Problems of searching for failures and interpretation of error codes (DTCs) in modern vehicles

Andrzej Sumorek [1], Marcin Buczaj[2]

[1]Lublin University of Technology, Department of Structural Mechanics, Poland, 20-618 Lublin, Nadbystrzycka 40, e-mail: a.sumorek@pollub.pl
[2]Lublin University of Technology, Institute of Electrical Engineering and Electrotechnologies, Poland, 20-618 Lublin, Nadbystrzycka 38A, e-mail: m.buczaj@pollub.pl

Received July 15.2016: accepted July 19.2016

Abstract. Volkswagen model launched in 1968 is deemed as the first motor vehicle provided with on-board diagnostics functions. However, the introduction of systems for the monitoring of vehicle sub-assemblies contributing to emission levels in all vehicles was enforced by environmental protection requirements. The California Air Resources Board (CARB) introduced the necessity to use the basic functions of on-board diagnostics (OBD) in all the motor vehicles sold in California since 1991.

The article presents the results of practical tests in the scope of on-board diagnostics for "premium" class vehicle. The tests were carried out by means of 4 diagnostic interfaces. Data volume obtained from motor vehicles varied depending on the applied device, although OBD II standards should be introduced in an identical manner by the manufacturers of motor vehicles and diagnostic devices.

Key words: On-board Diagnostics, Diagnostic Trouble Codes DTC.

INTRODUCTION

The introduction of on-board diagnostics systems is necessary due to air quality standards. This case has been expressed in regulation issued by the California Air Resources Board (CARB) introducing the necessity to use the basic functions of on-board diagnostics (OBD) in all the motor vehicles sold in California since 1991 [10]. The beginnings of OBD implementation encountered the problems in the form of non-uniform communication protocols, diversified diagnostic links and diversified interpretation of errors. The use of on-board diagnostics systems compliant with OBD II standard (increased number of monitored parameters, increased number of indicated and recorded data) has been mandatory since 1996. Since 2003 a similar standard, i.e. European On-Board Diagnostics (EOBD), has been mandatory in Europe.

The development of OBD standard commenced in the mid-eighties of the 20th century has additionally resulted in the development of communication networks in motor vehicles. The networks have been transformed from slow diagnostic networks with bandwidths lower than 10 Kbps (e.g. ALDL - Assembly Line Diagnostic Link) into reliable fibre optic solutions with bandwidths close to 150 Mpbs (e.g. MOST – Medium Oriented System Transport) [24, 25]. Simultaneously, data transfer security has been significantly improved [23]. Motor vehicle sub-assemblies have been transformed into mechatronic systems providing access to information about their condition, following the instructions or being reprogrammed. They can also establish the connections between vehicles, often characterized by different security levels [12, 13, 21].

The functions of on-board diagnostics systems are performed on electronic and mechatronic sub-assemblies installed in motor vehicle and connected by numerous communication networks. The manufacturers of sub-assemblies, motor vehicles and diagnostic testers shall ensure the support of non-uniform network environment. As a result of almost 30 years of development in the scope of networks, buses and data buses, there is no universal diagnostic tool which could be used for all types of motor vehicles. This study presents practical problems occurring in course of diagnostic procedures performed by means of diagnostic testers delivered by various manufacturers.

ON-BOARD DIAGNOSTICS

The variety of communication and diagnostics protocols applied in motor vehicles results from the long term evolution of OBD I and OBD II systems. Fig. 1 illustrates selected standards applicable in the scope of vehicle sub-assemblies diagnostics.

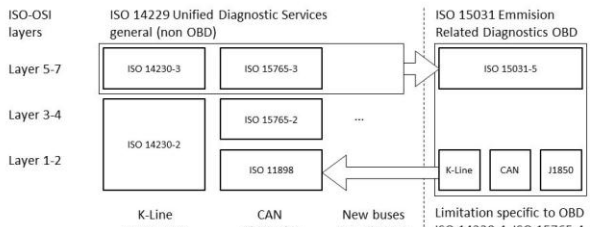

Fig. 1. Selected standards of diagnostic protocols [28]

A failure defined in accordance with OBD II standard will be indicated by means of DTC code consisting of a letter and four digit number e.g. P0484 Cooling Fan Circuit Over Current [19]. DTC codes values use generic and manufacturer-specific codes e.g. C0xxx or C3xxx- generic codes, C1xxx or C2xxx - manufacturer-specific codes (Fig. 2).

