POLITECNICO DI TORINO

Master's Degree in AUTOMOTIVE ENGINEERING

Master's Degree Thesis

On-Board Telematics: DTC analysis for maintenance plan

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A nonno Eduardo,
il mio più grande fan

Abstract

This thesis in collaboration with AKKA TECHNOLOGIES has the aim to study the tracing of a vehicle telematic control unit to improve the detection of possible failures.

The issue detection allows the programming of a correct maintenance plan to offer an optimal customer aftersales service.

After an introduction about the current scenario of connected vehicles and on-board telematic, the study will start from the state of the art of CAN networks and the most used protocols to control and manage the flow of data transmitted from the various vehicle's ECUs to off-board services (i.e. backend and cloud applications).

The core is the study of a test tracing with particular focus on the alerts (DTCs) related to vehicular issues and on the identification of two or more parameters that can help to define an algorithm to prevent the maintenance activity.

The output of the algorithm is a “trigger” used to forecast and manage the failure with some advance, allowing companies to plan correct workshops vehicles' calls and constantly monitor the state of health during their life.

In the final part is shown how output and execution of the triggers are visualized and reported using business intelligence tools.

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Chapter 1

Introduction

In the last years the automotive scenario is full of new challenges, growth opportunities, competitiveness between OEMs (Original Equipment Manufacturer) on products, technologies and services related to the aftermarket.

To answer to the continuous demanding needs in the market but also to the new regulations' requirements, companies are investing a lot of money and resources to become more digital, eco-friendly and "connected".

Companies are investing, evolving and developing a lot in the electronics of the vehicles because it allows to have a multitude of functionalities useful to improve the customer driving experience in terms of safety, fuel consumption, comfort, entertainment, communication and real time services.

One of the main innovations have been made in the field of diagnostics, thanks to the On-board Telematics.

On-board diagnostics, OBD, in the field of transport, refers to the ability to self-diagnose and report errors and/or breakdowns of a vehicle.

Before the introduction of this technology, it was the mechanics who had to diagnose the faults, while now it is the on-board control unit which checks itself and verifies the condition of the vehicle.

Early versions simply turned on a warning light signalling a problem, but it did not provide any additional information concerning its nature. Modern OBD implementations use a digital communications port to provide real-time information in addition to reporting the nature of problems via standard Diagnostic Trouble Codes (DTCs) that allow vehicle malfunctions to be quickly identified and resolved.

In the actual scenario for Fleet Managers and OEMs is even more dispending to manage and face up the increasing maintenance costs due the huge electronification of the vehicles.
For this reason it is necessary to develop new solutions to fit inefficacies of this system.
This work will focus on the improvement of an aftersales service aimed to manage and solve Diagnostic Trouble Codes coming from the Telematic Control Units, which transmit data wireless to off-board services in real time.

After an introduction to connected vehicles and telematics, the thesis will explore the protocols used to transfer data such as the CAN bus and OBD-II, passing to the definition of DTCs and some tools to read data from the control units.
The core will be the chapter 4 in which will be explained the methodology for the definition of a rule for the best planning of maintenance interventions avoiding the incurring of vehicles' unforeseen stops.
The chapter 5 will discuss some tools of Business intelligence useful to transform data into actionable insights that inform an organization's strategic and tactical business decisions.
Finally, the conclusions will explore some suggestions for future improvements.

Chapter 2

Working environments

2.1 Connected vehicles

In the automotive field, when it comes to connectivity, most people could maybe think of the connection between vehicle and smartphone useful to listen to music, to make phone calls or to use the navigator: this is just a face of the coin or better of a prism, because nowadays the functionalities of a connected vehicle through an advanced interface are various and in continuous growth.

Figure 1 - Connected vehicle

The growth is evident, at least four different connectivity devices have been introduced only in the last few years, with an improvement in the man-machine interaction and an increase of transport efficiency.

The potential expansion of the European connected car industry is impressive. Globally, estimates suggest that the connected car market will reach a total of $ 143 billion by 2026 with a growth rate of 16.4% (1). These numbers underline the importance of this sector, but let's deepen what is intended for "connected vehicle" and the benefits this technology can bring to fleets' businesses.

In practice, a connected vehicle is every vehicle connected to the Internet. However, a connected car, truck or van must set up an Internet access device and related software applications for a correct working behaviour.

The pillar of this technology is data sharing, which makes possible to control not only vehicle movements but also their status: planning of ordinary and not-ordinary maintenance, creation of customized profiles for each single driver, monitoring of driver attitudes and sharing of information to manage entire fleets. Data needs to be transmitted from engine, electronics and chassis to a vehicle tracking device, and then they must be sent to a processing center, the driver's smartphone or something else.

Vehicle connectivity is based on a mix of integrated and aftermarket technologies where software devices match with integrated products, which in turn connect to a central data management system. This technology can assume different forms and can be used in all commercial transport companies. The main forms are called:

- V2V
- V2I
- V2X.

V2V stands for Vehicle-to-Vehicle, it means data exchange between different vehicles with the scope of decreasing the incidence of road accidents or improving traffic viability. This happens through dedicated short-range communications frequencies (about 300 meters) which allow information access on other near vehicles enabled to the same technology. The kind of data they can exchange are for example position and speed, which are the most reliable variables that can be used to prevent collisions. V2V logic is also used to detect traffic and road conditions in real time, but especially adverse weather conditions.

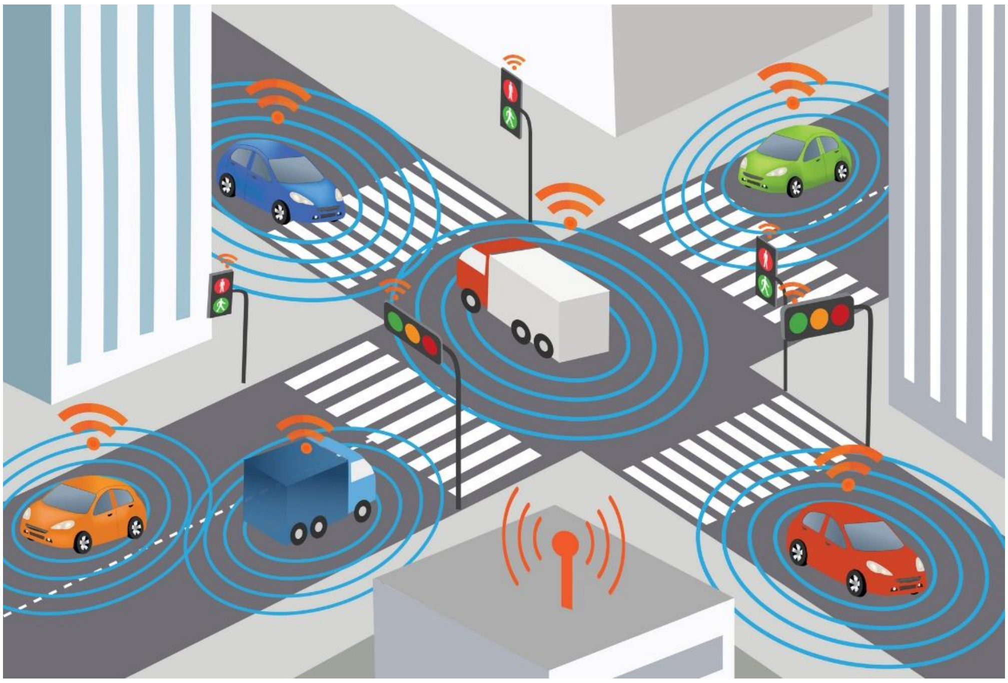


Figure 2 - V2V

V2I stands for Vehicle-to-Infrastructure, this technology is able to catch data regarding traffic, road, parking availability and weather from components that support country highway system such as: overhead RFID readers and cameras, traffic lights, lane markers, streetlights, signage and parking meters. An application of V2I are the traffic management supervision systems that use data to set speed limits and to introduce traffic signal in real time through smart road signs in order to have low fuel consumptions on roads and improve the traffic flow. This type of communication is typically wireless and bi-directional, and uses dedicated short-range communication (DSRC) frequencies to transfer data as in the previous case.

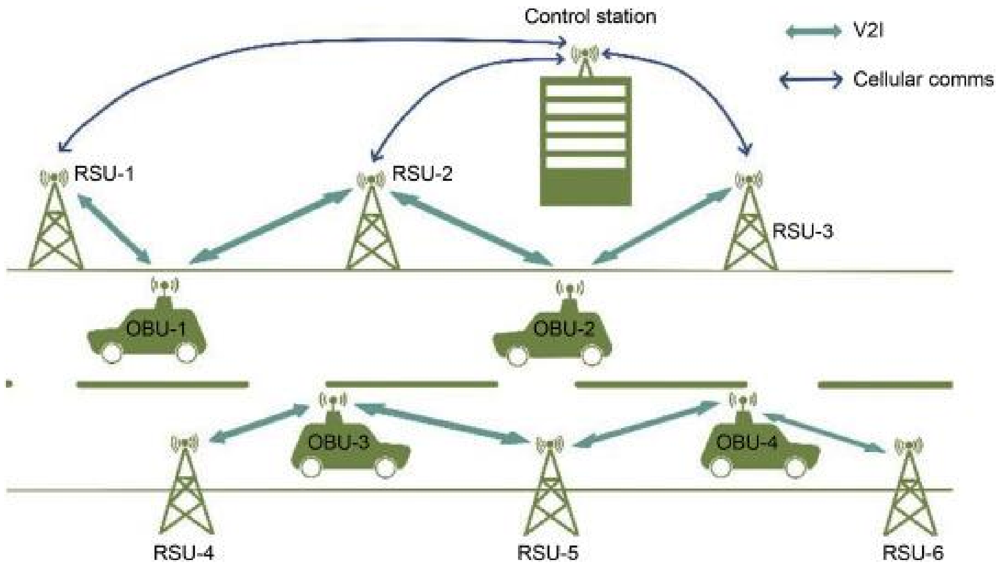


Figure 3 – V2I (2)

V2X, that stands for Vehicle-to-Everything, is communication between a vehicle and any entity that may affect, or may be affected by, the vehicle itself. It includes both V2V and V2I software and works to make vehicles smarter on the road through the possibility of communicating with the traffic system. It automates toll and parking payments too, making driving easier. The main purposes of this technology can be summarized in road safety, traffic efficiency, energy savings, and mass surveillance.

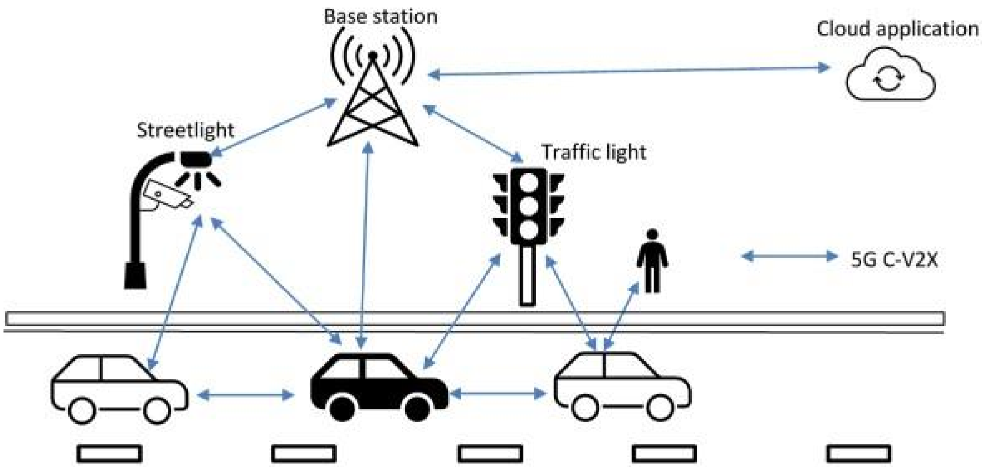


Figure 4 – V2X (3)

Obviously, they will be most effective only when every truck, bus, car, motorcycle and bicycle will be equipped with such technology as standard.

Other developed forms of connectivity can be mentioned:

- V2N, Vehicle-to-Network, with the use of the LTE network infrastructure and the E-UTRA.
- V2G, Vehicle-to-Grid, which uses the battery pack of an electric vehicle to stabilize the network, storing excess energy and returning it when needed, guaranteeing benefits to the community, energy managers and drivers.
- B2V, Brain-to-Vehicle, introduced by Nissan has the future scope to link driver brain with his vehicle.
- Platooning, indicates a convoy of trucks traveling in columns and connected to each other via a sophisticated wireless system so that a single driver can "drive" several semi-automatic trucks.

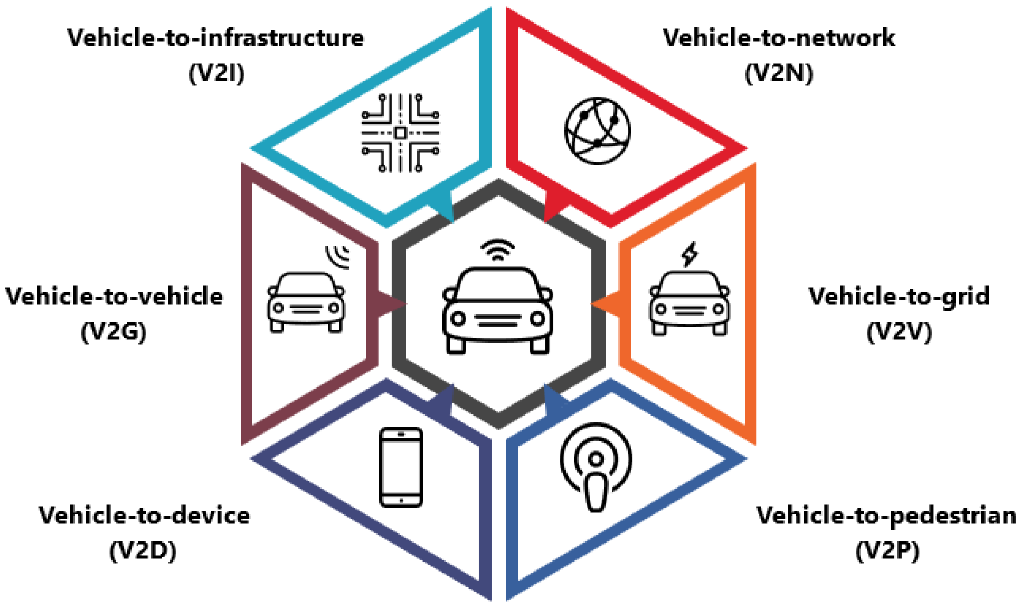


Figure 5 – Connectivity forms (4)

2.2 Telematic Control Unit

Telematics is a method of monitoring cars, trucks, equipment and other assets by using GPS technology and on-board diagnostics (OBD) to plot the asset's movements on a computerized map (5).

Connected fleets are a great opportunity for Companies of improving vehicles' management, but they especially represent a huge help in serving better customers, enhancing efficiency and quality, managing more reliable assets and vehicle performance but also promoting better and safer driving habits.

All these benefits are possible because of the telematics connectivity system that integrates all vehicles in the fleet into a single data stream.

Telematics is an interdisciplinary field which includes telecommunications, vehicular technologies (road transport, road safety, etc.), electrical engineering (sensors, instrumentation, wireless communications, etc.), and computer science (multimedia, Internet, etc.) (6).

GPS navigation, integrated hands-free cell phones, wireless safety communications, and automatic driving assistance systems are all part of the telematics world.

There are great advantages related to compliance, performance, safety and maintenance.

From collected data, fleet managers can verify and monitor:

- If transport required conditions are respected in terms of weight and temperature.
- If drivers' driving style complies with road laws, and avoids drowsiness with sufficient breaks.
- Driver's performance in terms of fuel economy, engine stress, safety and productivity in order to assign the employee to the right mission and area.
- Diagnostic alerts in real time and vehicle health tracings to plan the correct maintenance calls.
- Drivers' needs through traffic and weather conditions.

The data stream is possible thanks to the telematic control unit (TCU) which represents an embedded system on board of a vehicle wirelessly connected to cloud services over a Cellular Network (7).
Usually, a Fleet Telematics System (FTS) consists of mobile Vehicle Systems (VS) and a stationary Fleet Communication System (FCS). The FCS may be a stand-alone application owned and treated by the motor companies themselves or an internet service managed by the supplier of the system. The FCS comprehends a database where all vehicle positions and messages are stored. Telemetry data are collected from the vehicle such as position, speed, mileage range, engine data, fuel consumption, min and max values reached, timers and counters, interfacing with the various sub-systems over data and control busses in the vehicle.
The TCU can also provide internal connectivity via Wi-Fi and Bluetooth.
A TCU is made of the following components (7):

- a Satellite navigation (GNSS) unit, which records the latitude and longitude values of the vehicle;
- an external interface for mobile communication (GSM, GPRS, Wi-Fi, WiMax, LTE or 5G), which provides the tracked values to a centralized geographical information system (GIS) database server;
- an electronic processing unit;
- a microprocessor which processes the information and acts on the interfaces;
- a mobile communication unit;
- and some amount of memory for saving GPS values in case of mobile-free zones or to smartly store information about the vehicle's sensor data.

