Timo Murtonen

Data Acquisition System for Field Trial Vehicles

Metropolia University of Applied Sciences

Master of Engineering

Vehicle Technology

Master's Thesis

15 November 2024

Abstract

Author:	Timo Murtonen
Title:	Data Acquisition System for Field Trial Vehicles
Number of Pages:	29 pages
Date:	15 November 2024
Degree:	Master of Engineering
Degree Programme:	Automotive Engineering
Supervisor:	Pasi Oikarinen, Senior Lecturer Kalle Lehto, Senior Researcher

The Engine and Vehicle laboratory of Neste has a vehicle fleet for field trial purposes. Field trials are used for testing new types of fuel products under real life conditions. Until now, there has not been a systematic and automated way of collecting data from the vehicles during trials. In this thesis, the process for purchasing a needed system, is presented. In addition, the data transferring, handling and visualisation are presented in the thesis.

The work includes the definition of the system specifications and comparison of the quoted systems. After selecting the most promising system, a further evaluation was performed. The candidate vendor provided a system for a trial period. During the trial period, the system was tested with Neste's vehicles. The system was evaluated from technical perspective as well as from the usability point of view. After the evaluation, the final decision was made for acquiring the needed number of systems.

The outcome of the work meets the targets set in the beginning. A robust and reliable system was acquired for multiple vehicles and the systems are in use. Additionally, the data transfer, handling and visualisation is automatised. The data collected from the vehicles is used for monitoring the progress of field trials and for the evaluation of the test conditions during the trials.

Keywords: CAN, OBD, data acquisition, vehicle, field trial

Tiivistelmä

Tekijä:	Timo Murtonen
Otsikko:	Kenttäkoeautojen tiedonkeruujärjestelmä
Sivumäärä:	29 sivua
Aika:	15.11.2024
Tutkinto:	Maisteri (YAMK)
Tutkinto-ohjelma:	Ajoneuvotekniikka
Ohjaajat:	Lehtori Pasi Oikarinen Vanhempi tutkija Kalle Lehto

---

Nesteen Moottori- ja ajoneuvolaboratoriossa käytetään useita ajoneuvoja kenttäkokeiden suorittamiseen. Kenttäkokeita käytetään uudentyyppisten polttoaineiden testaamiseen todellisissa olosuhteissa. Toistaiseksi kenttäkokeissa ei ole ollut järjestelmällistä ja automatisoitua tapaa kerätä tietoja ajoneuvoista kokeiden aikana. Tässä opinnäytetyössä esitellään tarvittavan tiedonkeruujärjestelmän hankintaprosessi. Lisäksi opinnäytetyössä esitellään tiedon siirron, käsittelyn ja visualisoinnin toteutus.

Työ sisältää järjestelmän teknisten vaatimusten määrittelyn ja tarjottujen järjestelmien vertailun. Lupaavimmalle järjestelmälle suoritettiin lisäarviointi. Laitteiston toimittaja tarjosi järjestelmän koeajaksi, jonka aikana järjestelmää testattiin Nesteen ajoneuvoilla. Järjestelmää arvioitiin niin teknisesti kuin käytettävyydenkin näkökulmasta. Arvioinnin jälkeen tehtiin lopullinen päätös järjestelän hankinnasta ja tarvittavien laitteistojen lukumäärästä.

Työn tulos täyttää alussa asetetut tavoitteet. Kenttäkoeajoneuvoja varten hankittiin yksikertainen ja luotettava järjestelmä, joka on käytössä useaasa ajaoneuvossa. Tiedonsiirto ja tiedon käsittely sekä visualisointi ovat automatisoitu. Ajoneuvoista kerättyjä tietoja käytetään kenttäkokeiden etenemisen seurantaan ja testiolosuhteiden arviointiin kokeiden aikana.

Avainsanat: CAN, OBD, tiedonkeruu, ajoneuvo, kenttäkoe

Contents

1 Introduction

Neste's engine and vehicle laboratory is part of the R&D department Neste's organisation. One of the laboratory's functions is to support R&D activities by testing new products with various methods before the products are accepted for commercial use. There is a certain process for the acceptance, and the last step of the laboratory activities is a long-term field trial with Neste's vehicles. Typically, the field trial test is carried out with two vehicles which are driven for defined distance during the test. The test has a "no harm" approach, which means that if nothing abnormal is detected during the test or final measurements, the product has passed the test. Part of the field trial is emission measurement with chassis dynamometer in the beginning, middle and at the end of the test period. The target of the emission measurements is to ensure the operational performance of the vehicle.

Until now, there has not been systematic automated data collection method for the field trial cars. Information, such as the driven distance, ambient temperature, number of cold starts, fuel consumption and rough estimation of the driving profile, has been written down in the driving logbook. Occasionally, data acquisition systems have also been used for collecting more data. The logbook information has been transferred to MS Excel spreadsheet for data analysis. A clear need for updating the data collection routine to modern ways of working is the basis for the work presented in this thesis. The goal was set to select and purchase data acquisition system which reads data from the vehicle's Controller Area Network (CAN bus) via On-board Diagnostic (OBD) connector and transfers the data automatically to cloud storage service for storing and analysing the data. In addition, automatic data analysis tools and dashboard for reviewing the data is part of the solution and will be presented in this thesis. However, the thesis concentrates on the selection and technical features of the system.

The scope of this work was to define the needed specification of the system, identify possible vendors and select the technically most suitable system for trial period. This thesis presents the outcome of the trial period and the selected data acquisition system.