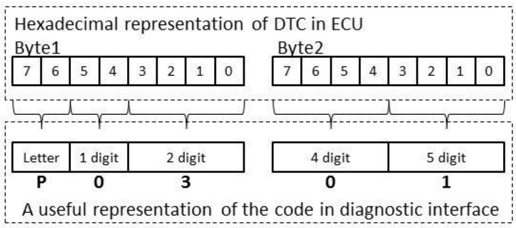

Fig. 2. Hexadecimal and useful representation of DTC error code [28]

Simultaneously, the vehicle manufacturer can define its own codes nonconforming with OBD standard provided that these codes are not colliding with standard requirements. The scientists and service personnel focus their attention not only on DTCs but on algorithm used for execution of repairs and for data acquisition [8, 20].

Wireless solutions are used in communication networks. Originally they have been used for motor vehicles protection (GSM, GPRS, GPS) [6]. Wireless solutions are also frequently used in OBD diagnosis. The connections between measurement interfaces installed in motor vehicle and the computer with testing software by means of Bluetooth and WiFi are standard solutions. The other solution consists in Bluetooth diagnostic communication of fleet motor vehicles when driving through the company gate or in sending messages on vehicle condition by means of GPRS network. Diagnostic data acquisition and processing in computing cloud seems to be the most interesting idea [11, 14]. The vehicle network itself is also regarded as a distributed system [2, 18, 26]. The efforts are still being made in order to find faster and reliable detection methods e.g. based on an additional database [7, 16].

Diagnostic network itself regarded as technical device can be also damaged which will affect the communication of motor vehicle subassemblies and diagnostics. Research works are carried out in the scope of detection of errors in communication networks e.g. by means of fuzzy logic [7, 27].

Problems with detection of trouble and with representation of error code are possible on several levels: tester – vehicle physical connection, a protocol in communication protocols stack, manufacturer – specific error code; method of determination by ECM whether the object status is incorrect.

PRACTICAL TESTS

Upper class vehicle manufactured in 2010 has been used as the object for checking the testers functionality. The vehicle was equipped with Diesel engine with the power of 150 kW (204 HP) and capacity of 3,0 litres. There are two reason of such choice. Firstly, it is the vehicle from premium segment with hybrid type network. Gateway integrates all types of networks from A class networks (Local Interconnect Network), typical B class solutions (Controller Area Network) and fast reliable C class networks (FlexRay) up to multimedia MOST network (Medium Oriented Systems Transport). Another reason of such choice was the period of 5 years elapsed after motor vehicle launch. This period is sufficient for the testers manufacturers to consider motor vehicle support in their devices.

Fig. 3 illustrates the engine compartment of motor vehicle. The engine system has been subjected to three modifications which should be indicated as errors in powertrain system. After disconnection of sensors, the engine was running for more than ten minutes. The errors generated by motor vehicle ECU shall be indicated in OBD diagnostic network because introduced troubles contribute to emission levels. In order to simulate real errors, the following sensors have been disconnected from engine controller:

- turbocharging pressure sensor (A);
- air flow sensor (B),
- air temperature sensor (B),
- intake manifold flap position sensor (C).

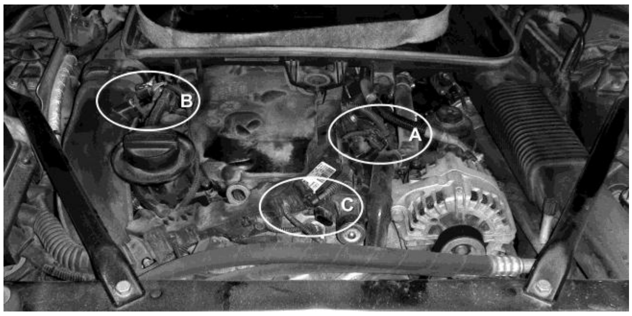

Fig. 3. View of the engine compartment

Practical test 1. X431 tester applied in the tests was manufactured in 2011 i.e. in the same period during which the vehicle under tests was manufactured (Fig. 4). On the basis of information published on websites of its distributors, the tester supports about 50 vehicles makes. Simultaneously, BMW and OBDII / EOBD standards are specified (Fig. 5). The following tester functions are specified: reading of controller version and system, cancelling of errors, reading of current parameters, actuators; systems encoding and programming, programming of keys and immobilizers; cancelling of service inspection; cancelling of crash data airbag.