An example of TCU from AKKA Technologies is the GIGABOX, suitable for cars and trucks.
The GIGABOX is a link between vehicles bus systems and mobile devices, with a great variety of switches and communication interfaces allowing more

complex networking for complex tasks. It is modular in such a way as to satisfy different customer requirements.

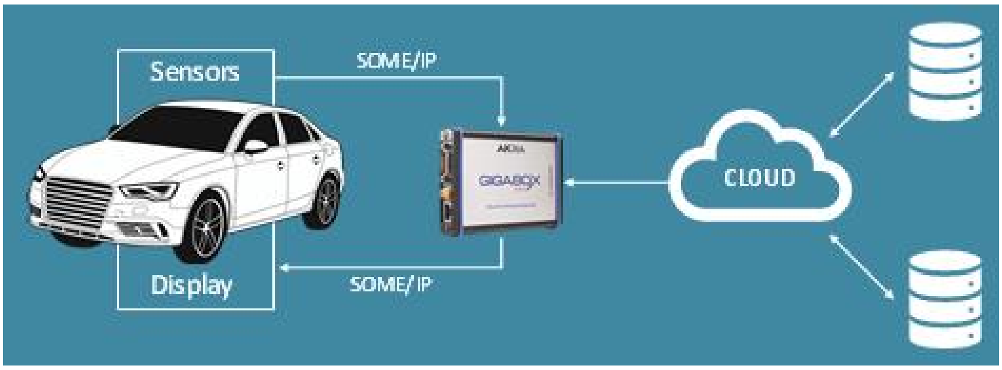


Figure 6 - Wireless communication

It offers the following features:

- Programmable via script to implement the desired functionality by yourself
- Versatile and free development environment
- Flash via USB or CAN
- Optional Bluetooth connection to Android and iOS devices
- Customer specific app-solutions
- Wakeup via CAN, CAN-FD, LIN, clamp 15, Bluetooth SMART (BLE)
- Load-Dump-Protection
- 12/24V power supply
- Fast booting time
- Modular structure, quickly extendable
- CE-certificated

Figure 7 – GIGABOX

Let's see some technical specifications.

The interfaces included in the GIGABOX are the following:

- 2 x CAN-interface (standard, extended or mixed-mode, optional with internal terminating resistor)
- 2 x CAN-FD-interface (standard, extended or mixed-mode, optional with internal terminating resistor)
- 2 x LIN-interface (master or slave)
- Output:
    - 2 x high-side-switch with up to 6 A output current
    - 8 x halfbridge, configurable as low-side, high-side-switch or full
- bridge with up to 1,75 A output current
- Input:
    - 4 x analog input
    - 6 x analog input (instead of halfbridges)
    - 1 x analog input (clamp 15) capable of wakeup
    - 8 x digital input (switching threshold and pull-up or pull-down configurable).

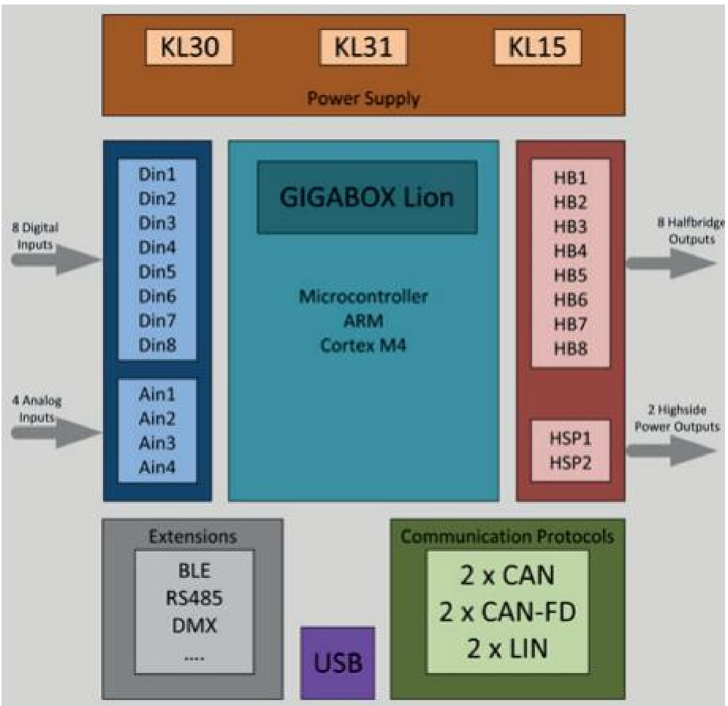


Figure 8 - GIGABOX architecture

The fields of application of this telematic control unit are:

- Bidirectional communication between different bus systems
- Vehicle diagnosis via smartphone-application (BLE)
- Emulation of not available LIN-slave or CAN(-FD)-control units
- Transmitting of CAN(-FD)-messages depending on input signals
- Controlling the in-/outputs depending on CAN (-FD), LIN or (BLE)-signals.

Through the CAN network data are transferred from the various control unit of the vehicle to the TCU and then they are diffused on cloud databases.
Let's see the types of control units which are installed on heavy vehicles.

2.3 On-Board Control Units

In a heavy family vehicle there is a set of control units which communicates between themselves through CAN lines.
The list of the most important control units which compose the BUS CAN layout is the following:

- Body Computer Module
- Frame Computer Module
- Automatic Climate Module
- Additional Heater Water
- Vehicle Control Module
- Tachograph Simulator Unit
- Expansion Module
- Brake System Module
- Air Suspension Module
- Lane Departure Warning System
- RADAR AEBS
- Tyre Pressure Monitoring System
- Digital Tachograph

- Instrument Cluster
- Engine Control Module
- Automatic Transmission Module
- Retarder Module
- New Infotainment System
- Secure Gateway
- Telematic Processing Communication Module

They are organized on the basis of the CAN lines on which they are installed and deliver data to the internal interface and outwards.
Due to the scope of this thesis, it's interesting to see deeply the most important ECUs which are involved in the trasmission of diagnostics data through the TCU and then to cloud systems.

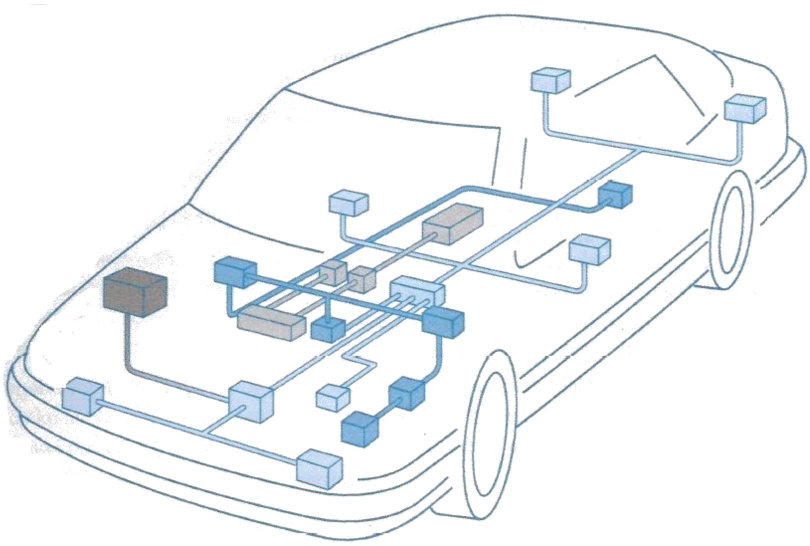


Figure 9 – Vehicle control units (8)

2.3.1 Vehicle Control Module

The Vehicle Control Module, VCM, is an intelligent IoT application that allows the control and monitoring of the devices/sensors present in a vehicle (9).

The VCM is used to control vehicle functions in complex vehicle wiring systems, or as a gateway between separate CAN buses.
It performes tasks like:

- analyzing and controlling the lighting system
- the opening and closing of all doors
- providing the monitoring of all the security services
- management of all the alarms
- means remote management.

In addition, it is equipped with Wi-Fi and GPS connections that can be used to upload collected data to the cloud, and to access that data, making it suitable for big-data applications.
It interfaces with a latest generation touch-screen panel, including all vehicle actuators in a single user-friendly interface.
The VCM is fully developed in-house, so it can be completely tailored to meet the customer’s wishes and requirements.

2.3.2 Body Control Module

In automotive, the Body Control Module, BCM, or 'body computer' is a generic term for an electronic control unit responsible for monitoring and controlling various electronic accessories in a vehicle's body.
Due to the increasing complexity, vehicles often have multiple BCMs, each dedicated to a specific sub-system, including:

- Lighting control: including incandescent, HID, Xenon, LED lamps and their related diagnostics monitoring (over-load and over-temperature protection, bulb outage detection, etc.);
- Motor control drivers for mirrors, wiper, windows, seat position, dome, locks, and climate control;
- Security control for immobilizer and NFC keyless entry systems.

The BCM communicates with other on-board computers via the vehicle CAN bus, and its main application is controlling load drivers – actuating relays that in turn perform actions in the vehicle such as locking the doors, flashing the turn signals (in older cars), or dimming the interior lighting (10).
To reduce the weight and size of these systems, relays are increasingly being replaced by integrated power devices with embedded diagnostics.

2.3.3 Engine Control Module

An engine control unit (ECU), also commonly called an engine control module (ECM), is a type of electronic control unit that controls a series of actuators on an internal combustion engine to ensure optimal engine performance. It does this by reading values from a multitude of sensors within the engine bay, interpreting the data using multidimensional performance maps (called lookup tables), and adjusting the engine actuators (11).
The ECM works on the following processes concerning:

- Control of air–fuel ratio: the ECU determines the amount of fuel to inject based on a number of sensor readings such as oxygen sensors, throttle position sensor, mass air flow sensor, engine coolant temperature sensor.
- Control of idle speed: most engine systems have idle speed control built into the ECU. The engine RPM is monitored by the crankshaft position sensor, which plays a primary role in the engine timing functions for fuel injection, spark events, and valve timing. Idle speed is controlled by a programmable throttle stop or an idle air bypass control stepper motor.
- Control of variable valve timing: some engines have variable valve timing. In such an engine, the ECU controls the time in the engine cycle at which the valves open. The valves are usually opened sooner at

higher speed than at lower speed. This can increase the flow of air into the cylinder, increasing power and fuel economy.

- Electronic valve control: experimental engines have been made and tested that have no camshaft, but have full electronic control of the intake and exhaust valve opening, valve closing, and area of the valve opening. Such engines can be started and run without a starter motor for certain multi-cylinder engines equipped with precision-timed electronic ignition and fuel injection. Such a static-start engine would provide the efficiency and pollution-reduction improvements of a mild hybrid-electric drive, but without the expense and complexity of an oversized starter motor.

2.3.4 Electronic Brake System

In situations where it is necessary to instantly brake or slow down to avoid obstacles, the EBS (Electronically Controlled Brake System) allows the driver to avoid potential hazards.

EBS is an electronically controlled anti-lock disc brake system with a high braking effect that is immediately activated thanks to the electronic signal transmission.

EBS increases road safety for chassis and semi-trailers / articulated trucks. The auxiliary brakes complement the service brakes, improving safety and efficiency. The system is fitted as standard to trucks with air suspension and can be installed in some applications with leaf spring suspension.

When the driver acts on the pedal, the brake signal is sent to the EBS control unit; then a series of sensors send information about wheels' speed and pads wear so that the control unit determines the braking pressure for each axle and wheel. In addition, the modulators regulate the pneumatic flow directed to the brake cylinders. EBS has a pneumatic auxiliary system.

2.3.5 ETC Traxon Gearbox

This control unit allows the clutch engagement and gear shifting so that they are electronically regulated and electro-pneumatically performed.
In order to use the ectronic transmission system, the following requirements are required:

- Electronic engine control unit
- CAN signal communication
- EBS

Thanks to the automated clutch, the driver does not have to operate the clutch for the engagement of gears as the clutches are performed by the electronic control unit.
All functions are displayed through the driver information such as neutral, gear shift, clutch overload and diagnostic information.

2.3.6 AEBS Radar

AEBS stands for Advanced Emergency Braking System, a semi-automatic braking system designed to avoid collisions and relative consequences.
A radar signal on the front of the vehicle constantly checks whether the safety distance is sufficient. If the minimum distance limit is exceeded, the system initially sends a warning signal. If the driver does not respond to the signal, the AEBS is activated. The vehicle slows down as much as possible to avoid a collision or minimize any impact.
AEBS should not be considered an infallible tool which allows the driver to maintain an adequate safety distance: obviously it is always essential that the driver pays attention by carefully controlling the vehicle. Drivers must also be able to calculate a safe safety distance from other road users while driving.

Chapter 3

Tools

3.1 Protocols

The definition of architectures, algorithms and protocols is necessary to build a network:

- Architecture: hardware objects that execute things.
- Algorithm: logical process to solve some issues.
- Protocol: special algorithm used to put in communication two or more entities consisting in a set of rules that must be executed to communicate.

Communication requests rules.
The definition from ITU (International Teletraffic Union) of *Communication* is the transfer of information according to pre-established rules.
An abstract definition of communication rules governing the interaction between two or more users requires to define a *reference model* which specifies a network architecture defining:

- The communication process,
- The relationships among objects,
- The functions required to communicate,
- How those functions are organized.

The Open System Interconnection (OSI) model is the reference model for network architectures.
It has a layered architecture, as in the Figure below, which characteristics are separate functions, streamline design, reduction of management complexity, simplification of standardization.

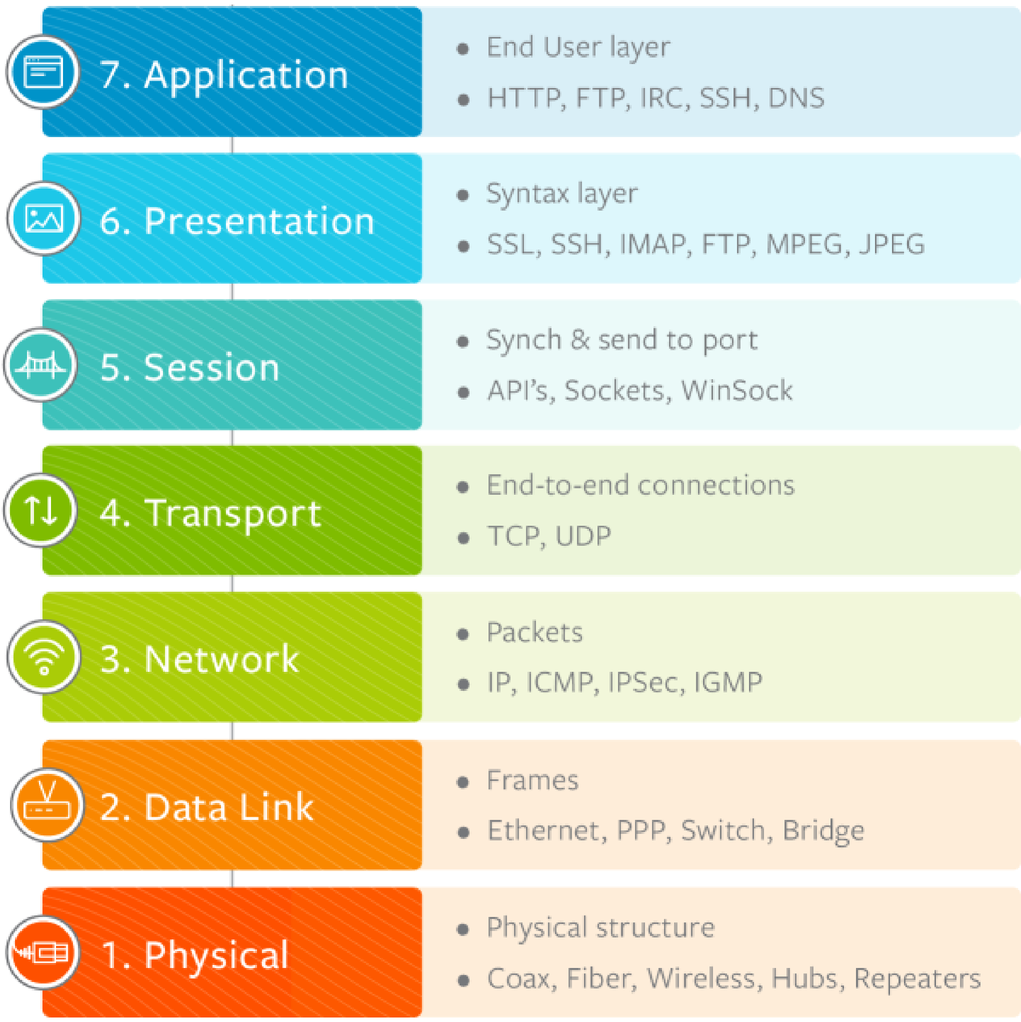


Figure 10 - OSI model (12)

This reference architecture is a standard for packet switching networks. There are several layers to put protocols in modules. So, the structure of protocols is layered, since every layer is responsible for some functionalities and ideally independent. Clear interfaces between layers are present. Today, the upper three layers are merged together in an unique layer called Application. This layer, also called Computer Science layer, is related to format and presentation, while functionalities related to the information transport are defined in the four bottom layers: Physical, Data Link, Network and Transport.

A *protocol* is the formal description of the procedure adopted to ensure the correct communication among two or more objects operating at the same hierarchical level.

Protocols are a set of rules concerning:

- Semantics (algorithms),
- Syntax (formats),
- Timing.