2 Controller Area Network (CAN) in automotive industry

2.1 History of CAN

CAN protocol was developed initially for automotive industry by Robert Bosch GmbH in early 1980’s. At the time, there was a need for a standardized real-time control system at having a low cost [1]. The outcome of the development work was published in 1986 at the SAE congress [2]. The CAN protocol enabled fast and reliable communication between multiple devices for real time control needs. CAN is widely used in vehicle industry and the use of CAN has expanded also to other industries. Bosch published CAN specification 2.0 in 1991 and in 1992 Mercedes Benz took the CAN in use as first vehicle manufacturer [3]. The first international standard (ISO 11898) for the CAN protocol was published in 1993. Initially CAN was used only for engine control function but the utilization of the CAN has been extended widely to different control functions in vehicles.

2.2 Features of CAN

CAN was initially defined by ISO 11898 standard in 1993. The latest version of the standard was published in 2024. The standard is divided into different parts, which describe the physical and communication related features.

Open Systems Interconnection (OSI) model is used for describing layers in communication networks [4]. There are seven layers in the model (Table 1) and CAN covers the layers 1 and 2, which means that CAN remains simple and efficient [5]. On top of CAN, it is possible to flexibly use other protocols for covering the higher OSI layers, e.g., on-board diagnostic (OBD) protocol covers layers 3 and 7. Depending on the application, it is not necessary to use all of the different layers.

Table 1. The description of OSI layers in communication networks.

Layer	Title	Description
Layer 7	Application	Software applications
Layer 6	Presentation	Data conversion/encryption
Layer 5	Session	Manage connections between applications (Ports)
Layer 4	Transport	Ensure valid data transfer/error checking (TCP)
Layer 3	Network	Transmit data from node to node (Routing)
Layer 2	Data link	Data package exchange at bit/byte level (switching/bridging, MAC addressing)
Layer 1	Physical	Physical hardware and wiring

2.2.1 Physical layer

The controllers in the CAN network are called nodes. Nodes collect information from sensors and based on that control actuators [6]. Each node is connected in parallel to the network. The physical connection is established via a twisted pair of wires for avoiding electrical interference. The wires are called CAN-high and CAN-low. The electrical interference is also prevented by measuring the differential voltage between the wires. A bit value 0 corresponds to 2 V voltage difference between CAN-high and low wires (CAN-high 3.5 V, CAN-low 1.5 V), and a bit value 1 corresponds to zero voltage difference between the wires (CAN-high and CAN-low both 2.5 V). If there is any electrical interference, it will affect equally to both wires and the differential voltage is not affected [5].

The physical length of the network is limited by the needed baud rate e.g. the speed of the CAN bus. Figure 1 presents the effect of cable length on baud rate. Maximum baud rate of CAN is 1 Mbit/s, automotive industry typically uses baud rates of 250 and 500 Mbit/s but there is indication to increase the baud rates to 1 Mbit/s which is the maximum speed of CAN.

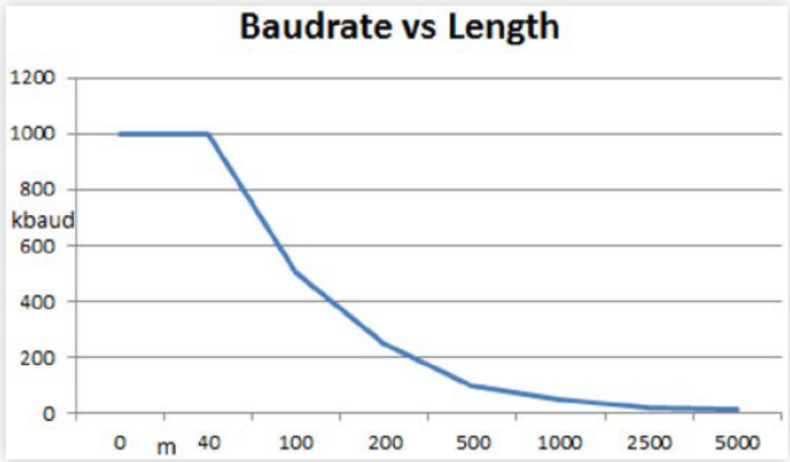

Figure 1. Baud rate vs. cable length. [5]

2.2.2 Data link layer

The ISO 11898 defines the main features of CAN data link layer as follows [7]:

- No master – slave hierarchy
- The highest priority message gets through
- All nodes see all messages
- Collision-free bus arbitration scheme for multiple messages
- Some error detection and handling features

Standard CAN message frame format has 11-bit identifier which also includes the message priority information. The maximum length of the frame can be 127 bits. The data field length of the CAN data frame can vary from 0 to 64 bits. In the extended CAN frame format, the identifier length is 27 bits and maximum length of the CAN data frame is 160 bits. Figure 2 presents the CAN data frame structure. Both types of frame formats can be used in the same network.

