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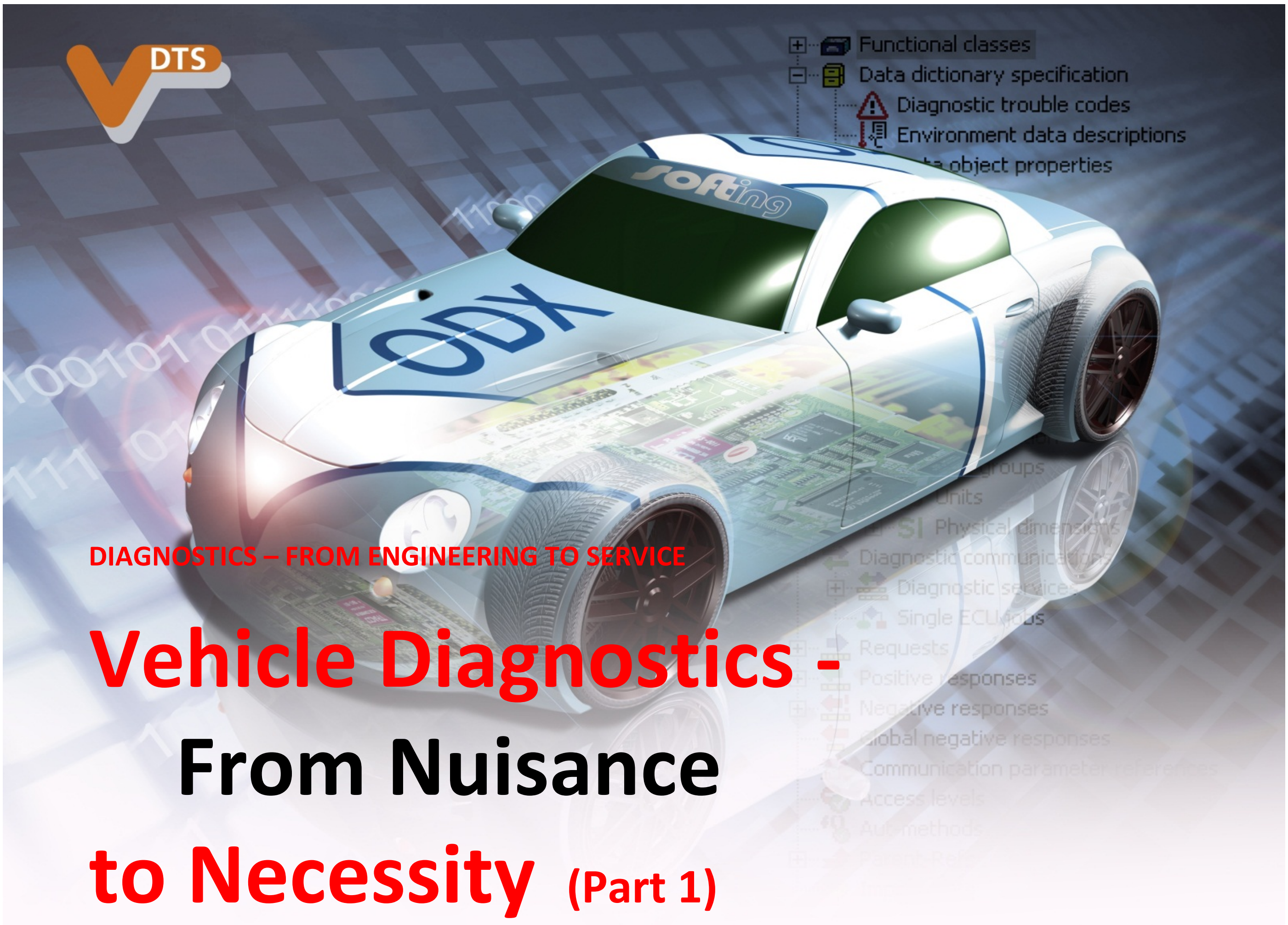

DIAGNOSTICS – FROM ENGINEERING TO SERVICE

Vehicle Diagnostics - From Nuisance to Necessity (Part 1)

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For some years now, the vehicle diagnostics is undergoing a process of rapid change. The number of electronic control units in cars has been increasing steadily after a brief consolidation phase and is fast approaching 100 ECUs in a vehicle. Paralleling this, the complexity and the functions of an ECU and the vehicle network is also increasing significantly. Diagnostics thus constitutes an individual class of requirements for the vehicle per se; these must be implemented parallel to the intrinsic functions.