By making a parallelism between human and machine, protocols mean common rules that allow people to understand. Human beings are flexible, and rules are flexible as well. But when there is the definition of a protocol to be executed by machines, it is important to take into account that machines are not flexible like humans, and they cannot deviate from the rules. Typically, protocols are expressed in a formal language, like a programming language; for example MATLAB has a syntax and if the syntax is not correct, the machine will not understand.

When there are different entities to communicate, there is the need to specify precise rules that must be standard and communicated to all the producers of routers in the world: the network will work only if all entities speak the same language.

In the last 40 Years, an exponential increase in electronic systems' number and complexity has caught on especially in high-end vehicles. Today, a car has about 4000 meters of cables in spite of 45 meters of 1955's vehicles, furthermore the impact of the electronic systems is huge with respect to the total cost of a vehicle, about a quarter of the total.

The use of *drive-by-wire* systems is foreseen for the near future: it will use electronics in place of mechanical or hydraulic control modes. These systems require highly reliable networks.

Just as LANs connect computers, on-board or communication networks connect and control the electronic equipment of a vehicle. These networks facilitate the exchange of information and data between sensors and ECUs.

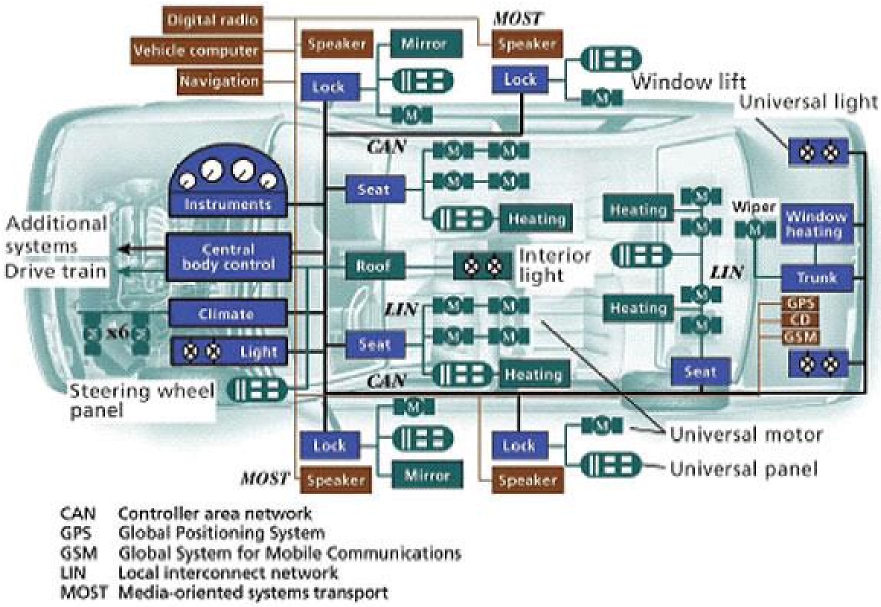


Figure 11 - On-board networks

The main protocols used in the automotive field are summarized in the bottom table.

	LIN	MOST	CAN	FLEXRAY	ETHERNET
Speed	up to 19.2 kbps	up to 23 kbps	up to 1000 kbps	up to 10 Mbps	up to 1 Gbps
Cable type	single cable 12V	Optical fiber / Coaxial	Two twisted cables 5V	2 or 4 cables	One or more double twisted cables
Cost	€	€€€€	€€	€€€	€€
Application	Electric seats, mirrors, headlights, rear door	Radio, CD, media players, infotainment	ABS, powertrain, engine control	Steering, traction control, active suspension	Camera IP, radar, infotainment

Table 1 - On board networks

LIN stands for Local Interconnect Network, it is used for:

- actuator control
- ECU-to-Actuator interconnection.

MOST stands for Media Oriented Systems Transport, it is used for:

- entertainment, personal communication, navigation

- GPS, display, speaker interconnection.

CAN stands for Controller Area Network, it is used for:

- vehicle control
- ECU-to-ECU interconnection.

FlexRay is an updated version of CAN, which is more performing and typically used on high-end vehicles.

Ethernet is a protocol in which the ECUs are arranged in a hierarchical order connected directly to each other by a data-highway with a network scalability typical of Ethernet.

In the Fig. 12, it's interesting to see how the growth of protocols increased in the years due to new requests in the automotive scenario in terms of electronic complexity.

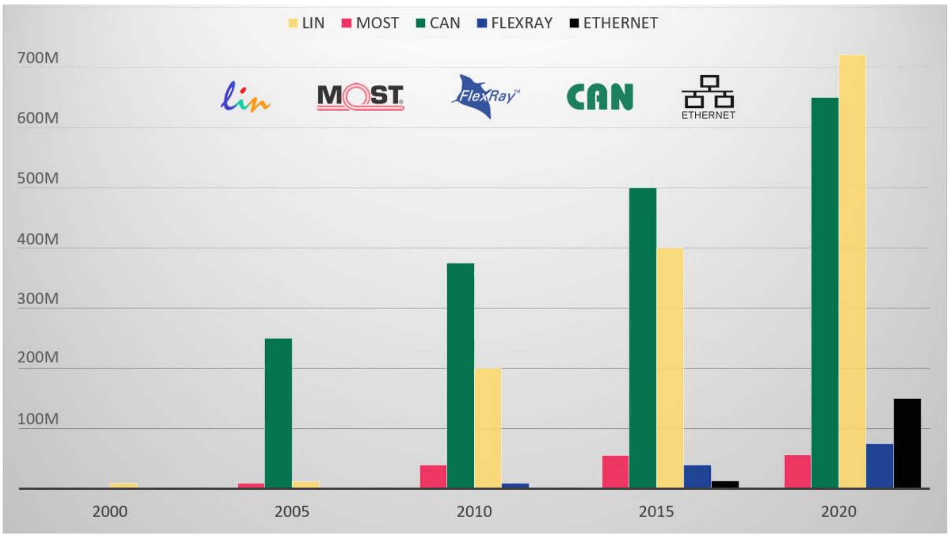


Figure 12 - Growth oh protocols in a vehicle (13)

This work will focus on CAN network, in next paragraph.

3.1.1 CAN-Bus architecture and functions

Serial communication bus for real-time control applications, CAN was born in the 1980s in Bosch and since 1993 is documented in ISO 11898 (for high-speed applications) and ISO 11519 (for low-speed applications) becoming the standard for on-board vehicle communications.

It consists of two wires and each node has the function of both master and slave.

The CAN specification only considers the Physical Layer and the Data Link Layer of the OSI / ISO 7498 model. Since a high-level protocol is also required, the CANopen standard has been developed which also uses the Application Layer.

For what concerns this work, it is necessary to introduce two CAN protocols: the ISO 11898 and the CAN SAE J1939.

ISO 11898

The International Standard Organization, ISO, published the first ISO 11898 published as one document in 1993.

ISO 11898 series specifies physical and data link layer (levels 1 and 2 of the ISO/OSI model) of serial communication category called Controller Area Network that supports distributed real-time control and multiplexing for use within road vehicles (14).

It is related to the CAN Data link layer, as well as the high-speed Physical layer.

ISO 11898 has been reviewed and restructured in a series of parts:

- Part 1 defines the data link layer including the logical link control (LLC) sub-layer and the medium access control (MAC) sub-layer, as well as the physical signalling (PHS) sub-layer;
- Part 2 defines the high-speed physical medium attachment (PMA);
- Part 3 defines the low-speed fault-tolerant physical medium attachment (PMA);
- Part 4 defines the time-triggered communication;
- Part 5 defines the power modes of the high-speed physical medium attachment (PMA);

- Part 6 defines the selective wake-up functionality of the high-speed physical medium attachment (PMA).

The figure below shows the field of action of the ISO 11898 series related to the OSI model.

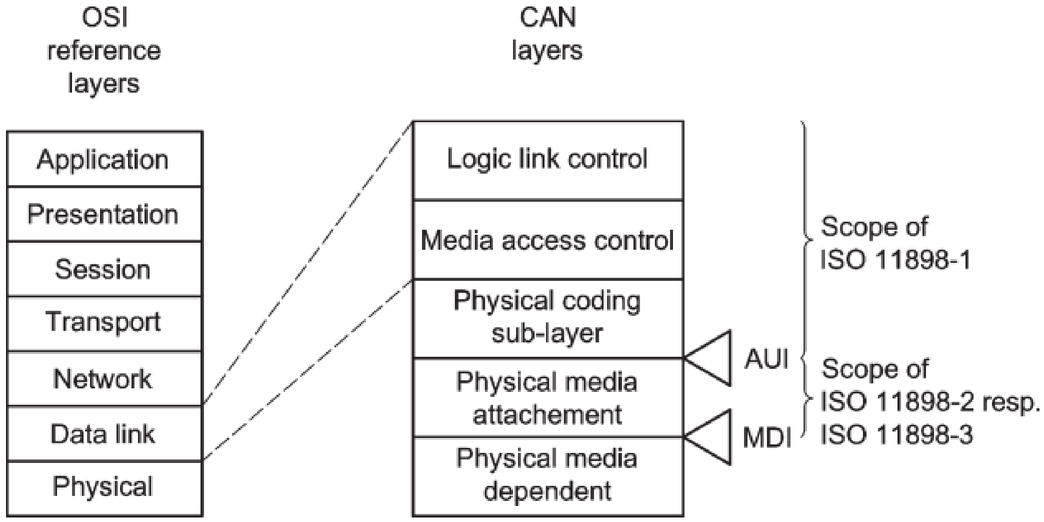


Figure 13 - ISO 11898 series

The CAN communications protocol, ISO-11898: 2003, describes how information is passed between devices on a network by conforming to the OSI model. Actual communication between devices connected by the physical medium is defined by the Physical layer of the model. The ISO 11898 architecture defines the lowest two layers of the seven layers OSI/ISO model as the data-link layer and physical layer (Fig. 13).

This part of ISO 11898 specifies the characteristics of setting up an interchange of digital information between modules implementing the CAN Data link layer. Controller area network is a serial communication protocol, which supports distributed real-time control and multiplexing for use within road vehicles and other control applications.

It describes the general architecture of CAN in terms of hierarchical layers according to the ISO reference model for open systems interconnection (OSI) according to ISO/IEC 7498-1. The CAN data link layer is specified according to ISO/IEC 8802-2 and ISO/IEC 8802-3 (15).

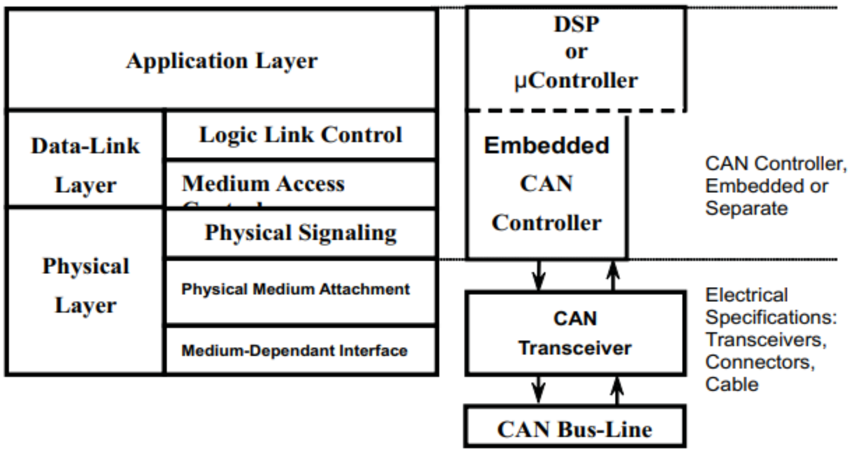


Figure 14 - Data-link layer and physical layer

The CAN communication protocol is a carrier-sense, multiple-access protocol with collision detection and arbitration on message priority (CSMA/CD+AMP). CSMA means that each node on a bus must wait for a prescribed period of inactivity before attempting to send a message. CD+AMP means that collisions are resolved through a bit-wise arbitration, based on a preprogrammed priority of each message in the identifier field of a message. The higher priority identifier always wins bus access. That is, the last logic-high in the identifier keeps on transmitting because it is the highest priority. Since every node on a bus takes part in writing every bit "as it is being written," an arbitrating node knows if it placed the logic-high bit on the bus. The ISO-11898:2003 Standard, with the standard 11-bit identifier, provides for signaling rates from 125 kbps to 1 Mbps. The standard was later amended with the “extended” 29-bit identifier.

CAN SAE J1939

The Society of Automotive Engineers (SAE) Truck and Bus Control and Communications Subcommittee has introduced a series of standards concerning the design and use of devices that transmit electronic signals and control information among vehicle components. SAE J1939 has quickly become the standard in the industry field and the default vehicle network for off-highway machines in applications such as construction, material handling, mass transportation, forestry machines, agricultural machinery, maritime and military applications.

From many years, this protocol is still gaining popularity, especially in view of the increased utilization in the fleet management systems, which will need data from the vehicle network, for instance, to calculate maintenance cycles. Fleet management is also tightly associated with the Internet of Things (IoT), and transportation is considered one of the fastest growing markets for IoT.

J1939 is a higher-layer protocol based on Controller Area Network (CAN). It provides serial data communications between microprocessor systems, such as the TCU, in any kind of heavy-duty vehicles. The messages exchanged between these units can be data such as vehicle road speed, torque control message from the transmission to the engine, oil temperature, and many more.

Even though extremely effective in automobiles and small, embedded applications, CAN alone is not suitable for projects that require a minimum of network management and messages with more than eight data bytes.

As a consequence, higher layer protocols (additional software on top of the CAN physical layer) such as SAE J1939 for vehicles were designed to provide an improved networking technology that support messages of unlimited length and allow network management, which includes the use of node IDs (CAN supports only message IDs where one node can manage multiple message IDs).

Let’s see the main characteristics (16):

- Is a Higher-Layer Protocol using CAN as the physical layer
- Uses shielded twisted pair wire
- Applies a maximum network length of 40 meters (~120 ft.)
- Applies a standard baud rate of 250 Kbit/sec
- Allows a maximum of 30 nodes (ECUs) in a network
- Allows a maximum of 253 controller applications (CA) where one ECU can manage several CAs
- Supports peer-to-peer and broadcast communication

- Supports message lengths up to 1785 bytes
- Defines a set of Parameter Group Numbers (PGNs, predefined vehicle parameters)
- Supports network management (includes node IDs and an address claiming procedure).

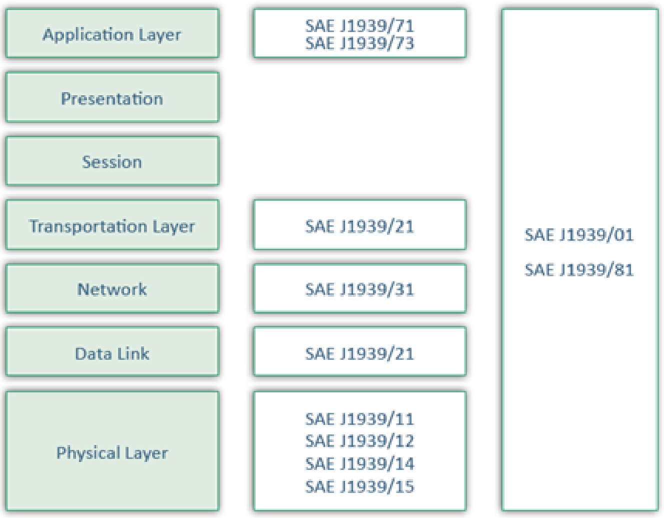


Figure 15 - SAE J1939 compared to OSI model

Compared to other, function-driven protocols such as CANopen and DeviceNet, SAE J1939 is primarily data-driven. In fact, J1939 provides a far better data bandwidth than any of these automation protocols.

J1939 data packets contain the actual data and a header, which contains an index called Parameter Group Number (PGN). A PGN identifies a message's function and associated data. J1939 attempts to define standard PGNs to encompass a wide range of automotive, agricultural, naval and off-road vehicle purposes.

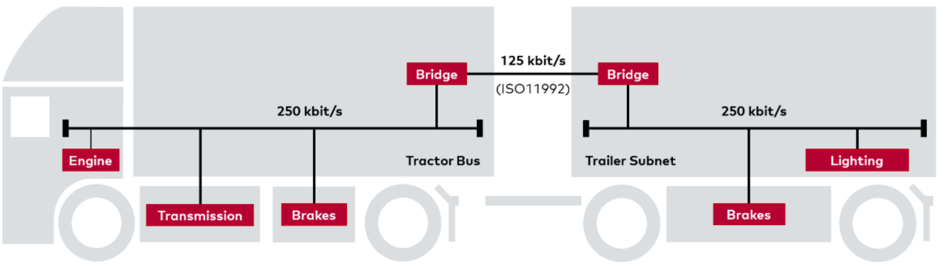


Figure 16 - Typical J1939 vehicle network

3.1.2 OBD

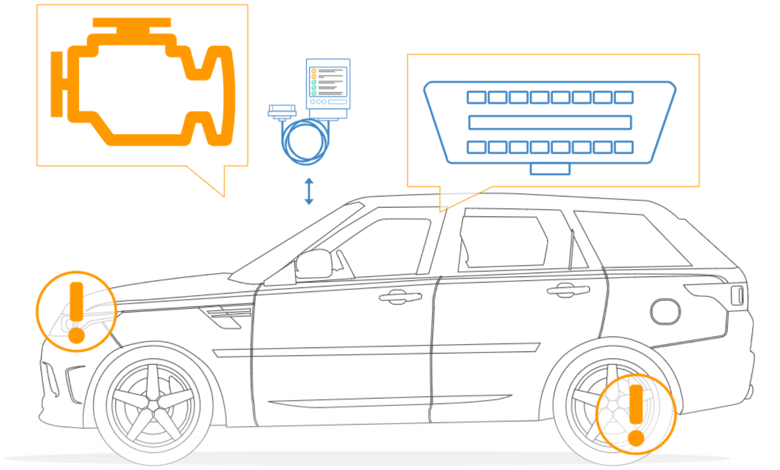


Figure 17 - On board diagnostics

On-board diagnostics, OBD or OBD-II, in an automotive context, is a generic term that refers to the ability to self-diagnose and report errors/failures of a vehicle (17).