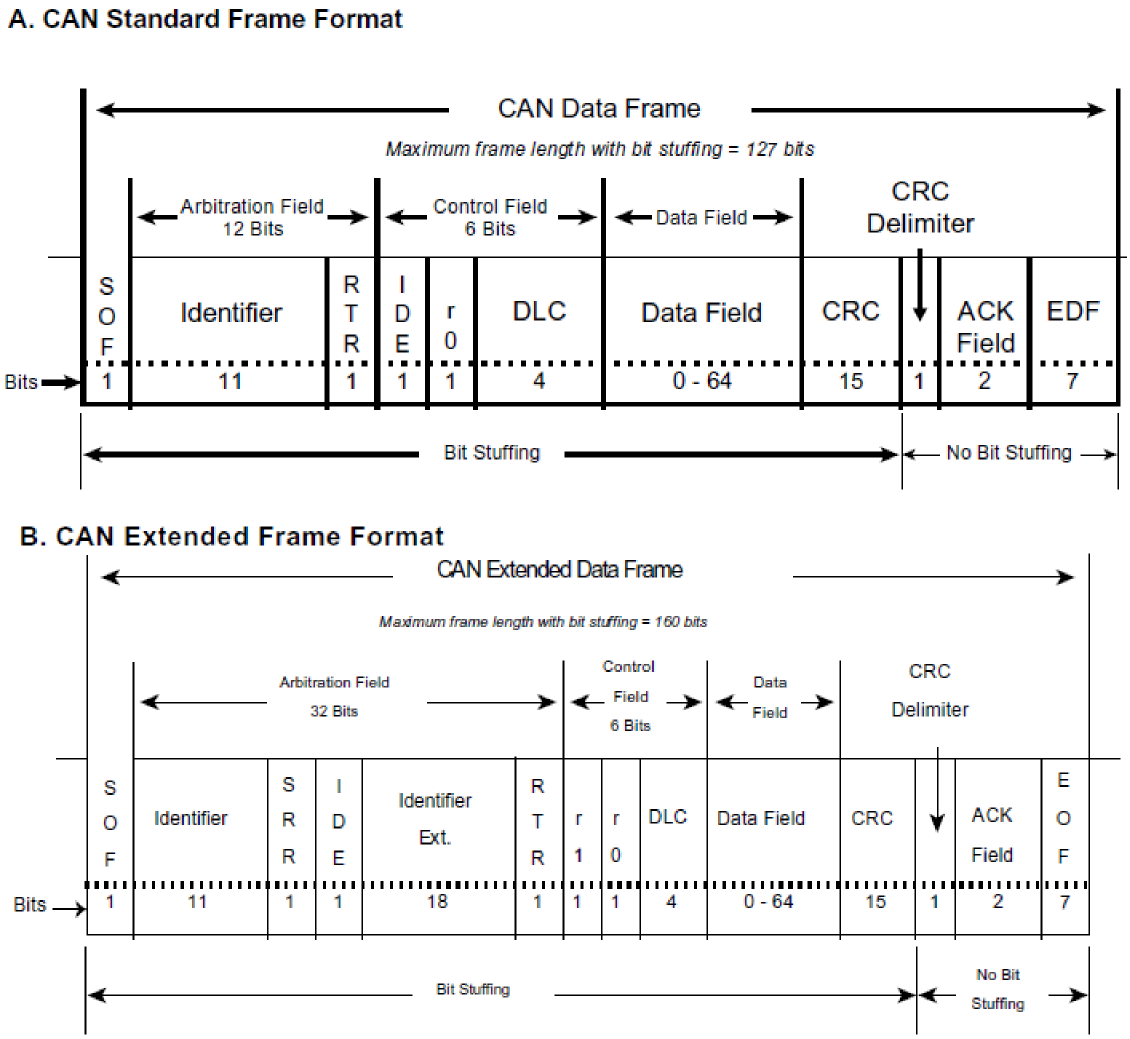

Figure 2. CAN data frame structure. [5]

As mentioned, the data frame identifier includes the priority information. When two nodes try to use the bus simultaneously, the higher priority message gets through.

The message from individual node is shared simultaneously to the other nodes in CAN network [8]. This is the main difference compared to traditional networks, which do not share the messages simultaneously between multiple nodes. This enables very fast communication and control functions.

2.3 Applications using CAN

As mentioned, on top of CAN it is possible to build other protocols for expanding to possibilities of CAN. The most popular protocols are CANopen, DeviceNet, SAE J1939 and ISO 15765. DeviceNet is designed for industrial applications and CANopen is for motion control [5]. SAE J1939 and ISO 15765 have been developed for automotive applications, the former for the heavy-duty vehicles and the latter is the light-duty OBD-II standard.

2.4 Data acquisition from CAN bus

CAN bus handles the data which is used for controlling the vehicle. One vehicle can have multiple parallel CAN busses for controlling variety of functions. So, there is an enormous amount of data related, for example, to engine temperatures, pressures, vehicle stability control system, safety systems, etc. There are simple tools for reading the messages from CAN bus in digital format. In that sense the CAN bus could be excellent source of data for multiple purposes but reading the data is just the first step on the way to have numerical values for the data analysis, since the read messages need to be converted from digital format to understandable information.

2.5 Challenges with CAN bus data collection

As mentioned, it is easy to read the messages from the CAN bus but without support from a particular vehicle manufacturer it is very challenging or even impossible to understand the data. Since the data is in digital format, it is necessary to have a transcription for translating the bits to understandable engineering units. Vehicle manufacturers want to protect the CAN data and they are not eager to share transcription data publicly. What can be done without help from the manufacturers is called reverse engineering.

In reverse engineering the goal is to recognize a single CAN message related e.g. to a specific sensor. Once the message has been recognized, the data frame identifier is identified and with that information it is possible to monitor the data from that specific sensor. In addition, the sensor data needs to be scaled for converting the data to engineering units.