We can already find four bus systems in a medium class car and two to three more in the luxury class: all of these must be networked among each other. For diagnostics, there are many consequences: A mere limitation of diagnostics to the legally required range regarding exhaust standards has not been sufficient for a long time. A vehicle repair in a garage is no longer possible without diagnostics. The same goes for vehicle production. Diagnostics must be integrated early in the engineering process and must accompany it throughout to be able to control the complexity at the manufacturers but also at the involved ECU's suppliers. For the interaction of all partners to function, standards are indispensable. They ensure that data and tools mesh at interfaces between ECU engineering, test facility, production and service organization and thus enable the concentration on intrinsic tasks. In the following, the underlying standards and the safeguarding of diagnostics in the engineering process will be comprehensively examined.

Today diagnostics plays a role throughout the entire value chain, from engineering through production to service. Decisive is that the diagnostic mechanisms - the communication of a tester with an ECU - are used today for a series of additional tasks (figure 1).

Engineering Area

In ECU engineering, diagnostics is used in the following steps. Basis is the diagnostic communication, with new ECUs usually the standard UDS (Unified Diagnostic Services). The classical diagnostics as a function in the ECU serves to identify unexpected behavior within the ECU and its environment, to benchmark and to record these in the fault memory. From there, the entries can be selected and processed through an external test system. In addition to the classical fault memory functionalities - including determining conditions for the fault entry (environmental conditions) and erasing the fault memory - the same basic functionality is also used today for related applications.

Examples are:

- Flash programming: interchange of code or data in the ECU
- Variant coding: adaptation of an ECU's behavior in accordance with legal regulations (for instance, daytime running light in Scandinavia) or commercial conditions ("Software as product")
- Starting routines: ECU functions are externally initiated and then executed autonomously, for instance, a self-test
- Measuring: readout of values determined by the ECU with the help of sensors

Diagnostics communication will thus always be used when a precise data and release process is necessary (flash programming, variant coding) or when it allows a simple and inexpensive access to the black-box ECU.

In the engineering area, diagnostics is used in numerous applications, whether they be in the development of communications, of ECU functions, of flash and variant coding functions or in HiL, system test stations or in the integration of ECUs. Subsequently, diagnostics is used diversely in vehicle tests.

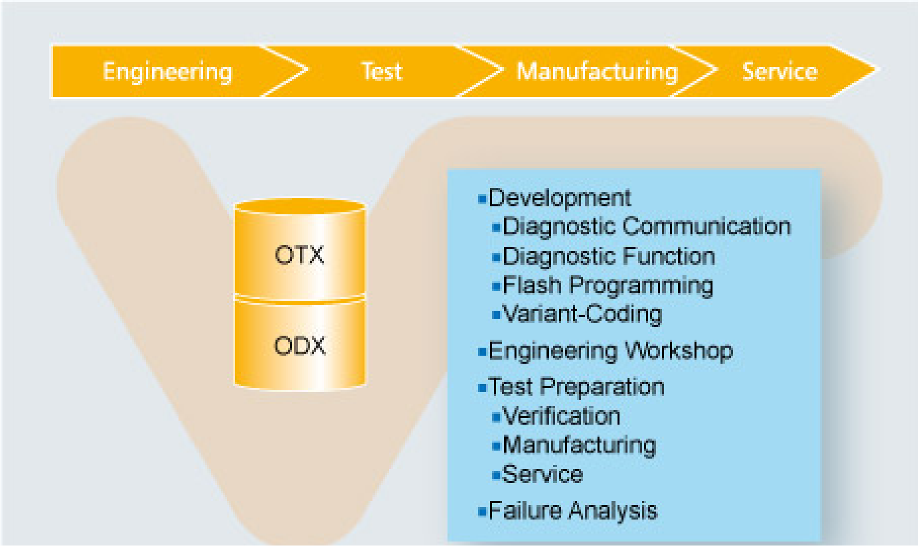

Figure 1: Application of diagnostics in the vehicle's lifecycle

Production

Precisely the simple access to the ECU allows a vast number of applications in production that would otherwise have been implemented only with more complex, cost-intensive solutions. The modern mechatronic systems can hardly undergo a test without access to the electronics. At the same time, they should be tested as early as possible. Also, a vehicle's variant coding, the key coding and initializing the vehicle immobilizer are carried out here. Ultimately, in the "end of line" test, a final control of vehicle functions and the deletion of the fault memory take place.