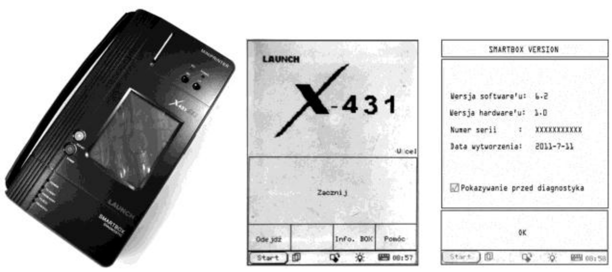

Fig. 4. Launch X431 GX3 tester view with starting screens [15]

In course of tests, it was possible to connect the tester to motor vehicles, to select the brand and controllers group of vehicle to be tested. Message informing about the lack of communication with the controller was the result of performed tests (Fig. 5). Similar negative result was obtained from general OBD test of motor vehicle. Despite declaration of vehicle manufacturer concerning the presence of vehicle diagnostic network conforming with OBD and despite of tester manufacturer declaration concerning OBD diagnostics support, it was impossible to establish communication between vehicle and tester. Tester communication is possible by means specified contacts of diagnostic socket (socket conforming with SAE 15031-3 standard): 2, 7, 10 and 15. Such configuration allows only the communication by means of protocols conforming with SAE J1850 (contacts 2 and 10) and K data bus (contacts 7 and 15) in accordance with ISO 9141-2 and 14230-4.

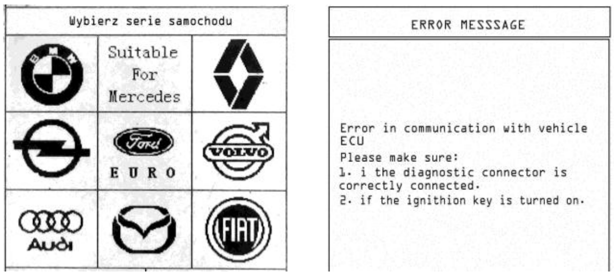

Fig. 5. X432 screens of: choice of car type (on the left); error message (on the right)

Practical test 2. Mobile tester Asian Gold is regarded by many employees working in independent service centres as a reliable device in case of the necessity to carry out the tests of motor vehicles originating from Far East markets. The tester incorporates built – in OBD II diagnostics function and supports the protocols conforming with SAE J1587, KWP-2000, OBD-II (ISO 9141-2 and SAE-J1850) as well as CAN Bus [17]. The device supports more than 40 makes of vehicles. In many cases, the access is possible to service functions accessible to authorized service centres only. The manufacturer ensured access to non-standard service connectors e.g. 20-pin BMW diagnostic conductor, 20-pin PSA diagnostic conductor or 20-pin Ford diagnostic conductor. Tester screens in course of successive steps of vehicle type declaration are presented in Fig. 6.

