4.1: Testing and approval process for EOBD / emissions test

During the test, every application can be subdivided into further substeps and elements. Here, in conjunction with the respective specification for the process, the complexity should be considered against the added value provided by the a greater depth of testing. This creates a direct connection between the compromise between test complexity (cost) and functional reliability (benefit). If the emissions test process is positively completed with the selection made, for instance with testing/acceptance equipment using non-editable simulations, a sufficiently high coverage can be assumed in conjunction with adequate conformity with the protocol.

5. Summary with conclusion and benefit

The increasing complexity of the overall systems in motor vehicles combined with ever more restrictive statutory stipulations demand fault-free and reliable testing equipment both for testing institutions and for workshops. Here, reproducibility and transparency during testing and during the acceptance of this equipment are extremely important and are fed directly into the result / evaluation.

The basis upon which these requirements are worked through is a process in conjunction with specified fringe conditions and stipulations. This new process requires both a physical connection and an interface to the user. Moreover, a database and various analysis and visualization tools for simulations are needed in the form of software and hardware.

It is possible to formulate and execute such test processes and applications on the basis of the available intelligent test environment and the related application modules. The specific simulations presented with corresponding fringe conditions make extensive, specific and individual testing possible, taking into account the requirements of the specific model. That is new. The modular structure means that any necessary extensions or modifications can be implemented at any time.

6. Outlook

The objective is now to apply the findings gained and the modules to other topics and questions relating to manufacturer-specific off-board diagnosis. This is against the background that from 2012, the electronic installation check for electronic systems that are of relevance to safety will specified by law as part of the statutory general inspection. It is still planned to gradually extend the use of the vehicle interface to conduct status and function tests. The check is to be prescribed as mandatory for the vehicle monitoring.

In order to satisfy these requirements in the future, systems such as brakes, airbag and restraint systems, lighting, suspension control systems and steering electronics will also be tested on the basis of the univ. IT, alongside the systems that are of relevance to emissions. These tests will also be conducted on the basis of a statistical consideration of the German vehicle population using data from the KBA and DEKRA, based on a selection of vehicles manufactured by various German and international carmakers. The focus here will be on the ability of the control units to perform self-diagnosis, i.e. to analyze functions, on detection mechanisms, on user information, on the meaningfulness of results and on the setting and resetting conditions.

The plausibility of the findings gained, for example about the available status information on vehicle-specific and general models, has to be verified. These findings represent the basis for subsequent tests and examinations. Measured values and their sources (calculated, modeled or measured), the physical background and thus the precision /resolution, or the correlation between the sensors and values are used and incorporated in this context.

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