A special challenge in production is the differentiation between "real" and "systematic" faults. The latter arise from the fact that the ECUs keep numerous fault log entries that are produced because of the missing system environment at the time of installation. For example, faults are recorded when a signal is not available on the CAN bus because it should be sent from an ECU not yet constructed. The entry is, of course, correct. It does not refer, however, to a defective (sub)system.

After-Sales Service

The origins of diagnostics lie in after-sales service, more specifically in the rational insight that a vehicle currently based on 30 to 80 ECUs with which a vast number of vehicle functions are realized can no longer be repaired in a garage. In case the client reports unexpected symptoms, the garage technician must have the correct "wrench" at hand. The relevant tool is the service tester. It interconnects the reported symptoms with fault entries in the ECUs and measured values that can be determined parallel. Expert systems combined with the technician's expertise usually lead to a repair recommendation. Additionally, it is generally possible to program ECUs with new software version.

In all of the above-mentioned applications, ODX data are used. Except in test systems, they are also used for setting ECU parameters and for automatically generating test procedures. It is clear that the quality of the ODX data - alone but also in connection with the ECU - represents a decisive influencing variable for the quality at all. Apart from carrying out intensive reviews, this is achieved through complex data verification. The data verification is an important application of a modern engineering tester. Furthermore, it is used throughout the complete engineering process: as test environment for the important ECU functions of diagnostics communication, diagnostics function, flash programming, and variant coding. The engineering tester is also continually used as an inexpensive "debugger". In later phases, it plays a major role in vehicle inspections in testing centers, sometimes even in road tests of individual vehicle functions and in fault analysis, especially of communication problems. The engineering tester as a commissioning tool also plays a large role in test preparation. For the engineer, the combination of ODX data and ECU in conjunction with the D Server essentially constitutes a black box, which is difficult for him to put into operation. With the engineering tester, communication can be easily implemented and the correct behavior simulated.

On-Board Diagnostics (OBD)

On-Board Diagnostics is a special area of diagnostics since it is statutory. It requires of the vehicle manufacturer - originally only of passenger cars but now also of trucks - that all exhaust relevant systems continually undergo a self-test. Anything irregular must be immediately communicated to the driver through a warning light so that he/she can have it repaired. For California, this "optional" provision is in so far a minimization as the driver must pay high fines if he/she does not have the exhaust system repaired. This self-test is supported through the demand that the findings of the OBD can be read at any time with a simple diagnostics tester, the so-called scan tool. A functioning OBD as well as a functioning communication with the scan tools constitutes a market-access requirement for manufacturers. Correspondingly exact must the tests of these functionalities be. They are also not completed with the car registration: an accumulation of reports concerning vehicles already sold can quickly lead to recalls, which can be demanded by the executives.

Requirements for Diagnostics Systems

If a modern test system in the vehicle environment is examined, general blocks that always recur can be identified. Initially, it is decisive that usually engineering system and a runtime environment is present. The engineering system configures the runtime environment in which the test engineer configures the test run and the visualization for later usage. In many cases, test documentation has already been defined. The engineering system often works in an administrator mode. In the runtime environment, the tester's possibilities to intervene are frequently very restricted. The tester only has access to the application mode. The objective is for the tester to concentrate only on the test environment and that the tool works with few interactions.

The test systems have input data for the set-up and test implementation that parameterize the configurations and side conditions. Standardized input parameters are ODX data, required today, and increasingly OTX data (figure 2). Besides these, proprietary data are frequently used, for example logistical information such as release status and assembly instructions. These are very dependent upon processes, sometimes also upon infrastructure and cannot easily be standardized.

In addition, corresponding output data is produced. These can also be standardized or proprietary. In diagnostics today, contrary (as of now) to measurement technology, there is no standardized output format still. A typical output format is test documentation in which the successful and failed test cases are recorded. These can either be analyzed by specialists or played back into the system for later regression tests. Error statistics are also frequently produced with the test results.