On-board diagnostics (OBD) refers to the vehicle's electronic system that provides self-diagnosis and signals any faults and errors giving technicians access to subsystem information in order to monitor performance to proceed with the necessary repairs (18).

It is a standard protocol used to catch diagnostic information from engine control units or engine control modules.

OBD-II was born in California where the California Air Resources Board (CARB) required OBD in all new cars for emission control purposes from 1991.

The OBD-II standard was recommended by the Society of Automotive Engineers (SAE) and standardized DTCs and the OBD connector across manufacturers (SAE J1962).

From there, the evolution of OBD-II standard was rolled out step-by-step:

- 1996: Mandatory in USA for cars/light trucks
- 2001: Required in EU for gasoline cars
- 2003: Required in EU also for diesel cars (EOBD)

- 2005: Required in US for medium duty vehicles
- 2008: US cars must use ISO 15765-4 (CAN) as OBD-II basis
- 2010: Finally, OBD-II was required in US heavy duty vehicles.

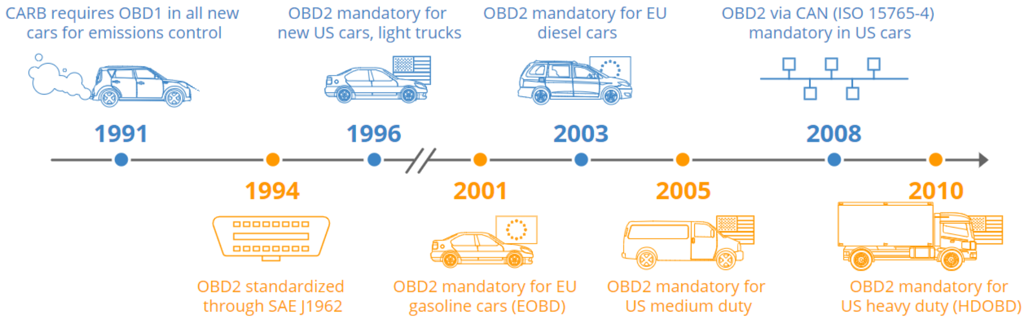


Figure 18 - OBD history (19)

By talking about telematics, OBD is its main part because it allows fleet management to measure and manage the status and driving of vehicles. Thanks to OBD, fleets can:

- monitor vehicle wear and determine which parts of the vehicle are deteriorating faster than others;
- instantly diagnose vehicle problems before they occur, supporting proactive rather than reactive management;
- repair any malfunction before it becomes a serious problem;
- measure driving style, speed, idle time, battery data and much more.

Usually, the OBD-II port is located under the dashboard and it has a configuration with 16, 6 or 9 pins on the basis of the vehicle type.

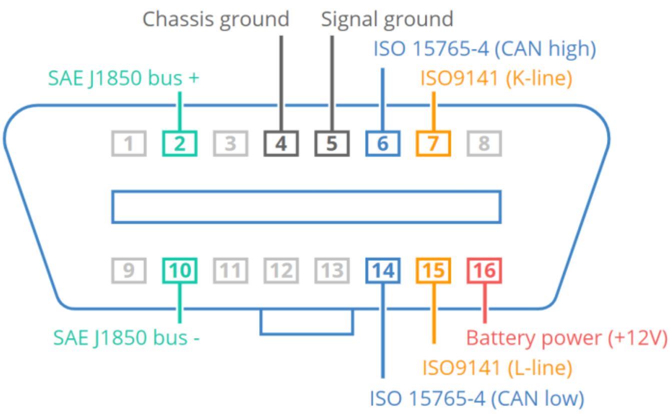


Figure 19 - OBD-II port (19)

OBD port is used by the technician to find faults in the vehicle. The action consists in connecting an OBD-II connector to this port that converts the error code into readable format. This error data is gathered by the vehicle diagnostics system.

It is possible to find two types of port: type A and type B. Typically, type A in installed on cars, while type B is common on medium and heavy-duty vehicles (see the figure below).

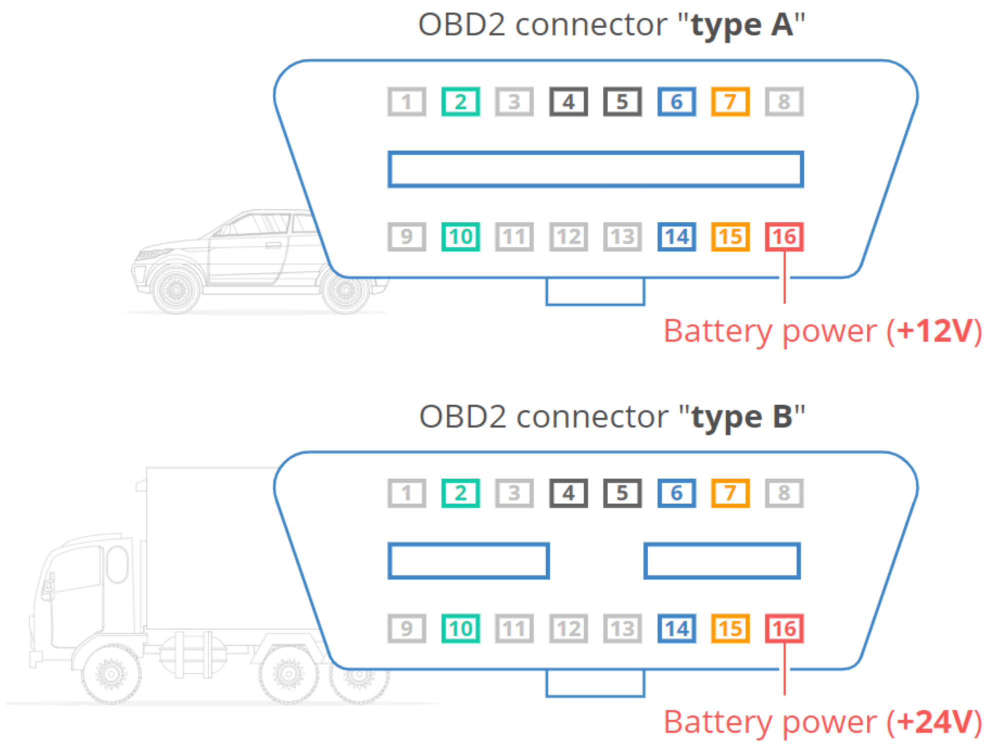


Figure 20 - OBD-II type A and type B (19)

As evident from the illustration, the two types share similar OBD-II pinouts, but provide two different power supply outputs: 12V for type A and 24V for type B.

To distinguish between the two ports of OBD-II sockets, an interrupted groove in the middle is present for the type B connector. As consequence, a type B OBD-II adapter cable will be compatible with both types A and B, while a type A will not fit into a type B socket.

OBD-II is a higher layer protocol (like a language). CAN is a method for communication (like a phone). In particular, the OBD-II standard specifies the OBD2 connector, including a set of five protocols that it can run on:

- **ISO 15765 (CAN bus):** Mandatory in US cars since 2008 and is today used in the vast majority of cars
- **ISO14230-4 (KWP2000):** The Keyword Protocol 2000 was a common protocol for 2003+ cars in e.g. Asia
- **ISO9141-2:** Used in EU, Chrysler & Asian cars in 2000-04
- **SAE J1850 (VPW):** Used mostly in older GM cars
- **SAE J1850 (PWM):** Used mostly in older Ford cars.

Further, since 2008, CAN bus has been the mandatory protocol for OBD-II in all cars sold in the US.

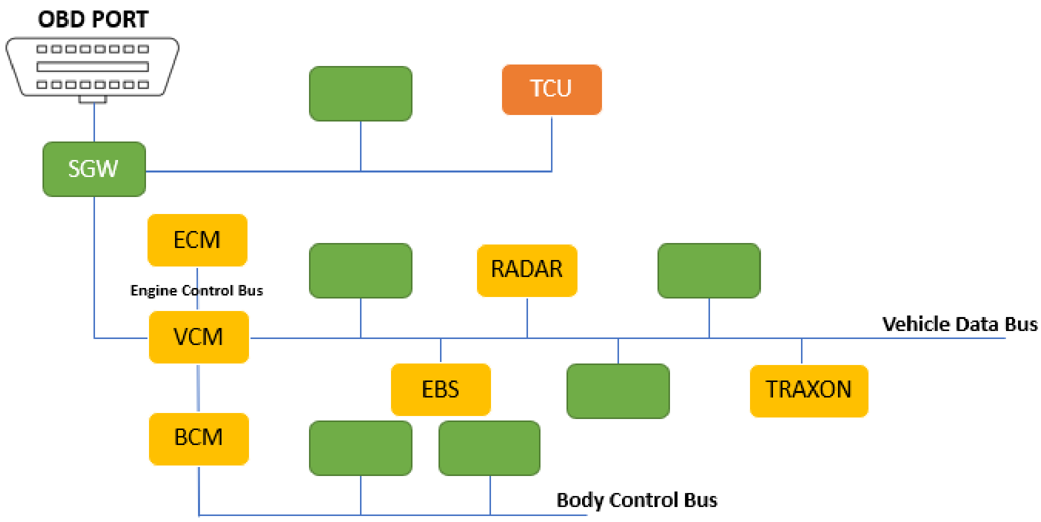


Figure 21 – OBD and CAN

The presence of OBD-II allows telematics devices to process information such as engine rpm, vehicle speed, DTCs, fuel consumption and much more in an easy way, by determining the start and end of a trip, the increase in revs, the overspeed, the reduction of the idle speed, the fuel consumption and so on. All this information is loaded into a software interface and allows mobility managers to monitor vehicle usage and performance.

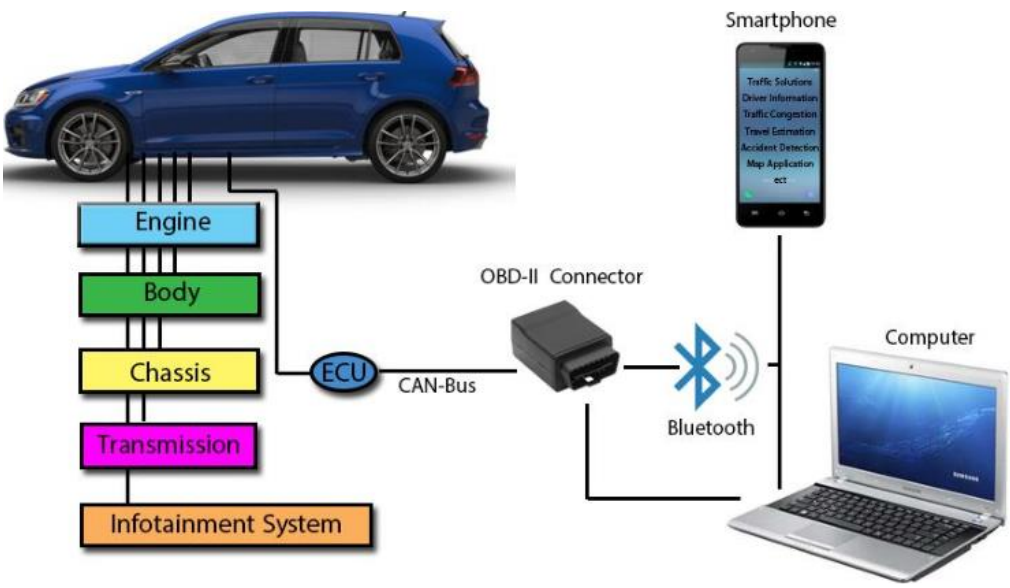


Figure 22 - OBD-II and CAN bus

OBD-II provides access to status information and *diagnostic trouble codes* (DTCs) for:

- powertrain (engine and transmission);
- emission control systems.

In addition, the following vehicle information can be accessed:

- vehicle identification number (VIN);
- identification number of the calibration software (CALID);
- ignition cycle counter;
- meters of the emission control system.

3.1.3 DTC

A DTC, short for Diagnostic Trouble Code, is a code used to diagnose malfunctions in a vehicle or heavy equipment. While the malfunction indicator lamp (MIL), also known as the check engine light, simply alerts drivers that

there is an issue, a DTC identifies what and where the issue is. DTCs are also called engine vehicle fault codes, and can be read with a scanner that plugs directly into the port of a vehicle (20).
These codes were created by the Society of Automotive Engineers (SAE) to help vehicles comply with emission regulations.
DTCs are generated by the vehicle's on-board diagnostics (OBD) system whenever a fault is detected. The OBD both diagnoses the fault and displays the DTC through visible warnings such as the illumination of a check engine light. It is also what allows external devices, such as an OBD scanner, to interact with a vehicle's onboard computer system.
Thanks to computerization and improvements in vehicle technology, as soon as an error is detected the fault codes are stored on an on-board module and, if it is a serious or emissions-related problem, the engine fault warning light is activated.
Using the diagnostic equipment connected to the 16-pin data transfer connector (OBD), a mechanic can acquire information related to fault codes and implement the correct actions reading the vehicle repair sheets.
Thanks to the Telematic Control Unit these codes are transmitted via cloud to off-board services such as backend and cloud applications, allowing vehicles' maintenance in real time, before the problem becomes critical.
When the TCU recognizes and identifies a problem, a DTC is stored in its memory under a code format which helps to find the root cause of the failure.
The diagnostic codes are required by law on all OBD-II systems and for this reason they are standardized do that all vehicle manufacturers could use the same code list.

OBD-II DTCs consist of five-digit alphanumeric characters. Each character in the DTC provides a different piece of information about the vehicle's problem.
The first character is always a letter. It indicates which control system has an issue, and has the following possible values and meanings (21):

- P (powertrain) refers to the engine, transmission, fuel system, and associated accessories.
- C (chassis) refers to mechanical systems generally outside the passenger compartment such as steering, suspension, and braking.
- B (body) refers to parts mainly found in the passenger compartment area.
- U (network) refers to the vehicle’s onboard computers and related systems.

The second character is a digit, typically 0 or 1, and shows whether or not the code is standardized:

- 0 indicates that the code is generic, standardized SAE (Society of Automotive Engineers) code. Generic codes are adopted by all cars that follow the OBD-II standard.
- 1 indicates that the code is vehicle manufacturer-specific. These codes are unique to a specific car make or model and are typically less common.
- 2 or 3 are more rare and their meanings are dependent on the preceding letter of the code. Most of the time, 2 or 3 indicates that a code is manufacturer-specific, with only a few exceptions.

The third character is also a digit, ranging from 1 to 8. This reveals the subsystem at fault.

- 1 refers to the fuel or air metering system
- 2 refers to the fuel or air metering injection system
- 3 refers to the ignition system
- 4 refers to the emissions system
- 5 refers to the vehicle speed controls and idle control system
- 6 refers to the computer output circuit
- 7 and 8 indicate that the issue is transmission-related.

The fourth and fifth characters are read together as a two-digit number between 0 and 99 known as the specific fault index. These characters identify the exact issue of the vehicle.
Failures occurring in non-powertrain systems such as ABS, HVAC (Bxxxx, Cxxxx, Uxxxx codes) may be get through the OBD-II connector but they do not illuminate the check engine light and are not involved with emissions inspections.
Below a chart which summarizes the logic behind the code.