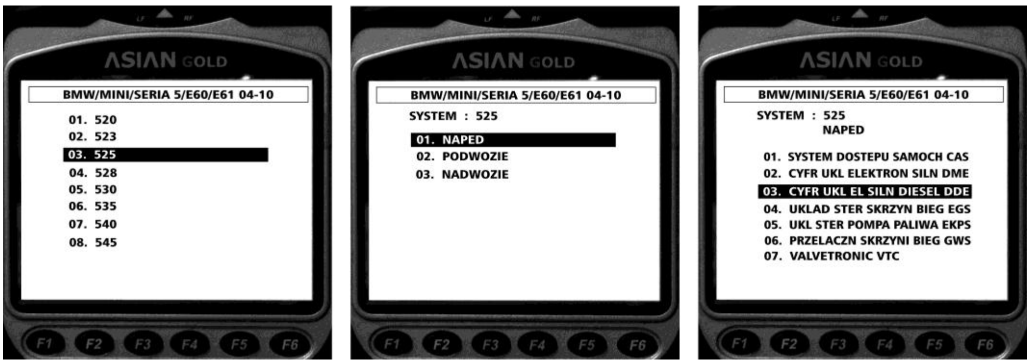

Fig. 6. Sequence of steps during the work with tester

The power supply to the tester was possible from diagnostics connector. The brand of vehicle being tested was present in the database. During next steps, it was possible to declare the type of motor vehicle (525), controllers group (powertrain) and to select diesel engine controller (diesel DDE) (Fig. 6). In connection with the wide range of additional equipment, it was necessary to select the type of conductor connecting the tester with vehicle (Fig. 7) before the commencement of diagnostics. However, the running of diagnostic scanning failed and message informing about the necessity to connect Gateway was displayed (Fig. 7). Similar attempts to establish communication with body and chassis systems were also unsuccessful. Motor vehicle scanning without indicating its type, on the basis of general OBD diagnostics also failed.

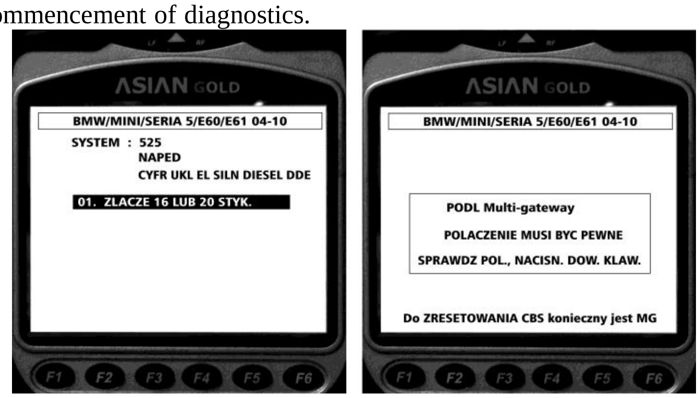

Fig. 7. Tester screens: choice of cable type (on the left), diagnosis effect (on the right)

Practical test 3. Solus Pro diagnostic scanner is characterized by functionality similar to two testers specified previously. Software provides vehicle-specific trouble codes for various vehicle control systems such as engine, transmission, antilock brake system (ABS), selected functional tests and troubleshooting information [22]. The scanner supports diagnostic protocols conforming with OBD-II/EOBD e.g. SAE J1850 (VPW), SAE J1850 (PWM), ISO 9141-2, ISO 14230-4 (KWP 2000), ISO 15765-4 (CAN). In the groups of vehicles service professionals, the device is equated with the tool necessary for servicing American, Japanese and Korean vehicles. A specific scanner feature consists in the use of memory cards dedicated for motor vehicles to be diagnosed. The cards are installed on the diagnostic conductor connector.

In the course of diagnosis, the scanner displayed information about the support of the type of vehicle identical to the type of vehicle connected to scanner. A card corresponding to the type of vehicle connected to scanner was included in the set of memory cards. Unfortunately, as in the previous tests, it was impossible to establish communication with any vehicle controller (Fig. 8).

Fig. 8. Solus Pro tester - communication error

The scanner makes it also possible to carry out diagnostic procedure in a general manner based on OBD diagnostics. It is possible to select communication protocol manually or to use all the built – in protocols automatically (Fig. 9a).