For recognizing a certain data frame in the CAN bus, the bus needs to be monitored while causing a controlled change in certain device. In some cases, this can be quite easy e.g. with on/off type of functions. But considering the amount of data handled by CAN bus, it can be impossible to recognize the needed data frame.

As described above, the reverse engineering is a very laborsome way of collecting data from CAN bus. Therefore, in this work it was decided to use OBD-II standard for data acquisition, even though it has a limitation on the amount of available data.

2.6 On-board Diagnostics (OBD)

The OBD standard has been initially established in the U.S. by Society of Automotive Engineers (SAE) in 1991. The standard was named J1979 and it has been revised multiple times. For combining the U.S. and European requirements for OBD, the ISO 15031-1 standard was published and it covers vehicles from model year 2000 upwards. There are multiple other standards related to the current OBD-II, e.g., for Diagnostic connector (J1962), Diagnostic Tool Requirements (J1978) and Diagnostic Trouble Code (DTC) Definitions (J2012).

OBD systems are developed for vehicle self-diagnostic and reporting purposes, initially for exhaust gas emission related systems. OBD helps in troubleshooting by giving DTCs and gives possibility to monitor the needed values from vehicle’s CAN system. In 1991, California Air Resources Board began to require OBD for newly sold vehicles. OBD came mandatory in the U.S. in 1996 and in Europe in 2001 for gasoline vehicles and in2003 for diesel vehicles. By 2019 OBD is required by regulations in over 20 countries [5].

The second generation OBD system called OBD-II has been used commonly in vehicles already over two decades. The ISO 15765 standard (Diagnostic Communication over Controller Area Network - DoCAN) defines how to execute OBD-II on CAN network [9]. As earlier mentioned, the CAN network covers layers 1 and 2 in OSI system. In addition to OSI layers 1 and 2, the ISO 15765 covers also layers 3 and 4, which are transport and network layers. The relationship between CAN and OBD could be described so, that CAN protocol is a kind of language and OBD defines what information should be communicated with the language [5]. OBD-II is used for indicating faults to driver, fault diagnostics in car repair shops and for annual inspections by authorities.

In CAN network, there are normal messages and requested messages. Normal messages are used for controlling the vehicle and requested messages are used for external purposes. The requested messages are sent only when requested by an external controller. The requested messages, e.g., requested by OBD-II tool, have always low priority. Low priority prevents the interferences in vehicle’s normal operation.

The OBD-II diagnostic tool or reader is connected to CAN via standardized diagnostic connector. The tool requests information from CAN and the requested parameters are identified by parameter identifiers (PID). ISO 15031 standard defines over 170 PIDs for OBD-II protocol [10]. This does not mean that all the defined PIDs would be easily available for individual vehicles. Vehicle manufacturers have a right to limit the amount of information available via OBD-II. The data collected via OBD-II is transferred to understandable format using CAN database file (DBC). These DBC files are available e.g. from OBD-II reader manufacturers.

3 System requirements

Before beginning to search for a suitable technical solution, defining the specifications for the system was needed. This was done together with the laboratory personnel and researchers. Easy usability, small size and capability of reading signals form analog sensors were some of the features that came up during the discussions. After acquiring information about the CAN and OBD-II, it was decided that vehicle's OBD-II connection is a more reasonable choice for Neste's purposes. In the following chapters, the system requirements are presented

3.1 Installation

From the beginning, it was clear that size of the system should be rather small since it would be installed in a hidden location inside the vehicle. The vehicle's trunk could have been one possibility for the installation and that would have not limited the size of the system. However, it was decided that the trunk is not preferred location for the installation, since the installation and routing the cables would have required more work instead of other options and there was also a need to have the trunk in normal use without limitations. The OBD-II connector is typically close to the driver's seat and therefore the clove compartment and other possible compartments in the front of the interior were preferred.

3.2 Usability and configuration

The usability and operability of the system should be as easy as possible. It was defined that the vehicle's driver should not have to pay any attention to the system. The system should turn on automatically as well as the storing of the data should start automatically. Configuration of the device could be done by a trained person but still it was expected that no programming skills would not be needed. The system provider should provide easy-to-use tools for the configuration. Additionally, support from the system provider would be under evaluation during tendering.

3.3 Data inputs

Data collected by OBD-II connection gives information from vehicle's sensors. In addition, the system needs to have capability to monitor external sensors, e.g. temperature and pressure sensors, which are added to the vehicle. The most probable need would be for temperature measurements with K-type thermocouples. In addition, a need for other types of analog signals like milliamperes (mA) and voltages (V) was recognised. The number of the needed channels was moderate, for the thermocouples 4-8 channels would be appropriate amount and the same for the analog inputs.

3.4 Connectivity to cloud storage services

There was a need to have the data transferred automatically to cloud storage service. It was decided that there is no need for online data monitoring, so systems storing data on internal memory card and sending data to cloud at user defined time intervals would be acceptable. For uploading the data, it was decided to use 4G router instead of a wireless local area network (WLAN) connection. The WLAN connection would be available only at the laboratory and therefore it was not suitable option, since the vehicles can be out of the laboratory for several days. There was also a need to be prepared for a situation where the system would be installed into other than Neste's vehicles and in those cases the use of laboratory WLAN would not be possible.

4 System vendors

Several system vendors were contacted during winter 2022 for device specifications and budgetary quotations. Information was shared via email and online meetings were held with the most promising system providers. In addition, a one-day demo session was arranged with one domestic vendor.