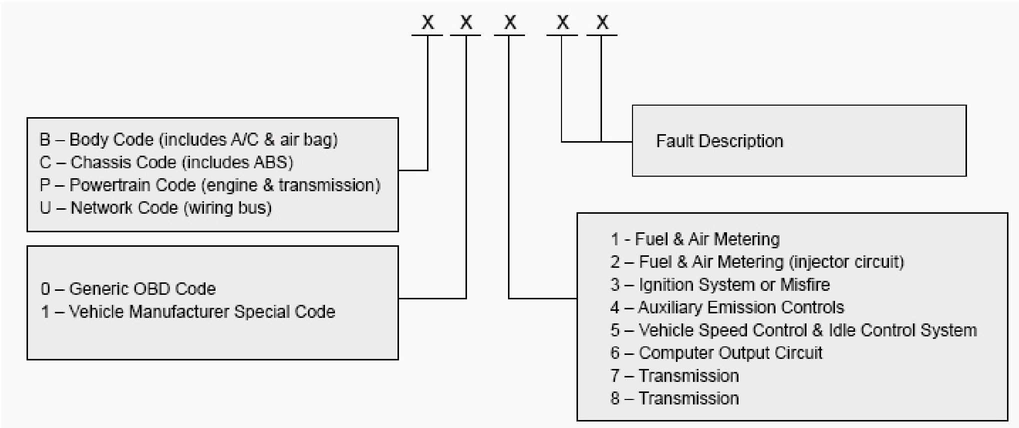


Figure 23 - DTCs description

For example, if the TCU commands the check engine light to illuminate there will be at least one P0xxx code stored in memory. However, in some cases in which there is a P0xxx code in memory, but the check engine light is not commanded to be illuminated. These codes are referred to as pending or maturing codes. Pending codes are caused by intermittent faults or faults that the TCU needs to see happen in two consecutive warm-up cycles to set the code. If the fault does not reappear within 40 warm-up cycles, the code will be cleared from memory. If the fault reappears for the specified number of times, the code will then mature into a diagnostic trouble code (DTC) and the TCU will command the check engine light to illuminate.
When a pending code is stored, freeze frame data is also captured. This last will give the actual operating conditions that were occurring when the fault triggered to the professional repair technician. This data allows for duplication

of conditions so that it is possible to isolate the fault. The component/process of the pending code is often involved as part of the enabling criteria to successfully complete the monitoring.
There are scanners which read DTCs, known as OBD-II scanners, but if there is the need to manage a wide fleet of vehicles it could be inefficient to manually check a vehicle every time an engine alert turns on.
A telematic solution is the right way to experience the fleet DTCs through a DTC tool which can identify quickly what is the issue and the steps to follow to schedule maintenance in real time.
For example, the Samsara vehicle gateway plugs directly into the OBD-II or the J1939 port of a vehicle and can thus relay any information regarding any DTC directly to the Samsara Dashboard. Furthermore, alerts can be triggered in the event that a DTC occurs by using the "Vehicle Fault" alert. It is possible also to use Samsara’s DTC filtering feature to get alerts for the DTCs that matter most to your fleet.

3.2. CAN Tools

CANoe and CANalyzer are software tool designed by Vector Informatik GmbH.
These tools are used to get and elaborate data from the vehicles’ CAN bus physically from the OBD-II port.

3.2.1 CANoe

CANoe is a development and testing software tool primarily used by automotive manufacturers and ECU suppliers for development, analysis,

simulation, testing, diagnostics and start-up of ECU networks and individual ECUs. The simulation and testing facilities in CANoe are performed with CAPL, a programming language. It supports CAN, LIN, FlexRay, Ethernet and MOST bus systems as well as CAN-based protocols such as J1939, CANopen, ARINC 825, ISOBUS and many more.
Beyond the scope of communication in a single car, CANoe is used in the development of cooperative systems via V2X.
At the beginning of the ECUs' development process, CANoe is used to create simulation models that simulate their behaviour. Throughout the course of this development, these models are used as a base for analysis, testing and integration of the bus systems and ECUs.

Application areas are (22):

- **Analysis**: users can analyse the multi-bus communication of ECUs and entire systems at their desk as well as in the vehicle through these smart support windows:
    1. **Trace Window** for listing all bus activities such as messages or error frames. For each message there is the possibility of displaying the individual signal values.
    2. **Graphics Window** for graphical online display for values transmitted in messages and diagnostic requests, such as rpm or temperature values, over a time axis.
    3. **Statistics Window** for displaying useful network and node statistics, e.g. bus load on node and frame levels, burst counter/duration, counter/rate for frames and errors, controller states.
    4. **Data Window** for displaying preselected data, e.g. numeric or bar graph data.
    5. **State Tracker** for displaying states and bit signals.

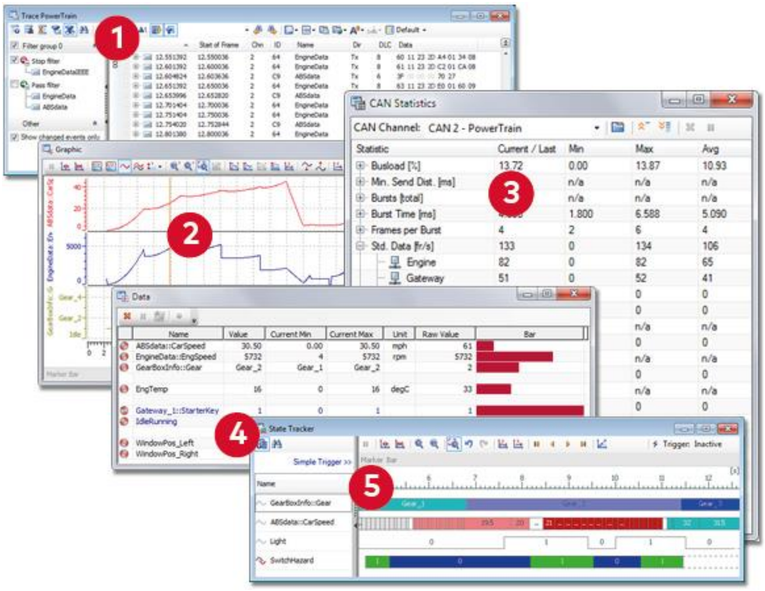


Figure 24 - Canoe Smart windows

- **Diagnostics**: it is possible to test and simulate ECUs diagnostically. CANoe supports all relevant automotive networks and transport protocols. You can perform diagnostic tests automatically, semi-automatically as well as interactively. For interactive tests, a diagnostic window is available for all important use cases (e.g. reading fault memory, variant coding, OBD-II).

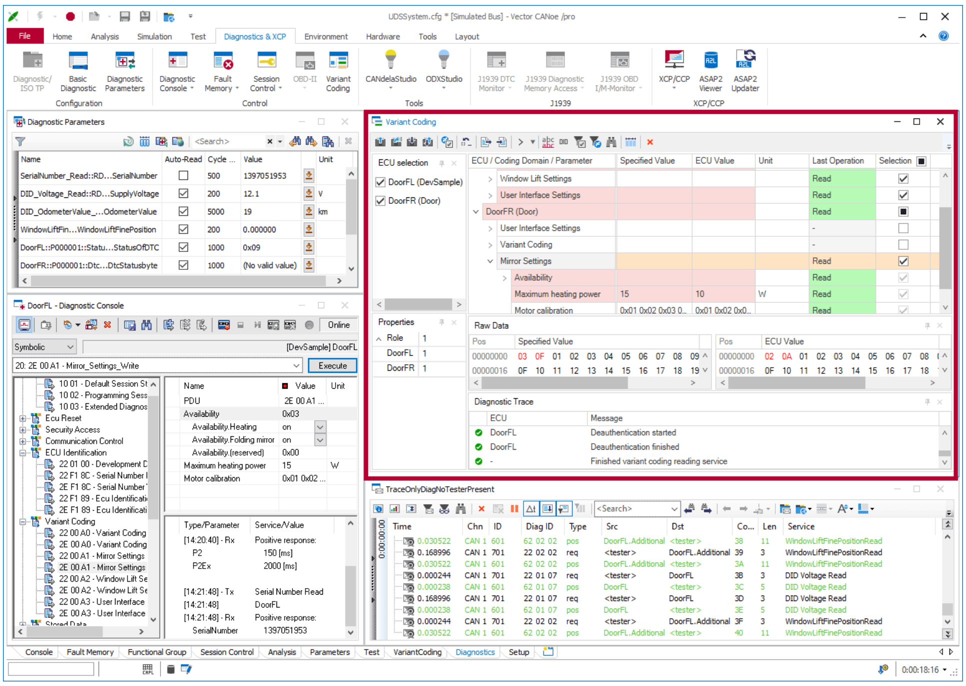


Figure 25 - Canoe diagnostics

- **Simulation**: it is possible to test and analyse a System Under Tests (SUT) by transferring real components to a simulation under laboratory conditions; in this way the SUT is operated under defined, controlled and reproducible situations in order to test limit and exceptional situations without risk. All development phases are supported with this residual bus simulation.

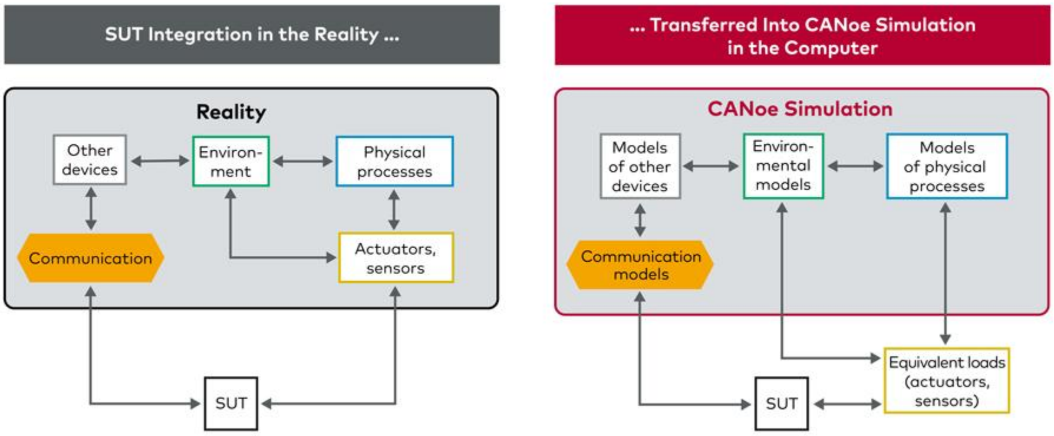


Figure 26 - Canoe simulation

- **Stimulation**: events are applied to a System Under Test (SUT) to produce a desired response. These stimuli can be planned controls or scheduled system disturbance for further investigations. The goals of a stimulus are:
  - Controlled, reproducible excitation of your SUT
  - Various test scenarios for your analyses
  - Determine optimal control parameters.

- **Testing**: CANoe represents the state-of-the-art test environment as well for the entire system as for efficient ECU testing. It supports users with impressive performance on:
  - ECU tests
  - Module tests
  - Integration tests
  - Conformance tests
  - Regression tests

- Testing of ECU prototypes.

3.2.2 CANalyzer

CANalyzer is a software tool for analysis and stimulation of network communication widely used, primarily by automotive and electronic control unit suppliers, to analyze the data traffic in serial bus systems. The most relevant bus systems here are CAN, LIN, FlexRay, Ethernet and MOST as well as CAN-based protocols such as J1939, CANopen, ARINC 825 and many more.

Beyond its robust bus monitoring functionality, CANalyzer has many stimulation and analysis functions for triggering and analyzing message traffic and data contents.

Application areas are (22):

- **Analysis**: in this case, intelligent analysis windows are:
  - **Trace Window** for listing all network activities such as messages or error frames. For each message there is the possibility of displaying the individual signal values.
  - **Graphics Window** for graphical online display for values transmitted in messages and diagnostic requests, such as rpm or temperature values, over a time axis.
  - **Statistics Window** for displaying useful network and node statistics, e.g. bus load on node and frame levels, burst counter/duration, counter/rate for frames and errors, controller states.
  - **Data Window** for displaying preselected data, e.g. numeric or bar graph data.

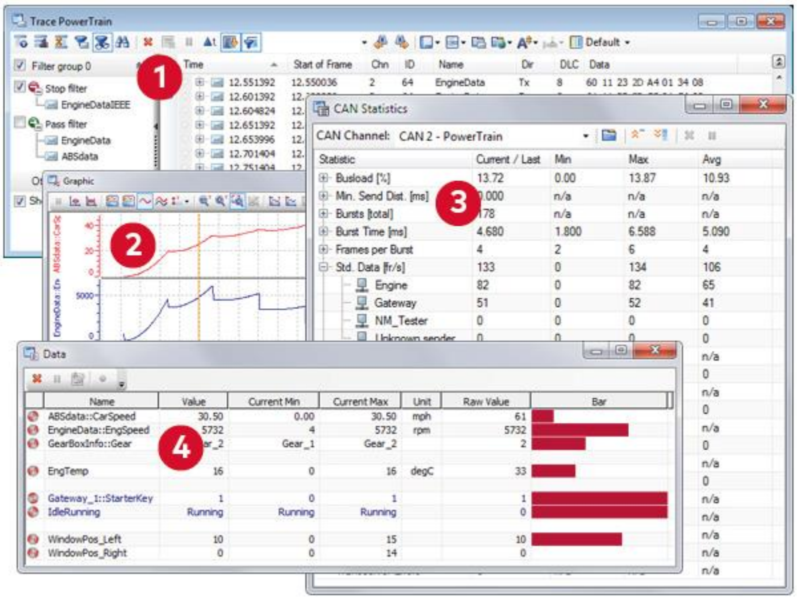


Figure 27 - Canalyzer analysis intelligent windows

- **Diagnostics**: same as CANoe.
- **Logging**: CANalyzer is used to log data and replay them for post-measurement analysis. The import/export functions allow time-independent processing of the logged bus communication. Logging is performed via special logging blocks in the measurement setup. It is also possible to log directly from the Graphic Window and Data Window. Then the logged data can be returned back into the system for offline analysis.

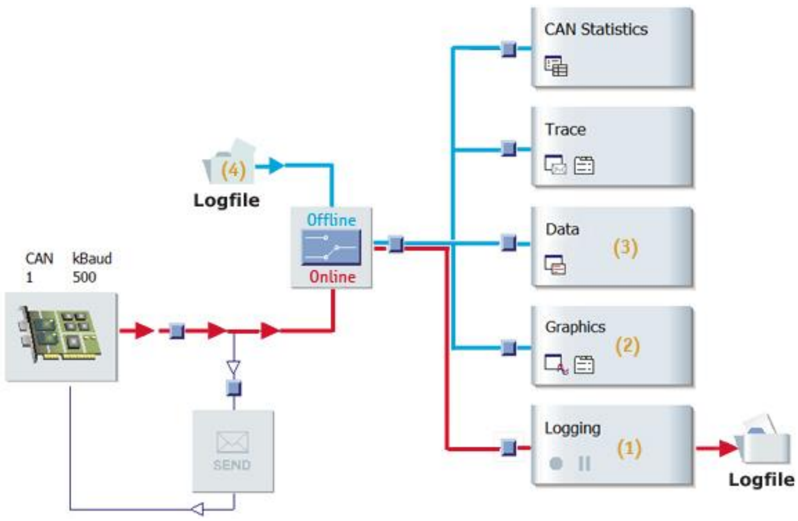


Figure 28 - Canalyzer logging

- **Stimulation**: observe, analyze and influence the data traffic of ECUs through preconfigured user interfaces, with which it's possible to send simple messages and signal values to the system.

The main difference between the two tools is that in CANalyzer there is only one simulated node, while in CANoe there are multiple simulated nodes. Using the last one, it's possible the access to the whole simulated CAN/Flex-ray bus. CANalyzer supports simulation on a single node, so for a distributed system you can only simulate a single node and rest of the nodes must be connected physically.

Chapter 4

Development

4.1. Methodology

After an introduction to Telematics and the state of the art of protocols used to transfer data from control units, now it's the moment to understand the application of this technology.
In this chapter, the work will focus on how to employ this huge amount of data of control units, in particular for diagnostics, in order to manage vehicle fleets.
On board diagnostics is an important tool to allow fleets' owners to reduce maintenance costs, consumption costs, vehicles loss due to breakdowns, increasing safety and controlling drivers use of the vehicles; furthermore, it helps vehicle producers to monitor its vehicles and obtain suggestions for improvement.
In fact, the knowledge of the most frequent vehicles faults and various issues related, is crucial not only to offer an optimal aftersales customer service performed by an experienced assistance, but also to improve internal processes related to vehicles' quality.
The workflow, discussed in the next paragraphs, is related to a test tracing coming from heavy-duty vehicles which shows the alerts, the so-called DTC mentioned in the previous chapter, occurred in a certain amount of time and mileage.
The data flux is managed through a web dashboard which is organized by various functions, and where it is possible to export into an Excel file the required data to analyze.

Through this portal the dirty data coming from control units are cleaned and reported in an easy and understanding way useful for engineering purposes and analysis; an example of portal could be QlikView, a tool of business intelligence which will be discussed in the next chapter. Here there are a set of windows each concerning a different action on data, such as trigger KPI computing, claims, geofencing, assists, dossier, statistics and the list of vehicles with DTC in real time, as shown in the figure below.

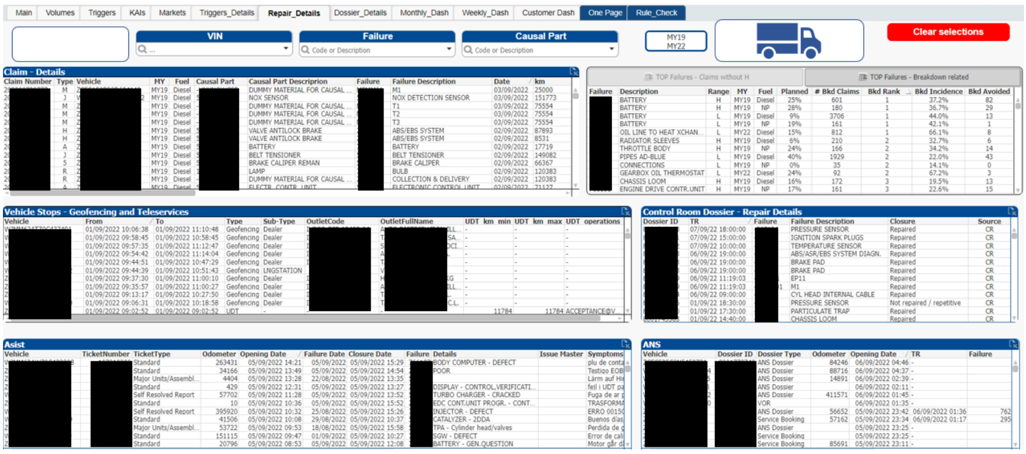


Figure 29 - Qlikview dashboard for the download of data

This little excursus is useful to understand the origin of the test tracing that will be analyzed and discussed in the next paragraph.