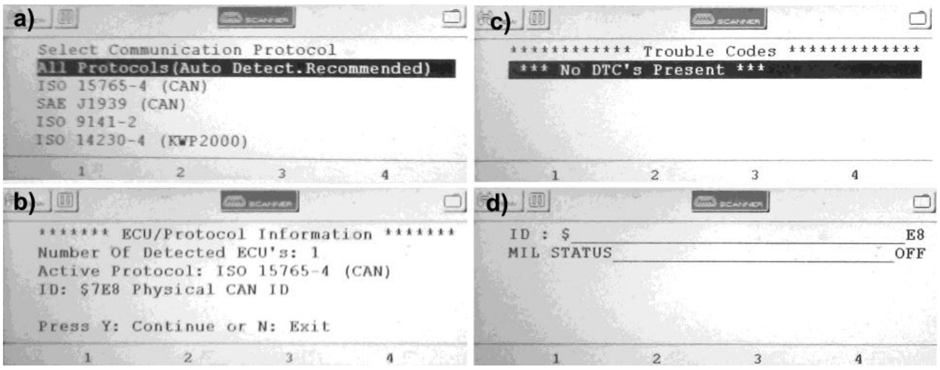

Fig. 9. Screen of tester in ODB mode

As a result of OBD diagnosis in automatic mode it was possible to establish communication between scanner and tester by means of ISO 15765-4 protocol (Fig. 9b). It is a significant progress in comparison with the two previous tests when it was impossible to establish communication with vehicle network. Message on lack of errors (Fig. 9b) was displayed as a result of further diagnosis. This message is non-conforming with real status because the signals from 4 sensors (turbocharging pressure sensor, air flow sensor, air temperature sensor, intake manifold flap position sensor) are not transmitted to the engine controller. Additionally an information has been received about disconnection of MIL (Malfunction Indicator Lamp). This message is non-conforming with real status because MIL lamp on the dashboard indicated errors presence in motor vehicle. In summary, like in the previous tests, it was impossible to establish correct communication with any vehicle controller.

Practical test 4a. Bosch KTS 540 tester with ESI[tronic] software package installed on a PC was used as diagnostic device. KTS 540 is not a stand – alone device but constitutes communication interface with motor vehicle. Diagnosis and signals interpretation is carried out by means of PC in programmed mode.

The diagnostics device incorporates additional multimeter functions. Therefore it is possible to perform voltage measurements up to 200V, current measurements up to 600A (with an additional shunt) and resistance measurements up to 1 M□. Within diagnostics area, the communication is possible by means of the following protocols: ISO 9141-2 (K and L lines), SAE J1850VPW, SAE J1850PWM, CAN ISO 11898, ISO 15765-4 (OBD) (CAN-H and CAN-L lines), CAN Single Wire and CAN Low Speed [4]. KTS 540 diagnostic interface was supported by ESI[tronic] software package 2.0. Its structure consists of modules. The following [Bosch 2013] elements have been used in described case:

- SD – motor vehicle controllers diagnosis module;
- SIS – errors and failures finding module;
- M – repair activities sequence module;
- P – electric diagrams for selected vehicle systems.

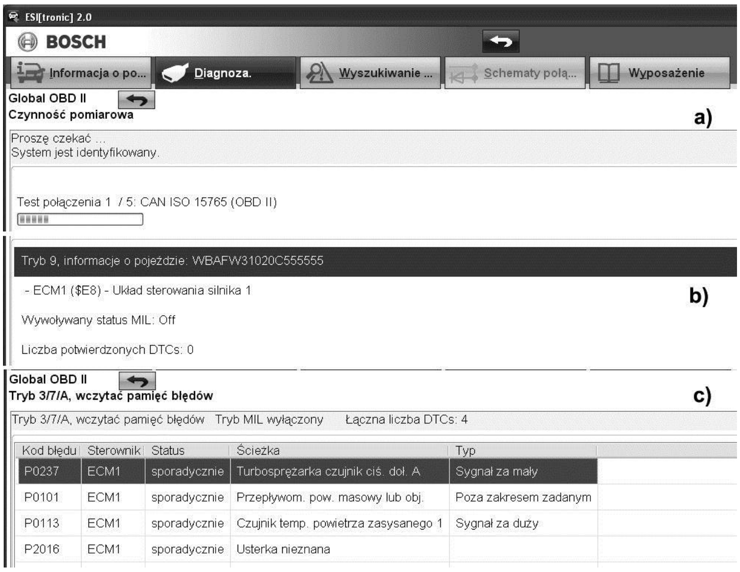

Fig. 10. Printscreens of ESI[tronic] software during diagnosis: a) starting communication; b) general vehicle information; c) list of diagnostic trouble codes

In the course of tests, KTS 540 interface with ESI[tronic] software was operated in two modes. In the first described case, KTS 540 interface with ESI[tronic] software performed typical diagnostic tests conforming with OBD II standard. The effects of tester operation should be identical to the effects of tests performed by means of other testers. Despite procedure followed in case of KTS interface identical to procedure applied for Solus Pro, Asian Gold and X431 interfaces, obtained effect was different:

- communication with ECU engine module has been established correctly. The same protocol (ISO 15765-4) has been effectively used in communication. Its functioning with Solus Pro (Fig. 9b, Fig. 10a) tester was possible in part only;

- reading of MIL control lamp status was incorrect (Fig. 9d, Fig. 10b). This reading made by Solus Pro tester was also incorrect;

- reading of DTC errors number (Fig. 9c, Fig. 10b) was incorrect. The errors number identified by Solus Pro tester was also incorrect;

- despite indicated lack of DTC diagnostic errors they are identified as sporadic errors.