4.1 Vendor 1

Vendor 1 is a manufacturer of high quality and robust data acquisition system for different applications. They have wide experience of vehicle applications. Based on the project specifications, Vendor 1 offered the following units

- Main unit of the system
- 8 channel isolated unit for thermocouples and voltages
- 6 channel differential unit for voltage, strain and potentiometer

The quotation included the needed software and cable accessories for power supply and communication between units. According to the manufacturer, the standardized OBD signals could be easily read with Vendor 1 CAN communication products. Data could be transferred via WLAN to, needed services. Vendor 1 system was open to different cloud storage services.

4.2 Vendor 2

Vendor 2 consisted of subsidiaries offering a wide range of solutions for the development of automotive electronics. Their product portfolio includes the data acquisition related hardware and software products especially for vehicle applications.

Subsidiaries made a joint suggestion for the setup for the project our needs. Suggestion covered OBD-II data acquisition and data analysis tools and the solutions for measuring analog signals (temperature, voltage, milliampere). Vendor 2 proposal included vendor’s cloud storage service platform and software tools for data analysis.

4.3 Vendor 3

Vendor 3 was not able to offer a system with analog signal inputs. Their solutions are designed to use vehicle sensor data via CAN bus. Therefore, their suggestion was based on devices and services for reverse engineering. This approach is very interesting and aims to provide vehicle data without installing an extra sensor to the vehicle. However, reverse engineering can be very time consuming. Vendor 3 suggested data logger for reading and logging data and a device for reverse engineering.

4.4 Vendor 4

The quotation from Vendor 4 included device for reading messages via OBD-II connection and a device for reading analog and digital signals as well as K-type temperature sensors. System is capable of sending data to cloud storage services via 4G router. For uploading data to cloud storage service, it is mandatory to use service provided by Vendor 4.

4.5 Vendor 5

Vendor 5 has created a low cost and easy to use solution for monitoring vehicle data via OBD-II. Their system includes modules for OBD-II, thermocouples, analog/digital signals and GPS. Data transfer to a cloud storage service is performed with 3G/4G router and it is possible to use the customer’s own cloud storage service functions. Vendor 5 provides also open-source software for different applications.

4.6 Comparison of the quoted systems

For the comparison of the vendors, a few boundary conditions were defined. On top of those, the size of the system was evaluated. Table 2 presents the boundary conditions and evaluation. On the first row the defined requirements are presented and on the following rows the vendors are evaluated and the outcome is indicated with green, yellow and red colours. Green is for meeting the requirements, yellow for acceptable deviation of the requirements and red for unacceptable deviation of the requirements.

Table 2. Comparison of the vendors, “+” for not meeting the requirements, “+++” for fully meeting the requirements.

	Automatic strat/stop	**Number of temperature channels**	**Number of AI channels**	**Operating voltage, V**	**Cloud storage service**	**Size**
Requirement	yes	min 8	min 8	12	Neste	-
Vendor 1	+++	+++	++	+++	Not discussed	+
Vendor 2	+++	+++	+++	+++	+	++
Vendor 3	+++	+	+	+++	+	+++
Vendor 4	+++	+++	+++	+++	++	++
Vendor 5	+++	+++	+++	+++	+++	+++

Based on the comparison it was easy to select the most promising supplier. As can be seen from the Table 2, most of the vendors filled the technical requirements but the size of the system did not meet the requirements. Vendor 5 products fitted very well for Neste’s needs. The performance of the system did not overperform the needs, the physical size was very small, cloud connectivity directly to Neste’s servers was available, and support for configuration and basic data handling was free of charge. It was decided that more detailed discussions with other suppliers were not needed. The devices from other vendors overperformed the needs, the size of the devices was larger and with some of the vendors there was a need to use their own cloud storage services which required fees paid.

At this point, the cyber security of the system quoted by Vendor 5 (CSS Electronics) was verified with Neste’s cyber security specialists. Based on the evaluation the system was found to meet the cyber security requirements and discussion with the system provider could be continued.

5 Trial period

CSS Electronics offered a possibility to have their devices for a trial period. The trial period was scheduled for summer 2022, and the practical work was performed by a summer worker according to given instructions. The purpose of the trial period was to get experience of the usability and functionality of the devices. It was also important to test the devices with each of the field trial cars for the checking what data is available via OBD-II. For the simplicity and available resources, it was decided to test only the CANedge2 and temperature modules.

5.1 Test plan

The test plan included several steps. The steps are listed below:

- Configuring the system settings
- Establishing cloud connection
- Investigating what data is available from Neste’s test vehicles
- Longer measurement period with selected vehicles
- Analysis of the data

5.2 Results

The results of the testing period were very promising. CSS Electronics have comprehensive instructions for configuring and setting up the system in their website. They also promise 24 h response time for questions. Even though the instructions were good, some support from the vendor was needed for setting up and configuring the system.

In 2022, Neste had eight test vehicles and the OBD-II data was read from each of the vehicles. Table 3 present the results of the trial. OBD-II defines 174 PIDs, which can be read via OBD-II. CSS Electronics provide the needed configuration information and files for reading the data. However, typically not all the data is available. With Neste’s vehicles, in the best case 24 data channels could be found and in the worst case only 9 channels. The worst case was Mazda 6, model year 2009. From each vehicle the following data channels were available:

- Calculated engine load
- Engine coolant temperature
- Engine rpm
- Vehicle speed
- Distance driven with malfunction indicator lamp (MIL) light on

The available data channels provide valuable information of the vehicle’s operating conditions during the field trials. The engine load, rpm and coolant temperature reveal the engine’s operating conditions and the vehicle speed gives information about the driving profile. These findings strongly supported the investment.