Requirements for engineering testers

Especially for engineering testers, which are used throughout the complete process, a range of additional requirements must be stipulated. This is primarily due to the applications but also to the underlying processing layers. Particularly ODX data are processed through a so-called D Server. This puts the processed data at disposal. For the test system, though, it is hardly possible to determine what purpose the data have. That is, diagnostics services for communications controls mostly do not differ in practice at the interface from diagnostics services for measurements or for parameterizing an ECU. The diagnostics tester must support the user, though, through application-specific presentations that must be correspondingly configured. Only then will the presentation be connected with the appropriate diagnostics services.

Working with the fault memory poses perhaps the most important diagnostics function. It must be read but also cleared in order to be able to check the correct re-entry of a fault. Depending on the user, relevant are: the faults of the complete vehicle or of an ECU; the list of failures alone; and/or the failures with the saved environmental conditions and the status information. Precisely the status information is important for deeper analysis. It describes the errors more closely. As it is possible, for instance to ascertain whether a fault is permanently or only temporarily noted, whether it recurs sporadically or constantly. Further important information is the readiness flag. It shows whether the routine implemented to identify faults in the ECU has already run completely. For a whole series of faults, preconditions must be met, for example: the motor temperature must have reached its minimum value, given revolutions must have been exceeded, etc.

The demands on the visualization of flash programming are completely different. These are essentially limited to the selection of programming data (i.e. program code, family of characteristics etc.), a start button and ideally a progress indicator since appreciable programming time accrues with data of a number of megabytes. The actual challenge is in the sequence of the flash programming. Here an authentication is first implemented, switched to the programming session, the remaining bus participants told not to enter bus faults in the following and, finally, the bus communication between the ECUs ended in order to have enough bandwidth. Then the data transmission begins as high-performance as possible. At the conclusion, checksums are reviewed, the programmed ECU re-initialized and the bus communication re-activated. To finish, sometimes system adaptations must still be carried out.

By measurements, the main differentiations are between graphic representations of individual measurement values and textual representations. With graphic representations, the limitations are mainly set by usability; almost everything is possible from the kind of representation (pointer instrument, bar charts, plotter, …) through the colors used up to and including the display area (values range, scope with color change, …). Additionally, blocks of measurements frequently must be shown. These are selected from the ECU at once in order not to allow latencies in corresponding values to flow into the measuring via bus transmission.

When carrying out ECU routines, however, a very wide application spectrum is to be covered. One end is formed through ECU routines through which the feedback alone is given through actuators. Examples include the pointer test on the instrument cluster and the valves on the ECU for the anti-lock braking system (ABS), which opens and closes. For this kind of routine, the tester must actually only provide a start button and