The sporadic errors detected by KTS 540 interface set with ESI[tronic] software 2.0 have been correctly interpreted as (Fig. 10c):

- P0237 - turbo charger boost - sensor A circuit low,
- P0101 - mass or volume air flow circuit range,
- P0113 - intake air temperature sensor 1 circuit high,
- P2016 – unknown trouble. No description introduced at P2016 error code. The trouble corresponding to description „Intake Manifold Runner Position Sensor/Switch Circuit Low” has been correctly interpreted by P2016 value.

Practical test 4b. In the second vehicle testing mode, the type of motor vehicle being tested was directly defined by means of Bosch KTS 540 tester with ESI[tronic] software. The obtained results were marked by means of error codes from out of OBD (Fig. 11). Thanks to indication of vehicle type, it was also possible to display information about other errors occurring in engine system. Spark plugs glowing time control error (not displayed before) has been presented. This error occurred in controlled system in Local Interconnect Network cluster.

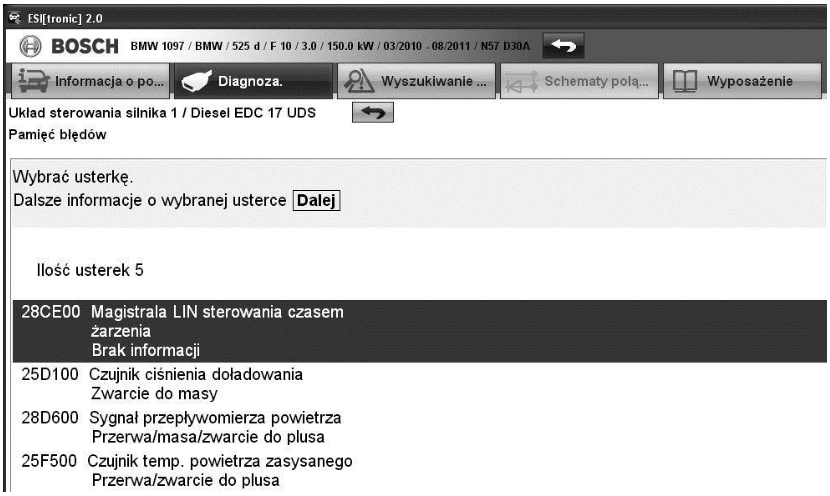

Fig. 11. Final screen of ESI[tronic] software after diagnosis

The appearance of list of errors marked with internal manufacturer's codes was as follows:

- 28CE00 - glow control LIN data bus missing,

- 25D100 = P0237 - turbo charger boost - sensor A circuit low,

- 28D600 = P0101 - mass or volume air flow circuit range,

- 25F500 = P0113 - intake air temperature sensor 1 circuit high,

- 264100 = P2016 - intake manifold runner position sensor/switch circuit low.

After selection of error code field it is possible to commence service procedures. It is possible to familiarize with information about damaged systems, to perform measurement of actual values, to familiarize with typical methods of trouble elimination.

In order to perform measurement of current values associated with P0101 error (28D600), it is possible to directly enter to measurement screen as illustrated in Fig. 12.

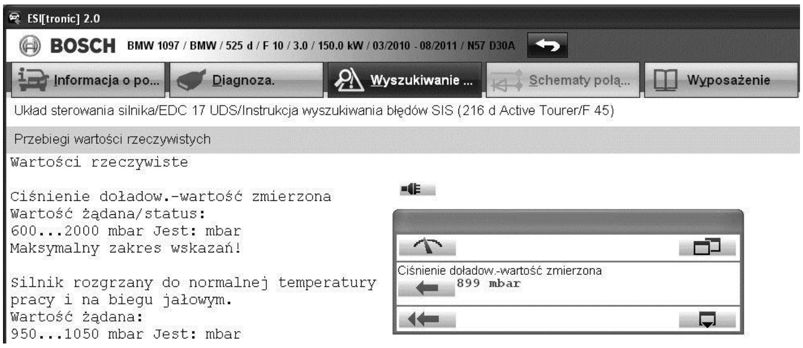

Fig. 12. Measurement of real values connected to DTC P0101

CONCLUSIONS

It is impossible to perform a full and error-free diagnosis in case of currently manufactured vehicles by means of a standard diagnostic tester. Unexpected situations could be faced as a result of tester design as well as vehicle communication network organization. Executed tests demonstrated that potential reasons of diagnosis failure could be as follows:

1. Impossibility of physical connection of the tester – lack of pins in diagnostics plug of the tester which correspond to protocol used for communication with vehicle (practical test 1).