The scope of the project is to create a trigger / rule which will allow the best planning of assistance interventions avoiding incurring of vehicles' unforeseen stops, starting from data coming from the field through on-board Telematics.

Figure 30 - Methodology phases

The methodology can be deployed in five main phases:

- **Telematics data** → assistance team receives data of the faults in real time through the TCU and visualize them on a web portal, with the possibility to export data and analyze them.
- **Trigger design** → analysis of DTC test tracing to create a rule with a threshold and a certain efficiency, which allows the most proper workshop call for the vehicle.
- **Alert** → when the trigger threshold is overcome, it generates an alert.
- **Customer contact** → after the alert, there could be a series of actions aimed to warn the customer for the programming of a vehicle stop.
- **Repair** → when the vehicle stops into the workshop, operators apply the proper actions to solve the fault following the sheets delivered by the vehicle producer company.

4.2. Trigger Design

The purpose of the trigger is to establish when to recall the vehicles in terms of duration and occurrence of the DTC studied.

For example, if the DTC occurrence number is too high there is the risk of vehicle stopping due a breakdown, while if the occurrence number is too low there is the risk of having false alerts and therefore recalling vehicles unnecessarily to the workshop.

The scope is to find an optimal threshold finding the best compromise between precision of the trigger and sensitivity, as will be explained further on.

In the following paragraphs is described the procedure to define, test and monitor a trigger.

4.2.1. Trigger definition

There are vehicles in test environment, available in a QlikView panel that are monitored to check if a particular faults, with an assigned severity, repeats more than others.
At this point, the question is “Is there a DTC related which can allow to prevent the issue?”:

- if YES, it can be studied and analyzed
- if NO, no trigger design.

From these observations the team starts to study the specific DTC analyzing information sent by the TCU of vehicles with that problem.

First level of analysis is based on the extraction, from the portal, of a test tracing in excel file, that contains the following information:

- **Vehicles’ codes** → identification code of the vehicle
- **DTC code** → standard code which identifies the fault
- **Class** → it can be:
    - **Workshop absorbed,** when the DTC switches off thanks to the actions performed in the workshop
    - **Naturally absorbed**, when the DTC switches off without going to the workshop or it goes to the workshop without taking actions related to that DTC
    - **Monitoring**, the vehicle is not called into workshop but is monitored for a certain mileage/time after the DTC switches off
- **DTC time first** → the time in which the DTC appears for the first time
- **DTC time last** → the time in which the DTC appears for the last time
- **DTC km first** → vehicle total mileage when first DTC appears
- **DTC km last** → vehicle total mileage when last DTC appears
- **Number of DTC occurrence** → how many times DTC appears
- **Duration** → how much time DTC appeared, expressed in seconds
- **Workshop time** → time the vehicle arrived in the workshop

- **Claim →** calibrations or replacements of components related to the failure
- **Claim note →** replacement or calibration
- **UDT →** actions made through diagnostics tool
- **Dossier →** a sheet opened by the workshops to list all the actions made on the vehicle accessible to customer service department engineers.

By looking at the information related to the claims, UDT operations and dossiers, a reclassification of the classes is performed:

- ***True positive***, if the DTC switched off thanks to the actions performed in the workshop
- ***False positive***, if the DTC switched off without going to the workshop or going to the workshop without taking actions related to that DTC.

When the reclassification is performed is possible to evaluate the efficiency of the trigger that has to be, at least, 80% in order to have a good trigger which properly calls the vehicle.
Trigger precision is calculated in this way:

$$\boldsymbol{trigger\ precision}\ [\%] = \frac{\boldsymbol{true\ positive}}{\boldsymbol{true\ positive} + \boldsymbol{false\ positive}}$$

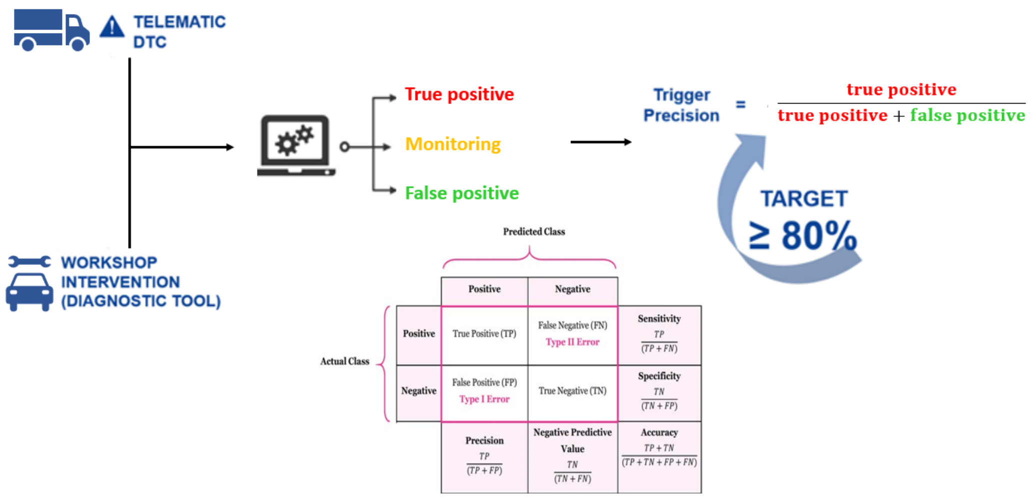


Figure 31 - Trigger definition and precision

The rule is set establishing some thresholds which purpose is to reduce the *false alerts* without excluding too many *true positive*, to increase the precision percentage.

The possible actions are:

- Set *occurrence* > of a certain number
- Set a maximum *duration*
- The DTC has to occur in different days.

Usually, the team acts on the occurrence, because it is a data which allows to play more with values, and it is more intuitive.

The example, shown in the Fig. 32, makes the idea of the procedure adopted to define the rule, acting as said before, on the occurrence number (it will be explained more in details in the study case).

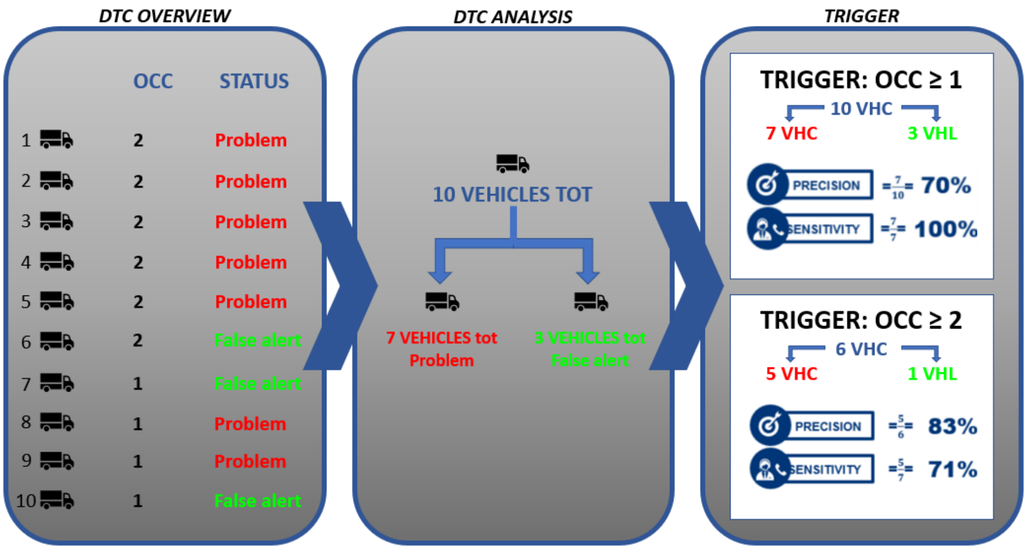


Figure 32 - Example of trigger design

4.2.2. Reliability assessment

The trigger precision is then optimized by an algorithm based on the Confusion Matrix, shown in the Fig. 33, also including the sensitivity and the accuracy.

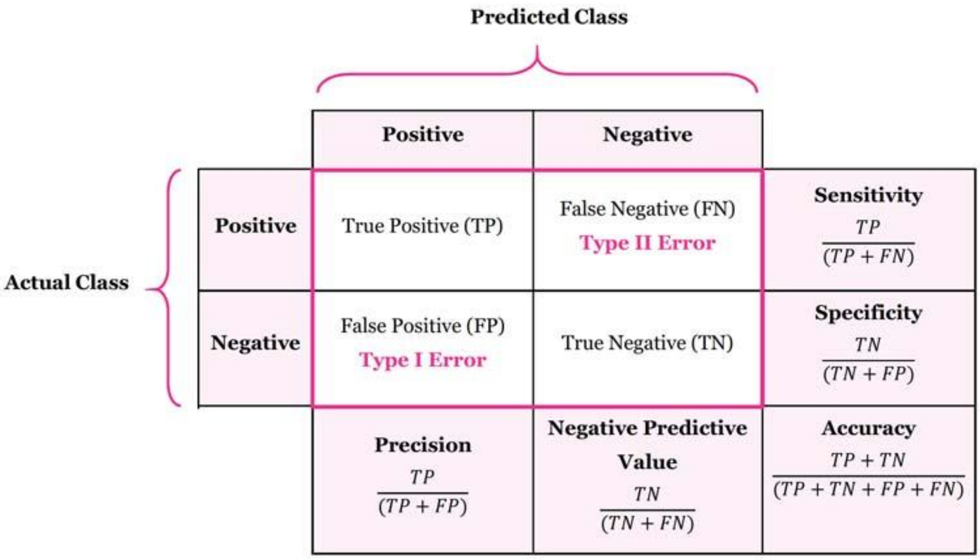


Figure 33 - Confusion Matrix

After the analysis which lead to the definition of the rule, the trigger is inserted in a web dashboard where it is monitored.

When a trigger is designed is important to define the maturity level, so there are two different environments:

- **Test** → added in this environment to allow the vehicle producer to monitor the efficiency of its studies. In this phase the driver doesn't know anything and no alarms on dashboard are implemented
- **Production** → the trigger is efficient and work correctly so is moved on production, but its monitoring continues. At this point alerting is possible.

The Key Performance Indicators' (KPIs) computing is a tool present on QlikView, which contains all the vehicles details and triggers' statistics.

The KPIs' computing (based on the indicators in the Fig. 34), gives a theoretical efficiency of the trigger which must be studied:

1. The focus in on high efficiencies and high volumes
2. Is the efficiency really so high?
    - If YES, the trigger goes in Production,
    - If NO, the trigger is discarded.

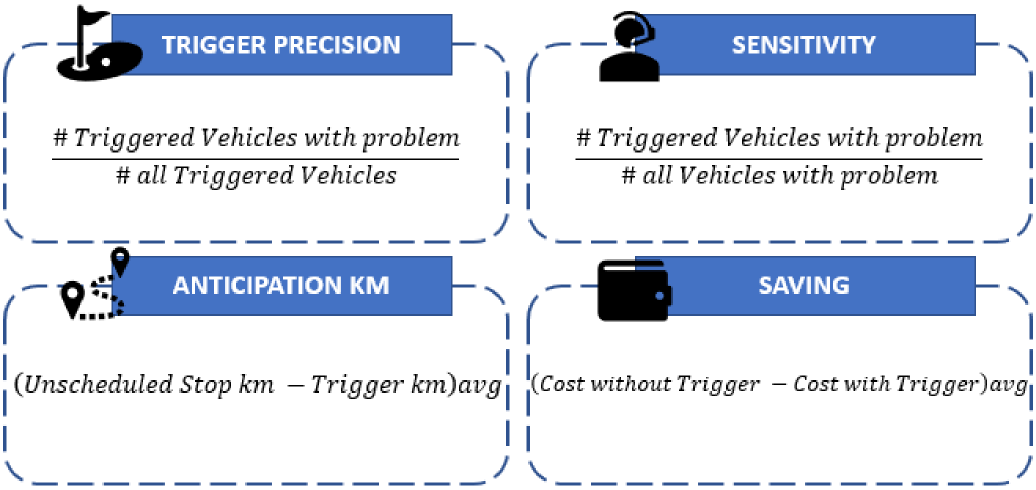


Figure 34 - KPI computing

4.2.3. Monitoring

After the trigger goes in production, the monitoring continues to verify:

- if there are too much false positive;
- the completeness of the repair sheets used by the workshops to absorb the DTCs.

In this phase, different studies and observations can be made referring to dossiers:

- For example, for a specific DTC the most of dossiers reports that they solved fault with the replacement of a component, which is not mentioned in the repair sheet, so in this case it is important to modify the sheets
- Every time a vehicle is called, a dossier is opened and then it is closed by the workshop, but, for example, if out of 50 files, 30 are closed as false alerts, it means that the trigger responsible for the vehicle call is not precise because it is wrong in 60% of cases (a precision of 40% is low)
- When a dossier is closed, it is traced as *SOLVED* or *NOT SOLVED* on the base of the resolution or not resolution of the fault, therefore if 50

vehicles stopped, 20 are *solved* and 30 are *not solved*, then the repair guide must be modified. It should have a resolution percentage of 90% at least.

4.3. Study case

The practical case under study is a test tracing downloaded from QlikView panel, for a recurrent fault related to a specific sensor.
The DTC chosen to represent the problem is the standard code **P2453**, which is a powertrain fault code related to the Particulate sensor electric error.

Figure 35 - Example of warning lights for particulate filter

When encountering a P2453 code, the powertrain control module (PCM) detects a malfunction in the electrical circuit of the diesel particulate filter (DPF) pressure sensor. This code should only appear in vehicles equipped with a diesel engine.

vehicles	DTC	Class	DTC TIME first	DTC TIME last	DTC km first	DTC km last	# occ	Duration [s]	workshop TIME	claim	note claim
vehicle 1	P2453	workshop_absorbed	10/02/2021 10:11:19	22/03/2021 13:40:39	1020	19256	817	1934060	22/03/2021 15:06:00	[24/03/2021] PM sensor 58	**replaced**

Figure 36 - DTC P2453 Example

From the repair sheet of this DTC, it's possible to know:

- **Cause:**
  The fault could be determined by a faulty particulate sensor or problems with the wiring.
- **Possible failure modes:**
  1. Fault in connectors
  2. Fault in the wiring harness
  3. Fault in the ECM engine control unit, presence of incorrect, intermittent or erratic data
  4. Fault in the particulate sensor.

This code should be considered urgent, as it indicates conditions that could cause damage to the internal engine or fuel system.

Figure 37 - DPF

DPF systems in OBD-II vehicles are designed to remove about 90% of carbon particles (soot) from diesel engine exhaust. Black smoke coming out of the exhaust of a diesel engine (under hard acceleration) can be attributed to soot. The DPF is housed in a steel inline exhaust housing resembling a muffler or catalytic converter. Ideally, large soot particles are trapped in the DPF element. Small particles and other compounds (exhaust gases) can flow through; a wide range of elemental compounds are used (by the DPF) to trap large soot particles and allow engine exhaust to flow.

The core element of any DPF is the filter element. Large soot particles are trapped between the fibers as the engine exhaust flows through the element. Exhaust pressure increases as soot builds up. After the discharge pressure has reached a programmed degree and an adequate amount of soot has accumulated, the filter element must be regenerated. This allows the spent exhaust gases to continue flowing through the DPF.
The DPF pressure sensor is usually mounted in the engine compartment and away from the DPF.
A P2453 code will be stored if the PCM detects an exhaust pressure condition that does not match the manufacturer's specifications or an electrical input signal from the DPF pressure sensor that exceeds programmed limits.

In the test tracing, showed in the Fig. 38, there are 27 vehicles, with an assigned class based on the passage into workshop:

- Workshop absorbed
- Monitoring
- Naturally absorbed.