Table 3. Available data from Neste’s vehicles.

	MB CLA	**Skoda Octavia**	**Skoda Octavia Hybrid**	**Volvo V50**	**Ford Focus**	**VW Golf**	**Mazda 6**	**VW Passat**
CalcEngineLoad	x	x	x	x	x	x	x	x
EngineCoolantTemp	x	x	x	x	x	x	x	x
IntakeManiAbsPress	x		x	x	x	x	x	x
EngineRPM	x	x	x	x	x	x	x	x
VehicleSpeed	x	x	x	x	x	x	x	x
IntakeAirTemperature		x		x	x	x	x	x
MAFAirFlowRate		x		x	x		x	x
ThrottlePosition	x	x	x	x		x		x
FuelTankLevel	x	x	x	x	x	x		
AbsBaroPres	x	x	x	x	x	x		
ControlModuleVolt	x	x	x	x	x	x		
EngineOilTemp		x			x			
EngineFuelRate		x	x		x			
ActualEngTorqPct		x	x		x			
Oxygen sensor (Lambda)				x				x
Oxygen sensor (Voltage)				x				x
Short fuel trim (%)	x		x			x		
Long fuel trim (%)	x		x			x		
Timing advance	x		x			x		
Time since engine start	x	x	x	x	x	x		
Distance MIL on	x	x	x	x	x	x	x	x
Fuel rail gauge pressure	x			x		x	x	x
Commanded EGR (%)				x				
Distance since code clear	x	x	x	x	x	x		
Catalyst temp 1	x		x	x		x		
Catalyst temp 2				x				
Absolute load value	x		x			x		
Commanded AFR	x					x		
Relative TPS	x	x	x			x		
Absolute TPS B	x		x			x		
Absolute TPS D	x	x	x	x	x	x		
Fuel rail absolute pressure					x			
Fuel injection timing					x			
Actual engine torque (%)		x	x		x			
Engine ref torque (Nm)		x	x		x			
Total	**22**	**20**	**24**	**21**	**21**	**23**	**9**	**12**

Next step was to perform a longer test with one vehicle. The aim of the test was to ensure the data flow and how the actual data looks during a longer testing period. The test proved that the concept works for the needed purpose. It was noted that the power supply for the module cannot be taken via OBD-II connector since in the connector the power is constantly on. In case the vehicle is not driven for couple of days, the vehicle battery will become empty even though the power consumption of the modules is relatively low. Additionally, the system records data at all times when it is powered up. Therefore, for the final installation, an alternative power supply source needed to be defined. The power should be taken from a connector where the power is available only when the vehicles ignition is in “on” position. For that purpose, CCS Electronics has an alternative wiring harness. The cigarette lighter would have been an easy solution for the power supply, but it was rejected due to visibility and practical reasons.

During the longer testing, the data was transferred to cloud storage service without problems. The device secures the data by storing it in a memory card in the CANedge2 module. The data can be transferred by user defined interval to the cloud storage service. After the data has been successfully transferred, the transferred data will be deleted from the memory card. The module recognizes if the data transfer is interrupted and the data in the memory card will be not deleted.

Figure 5 presents an example of the recorded engine and vehicle speed as well as engine load data for VW Golf. The data has been recorded with 1 Hz interval. As seen from the Figure, the vehicle is stopped just before 250 seconds and the engine is turned off right after that. When the ignition current of the engine is turned off the ECU is shut down and the data flow in the CAN bus stops. Therefore, the engine speed does not go down to 0 rpm when the engine is turned off. At this point, the CANedge2 module continues recording since there is constant power supply for the unit via OBD-II connector. When the engine’s ignition current is turned on for starting the engine, the engine rpm data is available again and at this point the value is zero, since the engine has not been started yet. It seems that the CANedge2 module fills in the missing data between ignition off and on period by interpolating the data between the last data point before ignition is turned off and the first data point when the ignition is turned on. This can be seen as a linear line between ca. 250 – 440 s in the Figure 6.

This unwanted phenomenon could be removed by having the power supply in a different location as described earlier. By cutting down the power from CANedge2 unit, the unit stops recording data when the engine is turned off. When the engine is turned on again, the unit starts record that data in new data file.