2. Lack of built–in diagnostics protocol conforming with protocol supported by motor vehicle (practical test 2).

3. Manner of DTC errors interpretation by the tester. Sporadic errors can be interpreted as non-existing errors (practical test 3).

Simultaneously, the following conclusions were drawn by the experiments participants in the course of tests:

1. Up–to–date software of the testers makes it possible to access to information and service functions included in the scope of OBD (practical test 4a).

2. Application of „dedicated" software for motor vehicle combined with the use of "standard" tester extends service capabilities beyond OBD standard (practical test 4b).

3. In case of the necessity to access to selected communication networks (e.g. MOST networks in case of BMW make) it is necessary to apply dedicated diagnostic heads /interfaces (e.g. GT1 or OPS head).

4. Currently, the capabilities of Electronic Control Units (ECUs) are much higher than only making diagnostic data available. It was demonstrated in Volkswagen group scandal in 2015. Thanks to the extended capabilities in the scope of engine ECU reprogramming, the values of emission levels were underestimated in the course of stationary tests. This problem occurred in diesel engines with the capacity of 2 litres manufactured in the years 2009–2015 [1, 9].

RREFERENCES

1. **Barrett S.R.H., Speth R.L., Eastham S.D., Dedoussi I.C., Ashok A., Malina R. Keith D.W. 2015.** Impact of the Volkswagen emissions control defeat device on US public health. Environmental Research Letters, 11, 2015, DOI: 10.1088/1748-9326/10/11/114005, pp. 10.
2. **Biteus J., Nyberg M., Frisk E., Åslund J. 2009.** Determining the fault status of a component and its readiness, with a distributed automotive application. Engineering Applications of Artificial Intelligence, vol 22, 3, 363-373.
3. **Bosch R. GmbH. 2008.** Data exchange network in vehicles. Wydawnictwa Komunikacji i Łączności, Warszawa (in Polish).
4. **Bosch R. GmbH. 2010.** Innovative and reliable: Professional electronic control unit diagnosis from Bosch. http://rb-aa.bosch.com/boaa-pl/Product.jsp?prod_id=154&ccat_id =73&language=en-GB&publication=3. January 2016.
5. **Bosch R. GmbH. 2013.** ESI[tronic]-C Vehicle diagnosis and troubleshooting instructions. http://rb-aa.bosch.com/boaa-pl/Category.jsp?ccat_id=119&language=en-GB&publication=4, Germany, January 2016.
6. **Buczaj M. 2011.** The elimination of the human decision factor by the technical medium of the transmission of information signal in control and supervision alarm systems. MOTROL - Motorization

and Power Industry in Agriculture, vol. 13, s. 34-42 (in Polish).