It's important to analyze the claims to perform a reclassification into True Positive and False Positive, as said in the paragraph 4.2.1.
The reclassification is noted manually by filling the cell of the vehicle with three different colors:

- Red, if it is considered a true positive, so the vehicle has a real problem
- Green, if it is considered a false positive, so the vehicle has not the problem
- White, if the vehicle is in monitoring.

vehicles	DTC	Class	DTC TIME first	DTC TIME last	DTC km first	DTC km last	# occ	Duration [s]	workshop TIME	claim	note claim	udt	dossier
vehicle 1	P2453	workshop_absorbed	10/02/2021 10:11:19	22/03/2021 13:40:39	1020	19256	817	1934060	22/03/2021 15:06:00	[24/03/2021] PM sensor 58	**replaced**		
vehicle 2	P2453	workshop_absorbed	19/02/2021 16:37:46	01/03/2021 10:51:10	15205	18198	130	678115	01/03/2021 13:23:29	[01/03/2021] PM sensor 58	**replaced**		ANS Dossier - **01/03/2021**
vehicle 3	P2453	workshop_absorbed	21/02/2021 08:41:01	24/02/2021 09:25:11	224899	226746	123	204958	24/02/2021 10:20:11	[24/02/2021] PM sensor 58	**replaced**		ANS Dossier - **24/02/2021**
vehicle 4	P2453	workshop_absorbed	24/02/2021 11:39:01	16/06/2021 06:19:02	106788	143000	630	6839727	16/06/2021 06:36:18	[15/06/2021] PM sensor 58	**replaced**		
vehicle 5	P2453	workshop_absorbed	01/03/2021 03:58:41	01/03/2021 11:03:31	5093	5398	8	25020	01/03/2021 11:13:25			[01/03/2021] sensor test: No intervention is needed or	
vehicle 6	P2453	workshop_absorbed	02/03/2021 05:07:30	25/03/2021 15:17:53	1048	11378	304	1168622	25/03/2021 15:25:00	[25/03/2021] PM sensor 58	**replaced**		
vehicle 7	P2453	workshop_absorbed	09/03/2021 19:05:50	03/04/2021 13:51:58	24118	41467	141	1306745	05/04/2021 15:10:33	[05/04/2021] PM sensor 58	**replaced**		
vehicle 8	P2453	naturally_absorbed	11/03/2021 08:31:33	11/03/2021 10:04:59	36555	36634	2	5601		[19/04/2021] PM sensor 58	**replaced**		
vehicle 9	P2453	workshop_absorbed	25/03/2021 16:55:32	06/05/2021 08:13:39	1255	11569	611	2046331	06/05/2021 09:02:19	[06/05/2021] PM sensor 58	**replaced**		Service Booking
vehicle 10	P2453	workshop_absorbed	30/03/2021 11:41:19	30/03/2021 17:03:10	126804	126990	2	15195	09/04/2021 14:30:28				
vehicle 11	P2453	workshop_absorbed	01/04/2021 14:37:46	13/04/2021 10:59:46	89285	94106	103	503743	13/04/2021 10:59:50	[13/04/2021] PM sensor 58	**replaced**		
vehicle 12	P2453	monitoring	05/04/2021 06:59:14		1021	5647	661	4295459					
vehicle 13	P2453	workshop_absorbed	06/04/2021 14:09:55	07/04/2021 03:54:58	138629	138690	1	49503	23/04/2021 14:01:21	[23/04/2021] oil and fuel filter		[23/08/2021] cambio olio, AdBlue Dosing System Test	
vehicle 14	P2453	workshop_absorbed	07/04/2021 06:50:48	27/04/2021 10:00:14	1304	3933	40	824621	27/04/2021 11:15:01	[16/04/2021] PM sensor 58	**replaced**		
vehicle 15	P2453	workshop_absorbed	08/04/2021 17:59:23	25/05/2021 07:51:12	9894	23637	681	3420962	25/05/2021 07:55:47	[25/05/2021] PM sensor 58	**replaced**		
vehicle 16	P2453	workshop_absorbed	15/04/2021 14:00:52	29/05/2021 07:18:35	2096	18175	453	3639802	29/05/2021 07:18:46	[29/05/2021] PM sensor 58	**replaced**		
vehicle 17	P2453	workshop_absorbed	18/04/2021 16:46:25	28/04/2021 06:04:25	36090	41528	45	617382	28/04/2021 07:32:34	[28/04/2021] PM sensor 58	**replaced**		ATS - PM SENSOR **on 21/04/2021**
vehicle 18	P2453	workshop_absorbed	19/04/2021 18:23:56	14/05/2021 10:55:09	77561	92157	126	957434	14/05/2021 11:03:06	[14/05/2021] PM sensor 58	**replaced**		
vehicle 19	P2453	workshop_absorbed	20/04/2021 08:08:20	10/06/2021 11:05:30	90944	111726	715	2667967	10/06/2021 16:02:06	[10/06/2021] PM sensor 58	**replaced**		
vehicle 20	P2453	monitoring	26/04/2021 10:26:35	25/06/2021 11:24:04	1010	17749	496	2575789	10/07/2021 07:42:27	[10/06/2021] PM sensor 58	**replaced**		
vehicle 21	P2453	workshop_absorbed	14/05/2021 04:36:55	23/06/2021 12:50:07	2103	18564	2019	2282234	25/06/2021 12:25:29	[25/06/2021] PM sensor 58	**replaced**		ATS - PM SENSOR **on 21/05/2021**
vehicle 22	P2453	workshop_absorbed	26/05/2021 16:03:24	28/06/2021 08:53:12	84284	102512	162	1724963	28/06/2021 09:03:15	[28/06/2021] PM sensor 58	**replaced**		
vehicle 23	P2453	monitoring	31/05/2021 19:51:58	01/06/2021 14:02:02	85952	87250	3	65326					
vehicle 24	P2453	monitoring	04/06/2021 04:01:42	11/06/2021 07:42:43	1108	4822	33	405761					
vehicle 25	P2453	naturally_absorbed	04/06/2021 05:28:06	04/06/2021 06:35:26	119037	119113	1	4040					
vehicle 26	P2453	monitoring	16/07/2021 09:57:27	01/08/2021 06:42:15	133336	138234	194	830269					
vehicle 27	P2453	monitoring	28/07/2021 12:56:05	28/07/2021 15:08:46	121488	121516	2	7956					

Figure 38 - Test tracing

In this case there are:

- 17 true positive, which are workshop absorbed, all with a replacement of the Particulate sensor as suggested in the Repair sheet of the DTC.
- 5 false positive, of which:
    - 3 DTC are workshop absorbed, but
        1. *Vehicle 5* has a negative test made by the diagnostic tool
        2. *Vehicle 10* has no solutions adopted
        3. *Vehicle 13* has a replacement which is not related to the DTC
    - 2 DTCs are naturally absorbed.

By following the example shown in the Fig. 32, it's possible to proceed to the definition of the trigger.
In the next figure (Fig. 39), two possibilities of trigger are defined by excluding the vehicles in monitoring:

- **OCC ≥ 1**, in this case we do not exclude any vehicle. The precision is 77 %, which is not so good considering the target of 80 %.

- **OCC ≥ 2**, in this case we are excluding two vehicles with occurrence equal to 1. Now the precision is 85 %, without losing in sensitivity because only false positives have been eliminated.

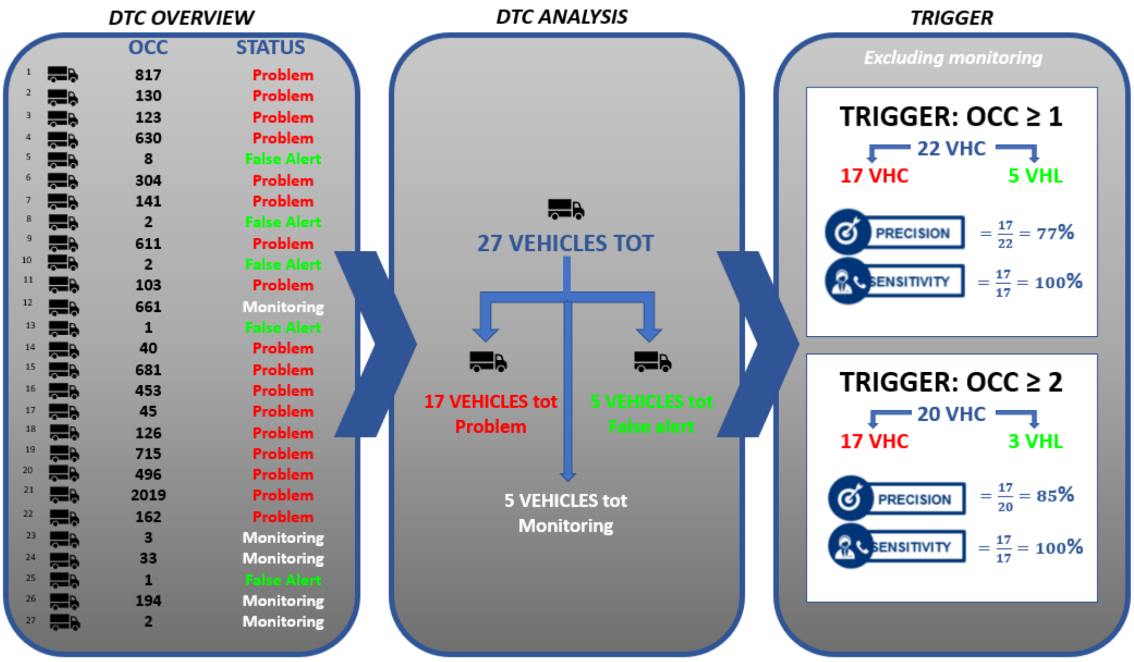


Figure 39 - Study case trigger design

A further improvement can be made.

But looking at all the occurrence numbers, there is a third trigger to consider, because by setting the **OCC ≥ 8**, other 2 false alert could be discarded without losing any true positive.

So, the best trigger results to be the one shown in the Fig. 40, with a precision of 94 % and a sensitivity always of 100%.

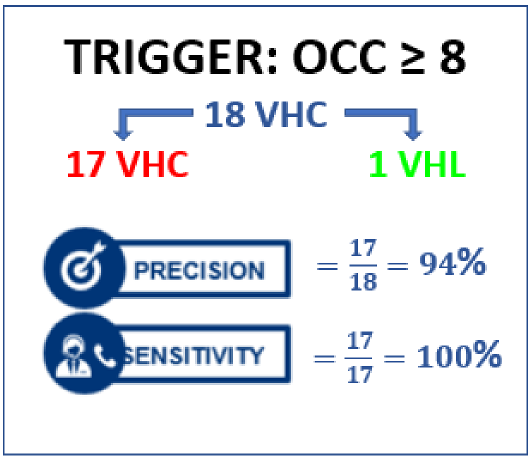


Figure 40 - Best trigger design

4.4. Alert

After the definition of the rule, the trigger is uploaded on a web dashboard where all the triggers could be monitored, reanalysed, improved or discarded. The trigger inserted has the following characteristics:

- Engine model
- DTC identification code
- Corresponding ECU
- Description of the anomaly
- Severity associated with colours for critical, high, medium and low
- Communication and type of communication will be adopted to call the vehicle
- Rule.

When it is uploaded, engineers monitor its efficiency and if it is good the trigger is sent in production.

The trigger created in the previous chapter is in test environment, so it is not possible to give information about the KPIs' computing.

But with a precision of 94% the probability to go in production environment is very high, and in that case the trigger will generate an Alert.

The alert is visible both on QlikView, to allows assistance team recall the vehicle, and on the vehicle on-board interface.

4.5. Customer Contact and Repair

Considering the study case, after trigger placement in Production, the phase of Customer contact starts in case the DTC number of occurrences is equal or higher than 8.

The assistance to customers is made in various ways based on the severity, which can be calls through Assist team, an alarm on the dashboard of the vehicle, an email to fleet managers, and so on.

When the vehicle is called in the workshop, a dossier is opened, and a Repair sheet is used by operators to solve the problem related to the DTC considered. Each DTC has its own Repair sheet divided in more concatenated steps which must be resolutive and complete.
By consulting the dossier opened for each vehicle with that active DTC, if it is noticed that the usual repair action used is different from the ones in the repair sheet, then starts a procedure aimed to contact Repair sheet's team to make changes or implementations to the sheets.

COMPANY

Guided Procedure

V.I.N.: [redacted]	PAGE:**1 / 5**
MODEL: [redacted])	DATE: **04 February 2022**
IU ID: [redacted]	DEALER USER [redacted]

P2453 - Particulate sensor - electric error - Root cause not known

Control Module : ECM

Variant list [redacted]

NOTICE: *before disconnecting and reconnecting a connector of the electrical system, make sure that the battery negative terminal has been disconnected following the procedure indicated (* ***BATTERY - Remove (76.20.10-*** [redacted]

Fault Description:

- Component: **PARTICULATE SENSOR - Overview** [redacted]

Cause:
The fault could be determined by a faulty particulate sensor or problems with the wiring.

Possible failure modes:

1. Fault in connectors;
2. Fault in the wiring harness;
3. Fault in the ECM engine control unit, presence of incorrect, intermittent or erratic data
4. Fault in the particulate sensor;

Beginning of the procedure: 2022/02/04 09:23:25

Solution:

1. Check that the connector of the particulate sensor [redacted] (**PARTICULATE SENSOR - Overview (50.74.41-C.10.A.10)**) does not show any signs of damage. Is the connector damaged?
   A. Yes, and it must be repaired, repair the connector and go to the next step. **2**
   B. Yes, and it must be replaced, replace the connector and go to the next step. **2**
   C. No, go to the next step. **3**

☑ **Check 1: Done** 2022/02/04 09:33:21

Risultato:
- Si e necessita della riparazione
- Si e necessita della sostituzione
- No - Selected by the user

Figure 41 - Repair sheet

Chapter 5

Business intelligence

5.1. Tool di Business Intelligence

Business intelligence (BI) leverages software and services to transform data into actionable insights that inform an organization's strategic and tactical business decisions. BI tools access and analyse data sets and present analytical findings in reports, summaries, dashboards, graphs, charts and maps to provide users with detailed intelligence about the state of the business (24).
The term business intelligence often also refers to a range of tools that provide quick, easy-to-digest access to insights about an organization's current state, based on available data.
Reporting is a central face of business intelligence, and the dashboard is perhaps the archetypical BI tool. Dashboards are hosted software applications that automatically pull together available data into charts and graphs that give a sense of the immediate state of the company.

Although business intelligence does not tell business users what to do or what will happen if they take a certain course, neither is BI solely about generating reports. Rather, BI offers a way for people to examine data to understand trends and derive insights by streamlining the effort needed to search for, merge and query the data necessary to make sound business decisions.

Figure 42 - BI purposes

So generally, the main benefits of business intelligence are (25):

- faster analysis, intuitive dashboards
- increased organizational efficiency
- data-driven business decisions
- improved customer experience
- improved employee satisfaction
- trusted and governed data
- increased competitive advantage.

There are a variety of different types of tools that fall under the business intelligence umbrella; the most important categories and features are:

- Dashboards
- Visualizations
- Reporting
- Data mining
- ETL (extract-transfer-load — tools that import data from one data store into another)
- OLAP (online analytical processing).

Of these tools dashboards and visualization are by far the most popular; they offer the quick and easy-to-digest data summaries that are at the heart of BI's value proposition.

Figure 43 - Main BI platforms

There are tons of vendors and offerings in the BI space, and wading through them can get overwhelming. Some of the major players include:

- **PowerBI**, a self-service analytics platform, available with client desktop or in SaaS mode on cloud, provides data visualization and can integrate with a range of data sources

- **Tableau**, a self-service analytics platform provides data visualization and can integrate with a range of data sources, including Microsoft Azure SQL Data Warehouse and Excel
- **Splunk**, a "guided analytics platform" capable of providing enterprise-grade business intelligence and data analytics
- **Alteryx**, which blends analytics from a range of sources to simplify workflows as well as provide a wealth of BI insights
- **Qlik**, which is grounded in data visualization, BI and analytics, providing an extensive, scalable BI platform
- **Domo**, a cloud-based platform that offers business intelligence tools tailored to various industries (such as financial services, health care, manufacturing and education) and roles (including CEOs, sales, BI professionals and IT workers)
- **Dundas BI**, which is mostly used for creating dashboards and scorecards, but can also do standard and ad-hoc reporting
- **Google Data Studio**, a supercharged version of the familiar Google Analytics offering

5.1.1. Microsoft PowerBI

Power BI is a business analytics service produced by Microsoft. It provides interactive visualizations and business intelligence capabilities with a simple and intuitive interface to allow users to create reports and dashboards (26). Power BI offers cloud business intelligence (BI) services, known as "Power BI Services", along with a desktop interface, called "Power BI Desktop". It offers data warehouse capabilities including data preparation, data tracking, and interactive dashboards. In March 2016, Microsoft released a service called Power BI Embedded on the Azure cloud platform. What sets it apart is the ability to upload custom views.
There, different versions of the tool, such us:

- Power BI Desktop
- Power BI PRO
- Power BI Premium
- Power BI Mobile
- Power BI Embedded
- Power BI report server.