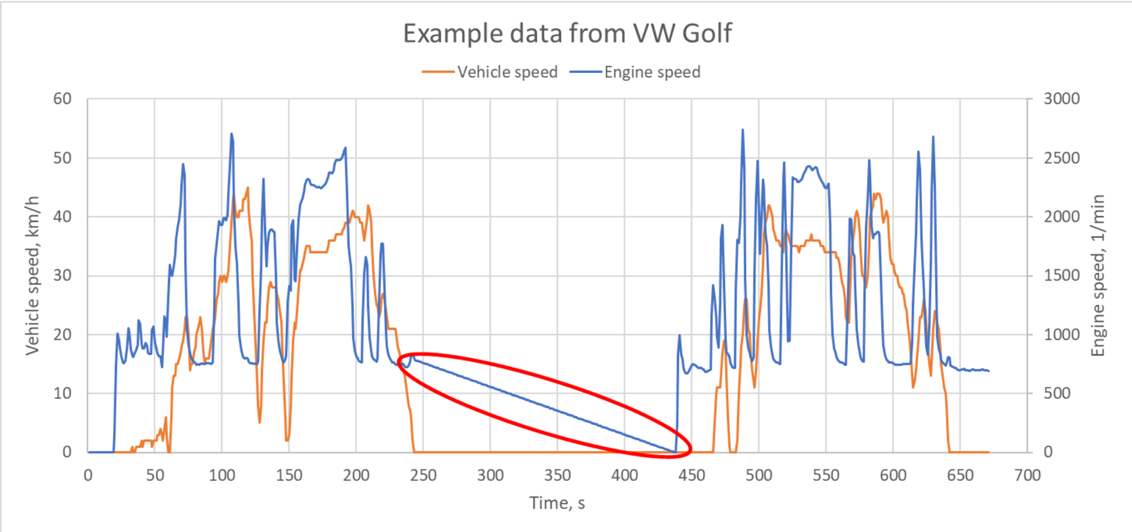

Figure 6. Example data from VW Golf.

5.3 Decision of the system provider

Trial period with CSS Electronics devices did not bring up any severe issues, which could have prevented their choice as the system vendor. The devices worked according to specifications, usability and configuration of the system was easy enough, technical support had high quality and integration to Neste cloud storage services could be established. Based on the trial period the decision of acquiring nine identical systems from CSS Electronics was made.

6 Selected system

The final configuration of the selected system included following components:

- CANedge2 main module
- CANmod.input
- CANmod.temp
- CANmod.gps
- 4G USB WiFi router
- Wiring harness

It was decided to acquire nine identical systems. Eight of those were installed on the Neste's test vehicles and one system is for temporary installations to, e.g. partner's vehicles. The installation of the systems was performed by a summer worker and the outcome of the work is presented in Bachelor Thesis by Flygare [11]. Figure 7 presents the physical lay-out of the system. The specifications of the modules are presented in Table 4.

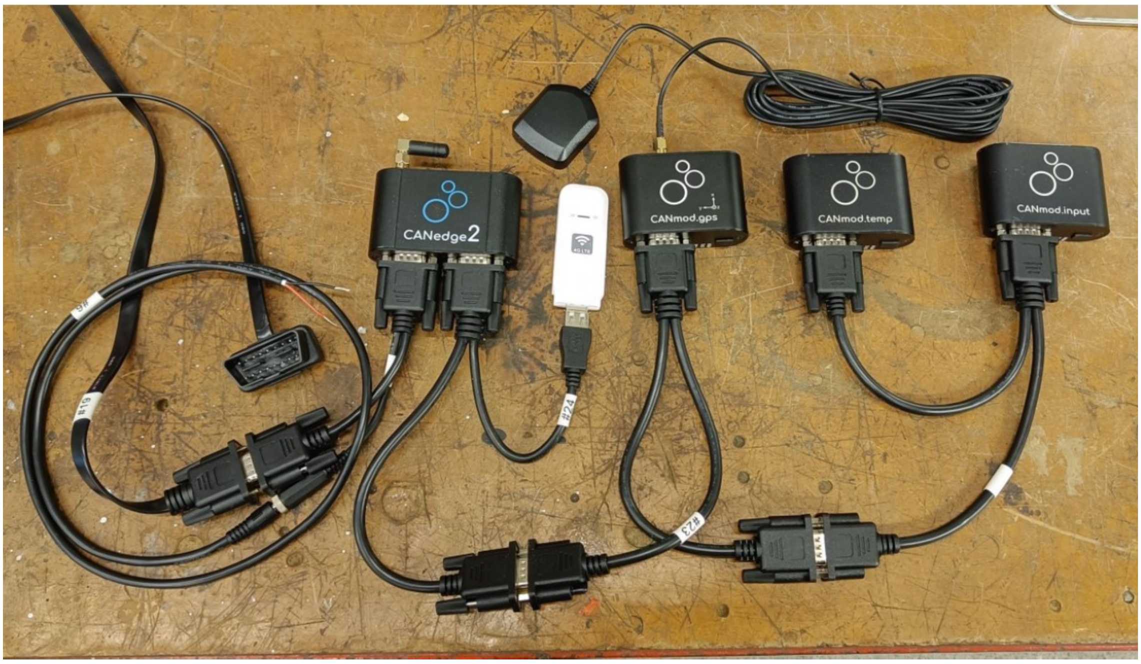

Figure 7. Physical lay-out of the system [11].

6.1 Main module

The CANedge2 module is used for logging the data via OBD-II connector of the vehicle. It has an internal 8 GB memory card and it is capable of transferring data to cloud storage services via WiFi access points or 3G/4G router. The module has two CAN channels, where the second channel can be used for connecting extra modules to main module. The module can be configured remotely.

6.2 Input module

The CANmod.input module is used for measuring analog, digital and pulse signals. The input ranges vary from 0.625 V up to 10 V. The module has 8 channels and it converts the measured signals to CAN protocol and the data transfer takes place via CAN. The module can be used as stand-alone unit which provides data for, e.g., ECU or any CAN tools.

6.3 Temperature module

The CANmod.temp module is used for temperature measurements utilizing thermocouple temperature sensors. The module can measure all types of thermocouples and the maximum measurement range is from -210°C to +1800°C. One module has 4 input channels. The module has cold junction compensation which is needed for precise measurement accuracy.