7. **Chen J., Roberts C., Weston P. 2008.** Fault detection and diagnosis for railway track circuits using neuro-fuzzy systems. Control Engineering Practice, vol 16, 5, 585–596.
8. **Chougule R., Rajpathak D., Bandyopadhyay P. 2011.** An integrated framework for effective service and repair in the automotive domain: An application of association mining and case-based-reasoning. Computers in Industry, vol 62, 7, 742-754.
9. **Davenport C., Ewing J. 2015.** VW Is Said to Cheat on Diesel Emissions; U.S. to Order Big Recall. The New York Times, 18 September 2015, ISSN 0362-4331.
10. **Eisinger D.S., Wathern P. 2008.** Policy evolution and clean air: The case of US motor vehicle inspection and maintenance. Transportation Research Part D: Transport and Environment, Vol. 13, 6, 359-368.
11. **Fan S., Yang D., Zhang T., Lian X. 2013.** Distributed Diagnostic Monitoring and Fault Tolerant Control of Vehicle Electrical and Electronic Devices. Proceedings of the FISITA 2012 World Automotive Congress. Vol. 6: Vehicle Electronics, SAE-China, FISITA, Springer Berlin Heidelberg, 221-230.
12. **Förster D., Kargl F., Löhr H. 2016.** PUCA: A pseudonym scheme with strong privacy guarantees for vehicular ad-hoc networks. Ad Hoc Networks, 37, 122–132.
13. **Gorrieri A., Martalò M., Busanelli S., Ferrari G. 2016.** Clustering and sensing with decentralized detection in vehicular ad hoc networks. Ad Hoc Networks, 36, 450–464.
14. **Jhou J.S., Chen S.H. 2014.** The Implementation of OBD-II Vehicle Diagnosis System Integrated with Cloud Computation Technology. Intelligent Data analysis and its Applications, Vol. I, Advances in Intelligent Systems and Computing, Springer International Publishing Switzerland, 413-416.
15. **Launch Tech. 2007.** X-431 User's Manual. http://www.diagtools.lv/soft/X431_ manual _English.pdf, January 2016.
16. **Li Yanqiang, Li Yang, Wang Z., Zhuang R., Li Jainxin. 2013.** Automotive ECUs Fault Diagnosis Modeling Based on the Fault Database. Proceedings of the FISITA 2012 World Automotive Congress. Vol. 6: Vehicle Electronics, SAE-China, FISITA, Springer Berlin Heidelberg, 271-281.
17. **Magneti Marelli. 2012.** Air conditioning, diagnostics, mechanics. Equipment for Magneti Marelli workshops. http://www.edpol.pl/frontend/files/urzadzenia/Katalog-MM-2012.pdf, January 2016 (in Polish).
18. **Murphey, Y. L., Crossman, J. A., Chen, Z., Cardill J. 2003.** Automotive fault diagnosis II: A distributed agent diagnostic system. IEEE Transactions on Vehicular Technology, Vol. 52, 4, 1076-1098.
19. **SAE Standard. 2002.** SAE J1979: E/E Diagnostic Test Modes. Vehicle EE Systems Diagnostics Standards Committee. SAE International.
20. **Saxena A., Wu B., Vachtsevanos G. 2005.** Integrated diagnosis and prognosis architecture for fleet vehicles using dynamic case-based-reasoning. Proceedings of the IEEE Autotestcon. 26-29 Sept. 2005, 96 - 102.
21. **Schaub F., Ma Z., Kargl F. 2009.** Privacy requirements in vehicular communication systems. Proceedings of the International Conference on Computational Science and Engineering, IEEE, 2009, 139–145.
22. **Snap-on Inc. 2012.** Solus Pro User Manual. Ver ZEESC316C Rev. C. https://www1.snapon.com/Files/Diagnostics/UserManuals/SOLUSPROUserManual_ZEESC316C.pdf, January 2016.
23. **Sumorek A. 2010.** Safe Communication Among Vehicle Sub-Assemblies on the Basis of the Embedded Functions of CAN Protocol. Teka (Archives) of the Commission of Motorization and Power Industry in Agriculture, Vol. 10, 432-439.
24. **Sumorek A., Buczaj M. 2011.** The Problems in Fibre Optic Communication in the Communication Systems of Vehicles. Teka (Archives) of the Commission of Motorization and Power Industry in Agriculture, Vol. 11, 363-372.
25. **Sumorek A., Buczaj M. 2012.** New elements in vehicle communication ”Media Oriented Systems Transport” protocol. Teka (Archives) of the Commission of Motorization and Power Industry in Agriculture. Vol. 12, 275-279.
26. **Suwatthikul J. 2010.** Fault detection and diagnosis for in-vehicle networks (chapter). Fault detection, ISBN 978-953-307-037-7, edited by Wei Zhang, 283-306.
27. **Suwatthikul J., McMurran R., Jones R.P. 2011.** In-vehicle network level fault diagnostics using fuzzy inference systems. Applied Soft Computing, vol. 11, 4, 3709-3719.
28. **Zimmermann W., Schmidgall R. 2008.** Bussystems in Automotivetechnology: Protocolls and Standards. Wydawnictwa Komunikacji i Łączności, Warszawa (in Polish).