	Power BI Desktop	Power BI Pro	Power BI Premium
Included with Office 365 E5:		✓	
Licensed per:	User	User	Cloud Compute
Data Refresh Rate:	8/day	8/day	48/day
Unrestricted Report Sharing:	✓	✓	✓
Export to CSV, XLS, PDF & PPTX:		✓	✓
Embed Visuals into Apps (Teams, SharePoint, etc.,):		✓	✓
Storage Limit:	10GB	10GB	100TB
Fixed paginated layout for printing:			✓

Table 2 - Power BI characteristics

The main features of Power BI are (27):

- **Connect your data from different data sources:**

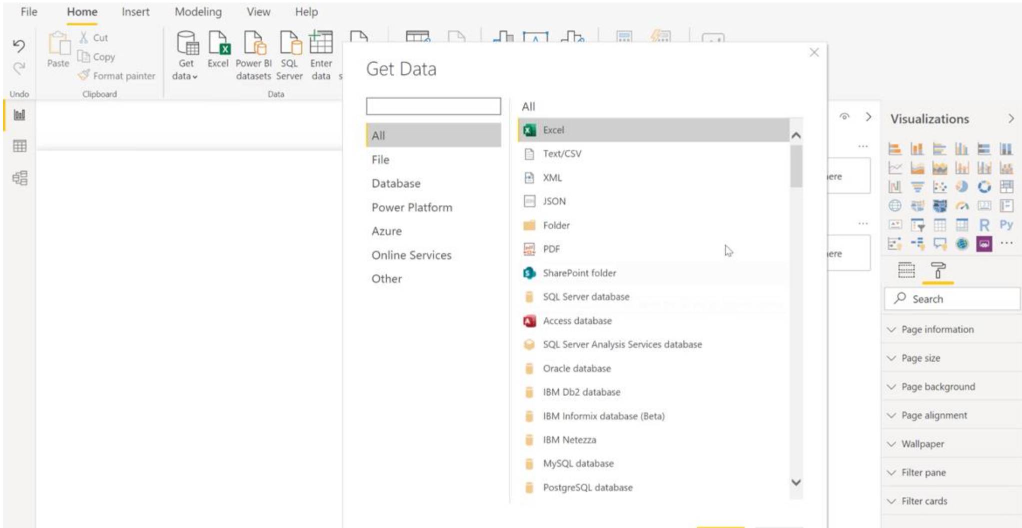


Figure 44 - Power BI data access

PowerBI provide the possibility to Access data from hundreds of supported on-premises and cloud-based sources, such as Dynamics 365, Salesforce, Azure SQL DB, Excel, and SharePoint.

- **Prep and model your data**

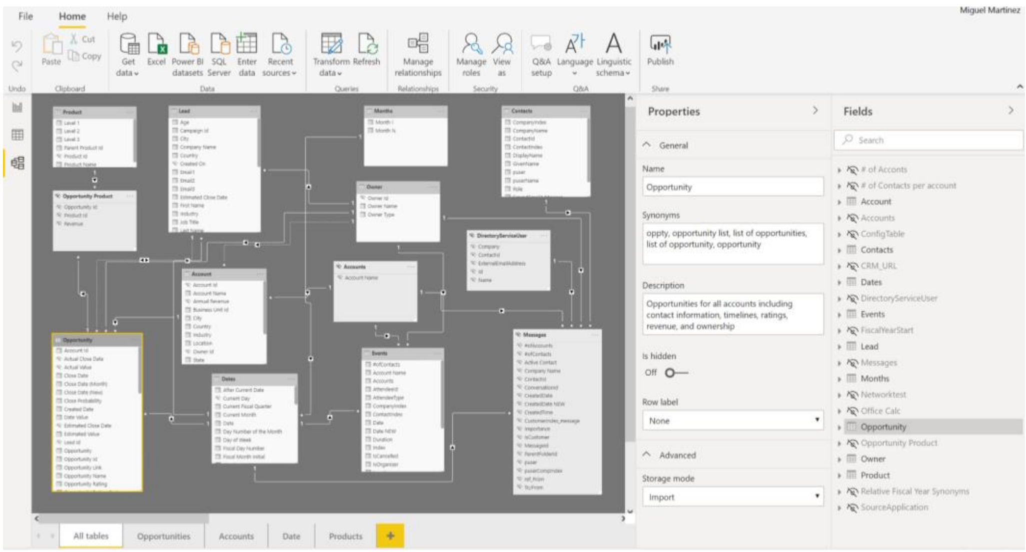


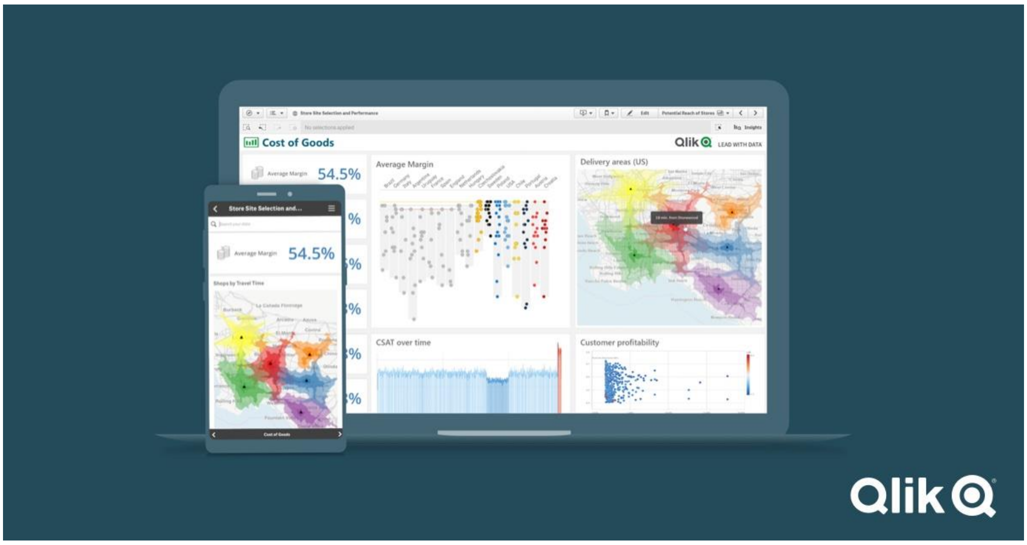
Figure 45 - Power BI data modelling

Save time and make data prep easier with data modeling tools. Reclaim hours in your day using the self-service Power Query experience familiar to millions of Excel users. Ingest, transform, integrate, and enrich data in Power BI.

- **Provide advanced analytics with the familiarity of Office**
  Dig deeper into data and find patterns you may have otherwise missed that lead to actionable insights. Use features like quick measures, grouping, forecasting, and clustering. Give advanced users full control over their model using powerful DAX formula language. If you're familiar with Office, you'll feel at home in Power BI.
- **Deepen your data insights with AI-driven augmented analytics**
  Explore your data, automatically find patterns, understand what your data means, and predict future outcomes to drive business results. The new AI capabilities—pioneered in Azure and now available in Power BI—require no code, enabling all of your Power BI users to discover hidden, actionable insights and drive more strategic business outcomes.
- **Create interactive reports customized for your business**
  Create stunning reports with interactive data visualizations. Tell your data story using a drag-and-drop canvas and hundreds of modern data visuals from Microsoft and partners—or create your own, using the Power BI open source custom visuals framework. Design your report with theming, formatting, and layout tools.
- **Author for everyone, anywhere**
  Get visual analytics to the people who need it. Create mobile-optimized reports for viewers to consume on the go. Publish from Power BI Desktop to the cloud or on-premises. Embed reports created in Power BI Desktop into existing apps or websites.

- **Publish and share reports**
  Distribute and access insights anywhere by combining Power BI Desktop and Power BI Pro. Collaborate and build reports with colleagues and then publish and share those reports anytime, anywhere, and on any device.

5.1.2. Qlik Sense



Qlik Sense emerged in the market of **Business Intelligence** tools as a new-age technology which offers many user-friendly features. So, it is loaded with advanced data analysis and visualizations services (28).

Qlik Sense is a data analysis and visualization software. It operates with an associative QIX engine which enables the user to link and associate data from varied sources and carries out **dynamic searching** and selections. Qlik Sense serves as a data analytics platform for a wide range of users i.e. from non-technical to technical users. As opposed to QlikView, Qlik Sense is more about data visualization as it has augmented graphics. Whereas in QlikView, you can manipulate the data in a lot of technical ways through scripting. Nevertheless, if your motive of using Qlik Sense is showing and analyzing data in the best possible graphical ways, then you have made the right choice.

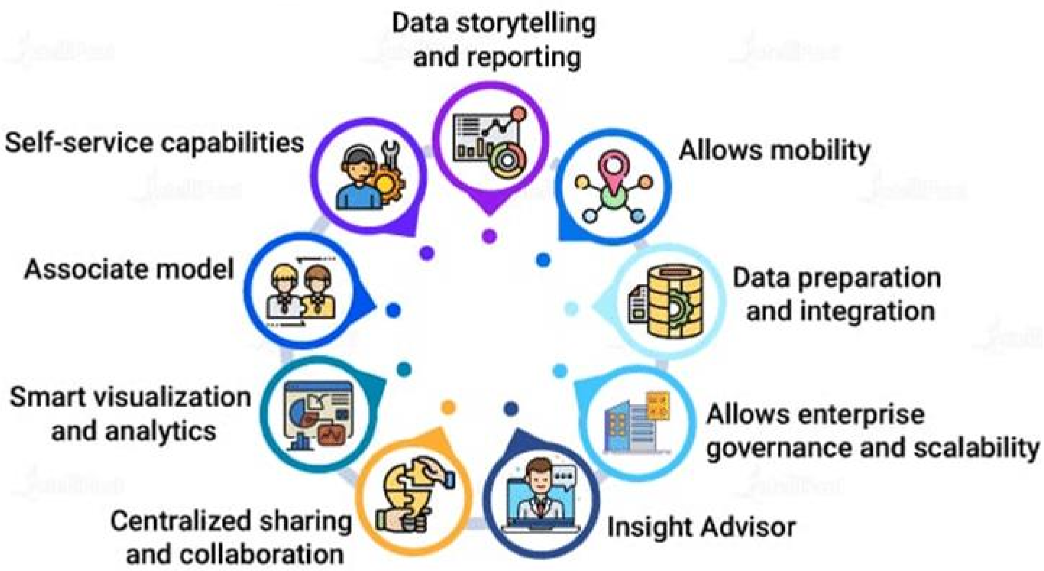


Figure 46 - Qlik Sense capabilities

Given below are some key capabilities of Qlik Sense:

- Self-service capabilities
- Augmented visualizations and smart searches/explorations
- Associative model
- Centralized sharing and collaboration
- Hybrid multi-cloud architecture
- Interactive analysis
- Interactive storytelling and reporting
- Mobility and multiple device support
- Big and small data integration
- Enterprise management and scalability
- Robust security
- Geographic and advanced analytics
- Qlik Insight Advisor (AI supported)

- Scalability across on-premise, private, and public cloud environments

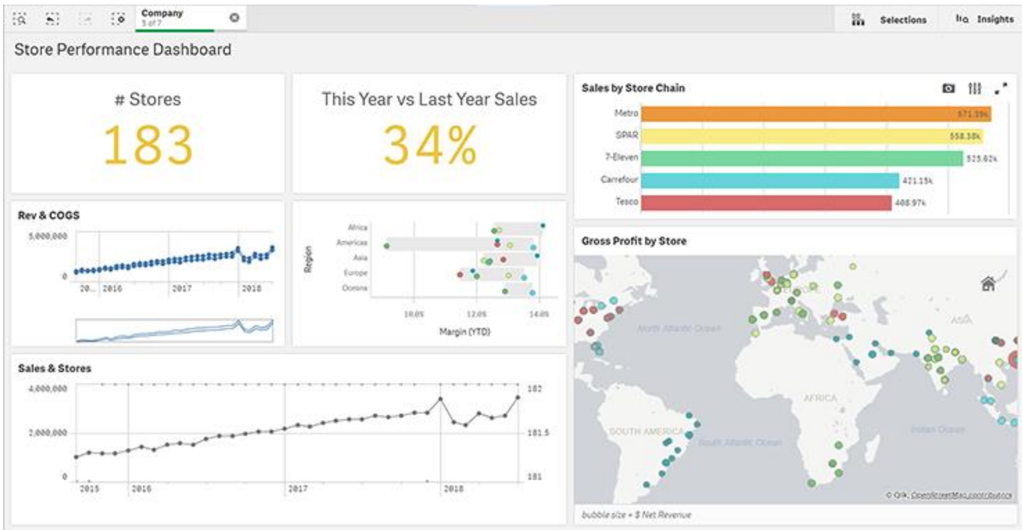


Figure 47 - Qlik Sense dashboard

There are different versions of Qlik Sense:

- **Qlik Sense Desktop**
  The Qlik Sense Desktop edition is a windows version, which can be locally installed on the system's desktop. It provides all the important features like local file sharing, visualizing and exploring, data loading and preparation, exporting applications to the cloud, enterprise support, storytelling etc. Although this version is not the full version as it provides limited functionalities as opposed to the enterprise edition. The Desktop version is used on an individual level and is free of cost.
- **Qlik Sense Cloud**
  Qlik Sense Cloud is a cloud deployed edition. Users can create and share applications. They can also share analytics reports in with others. It also provides access to multiple devices. The benefit of cloud edition is expanded storage and unlimited data.

- **Qlik Sense Enterprise**

  Qlik Sense Enterprise version is the premium or full version specific for enterprise use. It provides a complete set of data analysis features like reporting, visualization, exploration, multi-platform cloud deployment, collaboration, data integration, API for custom analytics, enterprise governance and scalability.

Figure 48 - Qlik Sense features

Given below are the key features of Qlik Sense:

- Associative model
- Smart visualization and analytics
- Self-service creation
- Centralized sharing and collaboration
- Data storytelling and reporting
- App Mobility
- Data preparation and integration
- The QIX engine
- Enterprise governance and scalability.

5.2. Trigger Data visualization

The tools explored in the previous paragraphs are very useful for several application in several industries, for example automotive industry.

The specific scenario described in the chapter 4 allows the car makers to trigger specific rules on real-time data received from telematic boards of the vehicles.
All these rules produce effects and have to be monitored.

As explained the BI can help the car makers to monitor and visualize the effects of the triggers on the vehicles fleet and provide statistics.
The figure below is an example of a QlikView dashboard used for this scope.

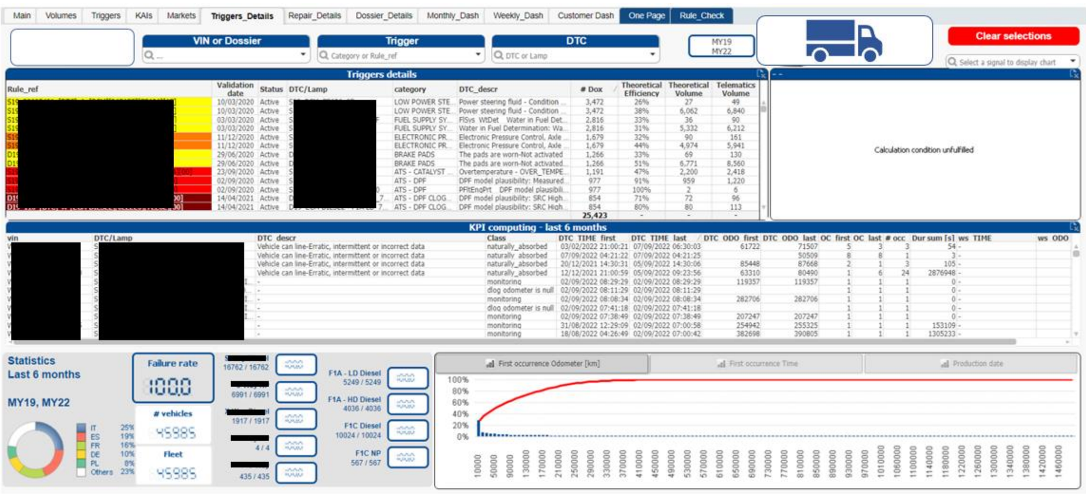


Figure 49 - Trigger data visualization

Chapter 6

Conclusions

At the beginning of this work, an introduction to connected vehicles and its new technologies was due, in order to understand the direction which the automotive field is following in these last years and moreover for the next future.
Connectivity is one of the top four trends in the automotive industry. In addition, OEMs are working on autonomous driving, mobility services and electrification, however, connectivity can be seen as a foundation for all other trends.
The main technology which is the core of the thesis is the On-Board Telematics. It allows the exchange of data between vehicle – driver – fleet manager – OEM, creating a network of information and benefits.
Telematics allows to access a new world of value-added services that will change the concept of vehicle and assistance. The market context and the evolution of mobility will lead to great change also for after-sales which will configure a workshop of the future based on remote and predictive diagnosis, value-added services, advanced assistance and "problem solving" for the driver.

In this project, we have seen that thanks to the data transmitted by the telematic control unit it's possible to monitor a series of factors related to the vehicle and in particular its maintenance activity; this is done by monitoring the faults occurrences in real time and as consequence trying to avoid that vehicles' stops by calling it in workshops before.

The predictive diagnosis is approaching slowly the remote one giving the opportunity to analyse the behaviour of a vehicle throughout its life, and the phenomena that may occur before a problem arises; this allows to create algorithms that can detect the problem before it happens.

It would be interesting to substitute the programmed maintenance with a customized maintenance plan based on the real use of the vehicle in order to minimize the costs related and the efficiency of the offered service.

Today, the first steps have been taken but at the moment only a few car manufacturers use advanced systems of this type, and only on high-end cars. In the future these systems will be provided to all vehicles, together with ever closer integration with telematics.

Another way aimed to improve the entire process could be the use of algorithms of Machine Learning.

Machine Learning is a branch of Artificial Intelligence, in particular a data analysis method used to automate the design of analytical models. It is based on the idea that systems can learn from data, in fact they can identify models autonomously and make decisions with even less human approach.

A possible improvement of the process is the introduction of a Classifier (ML Model) able to identify true-positive and false-positive. The enable condition to develop this kind of ML Model is the increase of the quantity and the quality of the data, for example the inclusion of physical variables linked to the problem could improve the performance. This approach could lead to reduce the human effort in the process and to increase the efficiency of the entire process.

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