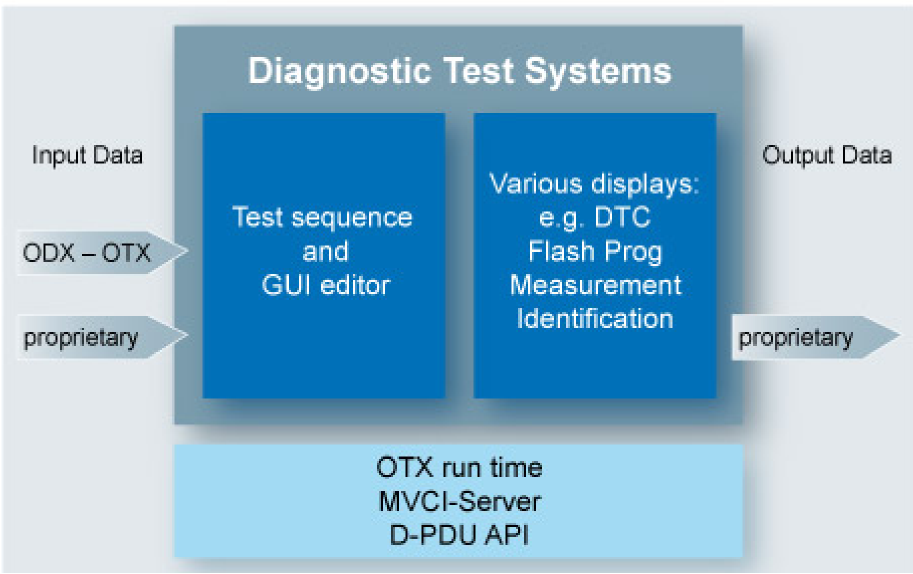

Figure 2: General demands on diagnostic test systems

perhaps a description field for the test. The opposite end is represented by self-tests that, as a result, return a list of results via the bus. Here the tester must present the relevant parts of the ECU reply on the monitor. Similar is the important representation of the vehicle or ECU identification, which is made up from a list of information such as the VIN (vehicle identification number), hardware and software versions etc.

The use case data verification requires a much broader presentation scope. The access to the parameterization of diagnostics services and to the results must be so thorough that all methods used in automatic tests can be manually checked by the engineering tester. In the engineering tester, all values must be adjustable, even those that are actually not allowed, so that correct behavior on the periphery can be verified. With the inspection, it is especially important that not only values can be analyzed but also the structure of the results. This is a source of error for the access through a test automation that may not be underestimated. All tests, incidentally, are not automatable, for the plausibility can be investigated but not the correct conversion of hexadecimal (bus) data into symbolic data. This is a task for specialists that have a massive influence on the over-all quality of the system.

Variant Coding

With the help of variant coding, functions in the ECU are turned on and off. This has immense cost advantages because not every variant of the ECU software must be singly verified. The function "variant coding" must therefore be tested even more exactly. This is connected with a great deal of effort because the individual code bits are not independent. This applied to within an ECU and all the more for the total vehicle. This becomes apparent with the combination of motor and transmission. The engine performance is usually coded for an engine nowadays but must be combined with designated transmissions: on the one side, a transmission is not specified for a torque; on the other, frequently only an automatic transmission is offered for high output. The diagnostic tester must allow combining simply a variety of codes for the test. Simultaneously, setting faulty code combinations should be possible here in order to be able to check fault behavior.

Residual Bus Simulation

Residual bus simulation is actually not a subject for diagnostics. However, it has a great influence since the diagnostics does not function in many cases - especially when only a single ECU or a subnetwork should be implemented. Frequently, the diagnostics in an ECU is not active as long as certain signals are not transmitted to the bus. A typical example is the ignition detection, which is carried out from an ECU and then put to the disposal of all other ECUs as a signal on the CAN bus. The same holds for all signals that are necessary for a plausible diagnostics (for example, a speed signal). In any case, the engineering tester can simulate these signals by sending individual CAN messages on the bus cyclically. Logically, the individual signals should also be alterable since, for instance, the diagnostics behavior of low vehicle speeds to high can change.

Also the use case analysis generates demands on the engineering tester. On the one hand, he contributes to data visualization. He must therefore prepare the data accordingly and represent the measurements on appropriate instruments, list the fault memory, and present the data for flash programming so that they can be programmed accurately into the ECU. On the other hand, he contributes to the commissioning and should therefore be able to enable an exact as possible access to ODX information and possible communication errors. If problems in the communication itself should arise, the bus communication too must be presented so that the particular problem can be efficiently located and documented.

For the test of OBD functions, the OBD modes - specialized diagnostic services - must always be presented in adequate forms. Roughly structured, they serve to read measurement values, to process the failure memory and to analyze test results. The addressing always takes place on the function OBD; therefore a number of ECUs can be concerned. The Vehicle Communication Interface (VCI) must control the functional addressing, and the diagnostics system must be able to handle a number of answers from different ECUs. The subfunction supported by the individual OBD modes will be reported by the ECUs in bit codes to the test system. It is especially important here that the tester allows requests that initially seem incorrect to be sent to the ECU since the scan tools can sometimes interpret specifications differently.

Which of the important standards must be observed?

Standards used today in diagnostics can be divided into three categories: protocols, data descriptions and application programming interfaces.

The oldest category is surely that of protocols. Originally introduced to comply with legislature's demands for a possibility to supervise exhaust emissions, these protocols fulfill innumerable other tasks today. The huge number of protocols specified for manufacturers has been be replaced today by standardized protocols; however, the importance of these earlier protocols for after-sales testers should not be underestimated: after all, the vehicles can be seen on the streets for many years.