6.4 GPS module

The CANmod.gps module converts the position and inertial data to CAN protocol. The module supports “Untethered Dead Reckoning”, which means that it can deliver continuous positioning data based on estimate, even though the Global Navigation Satellite System (GNSS) signal is lost.

Table 4. Specifications of the modules.

Device	Size, mm (LxWxH)	Weight, g	Power consumption, W	Number of channels	Max. sampling frequency, Hz	Resolution
CANedge2	50 x 75 x 20	80	1	2	-	-
CANmod.input	52 x 70 x 25	70	<1	8	Analog: 1 kHz Digital: 1 kHz Pulse: 16 kHz	10 bit
CANmod.temp	65 x 48 x 24	80	<1	4	5 Hz	1 degC
CANmod.GPS	53 x 70 x 25	70	<1	-	1 Hz	Position: 2.5 m Heading: 1 degree Velocity 0.05 m/s

7 Data transfer, conversion and dashboard

As mentioned before, the measurement system transfers the data automatically to cloud storage bucket. Initially the raw data read via OBD-II is stored in a Secure Digital (SD) memory card of the CANedge2 module. The raw data is in Measurement Data Format (MDF), which is the industry standard for CAN bus raw data. The latest version of the MDF is MDF4. From the memory card, the data is transferred to Neste’s cloud storage bucket.

7.1 Data transfer

CANedge2 module uploads the data to cloud storage bucket by user defined time interval. From Neste’s field trial cars the data is uploaded to cloud storage bucket once per 24 hours. If the CANedge2 module is not powered up, when the scheduled data transfer should occur, the data will be transferred when the module is powered up for the next time.

Flygare has described the data transfer method in his thesis (Figure 8). The 4G router is powered by CANedge2 module and the module transfers the data to router via Wireless Local Area Network (WLAN). The router forwards the data to cloud storage bucket using 4G network.

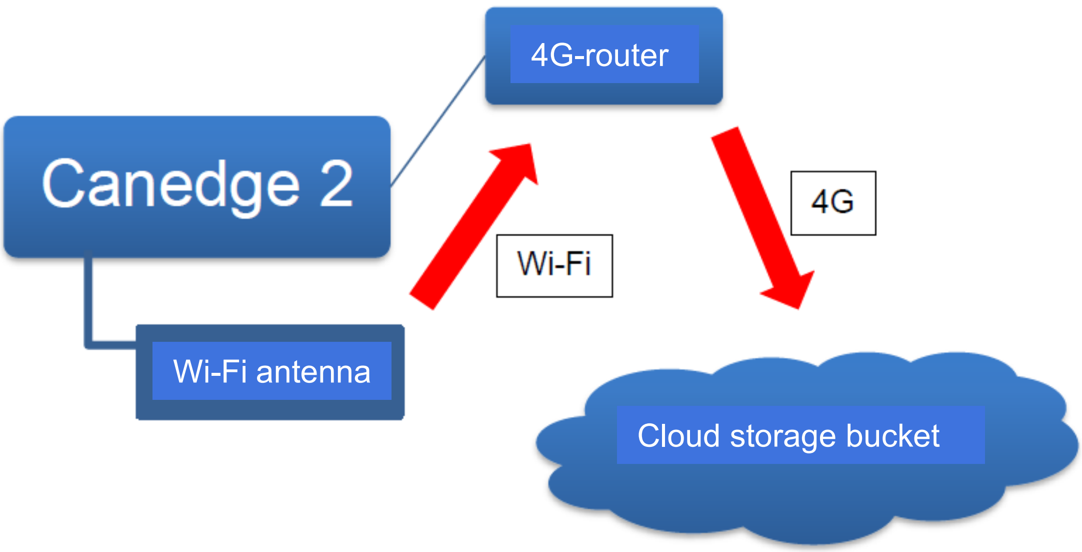

Figure 8, Schematic of the data transfer route, red arrows indicate the wireless data transfer. [11]

7.2 Data conversion

In the cloud storage bucket, there is a function created for converting the raw data to engineering units. A Python code provided by the vendor (open access code) is used for the data conversion. For the conversion, the so-called CAN database files (also known as dbc-files) are used. With the dbc-file, the data is converted to a measurement channel specific numerical data. The converted data is stored in csv-file format in the same location with the raw data. The function in the cloud service checks for new uploaded data files on daily basis and converts all the new files at the same time.

7.3 Dashboard

Dashboard is a user interface for visualising and filtering the collected data. CSS Electronics provides some ready-made tools for this purpose. However, it was decided to use other data visualisation software for creating the dashboard. The selected software it is already used in Neste for similar purposes.

Once the raw data is converted to csv-files, it can be uploaded automatically by the data visualisation software. The software is used for visualising the data and it has filtering tools for presenting the needed data. The converted data is in multiple files, since each time the vehicle's ignition current is turned on and off, a new data file is created by the CANedge2 module. For analysing the data, the information from separate files needs to be combined. data visualization software is capable of reading data from multiple files and the time stamps for individual data points are used for organizing data in correct order when data is combined.

The dashboard for field trial cars has three tabs: "Data Viewer", "Overview" and "Comparison". Within the selected tab it is possible to filter the data with pre-defined functions, select the vehicle and the time period to be viewed. The dashboard is used as a follow-up tool for monitoring the progress and driving conditions of the field trial. At the moment no further analysis of the data is done.

7.3.1 Data Viewer tab

In the Data Viewer tab (Figure 9), it is possible to see the data in a graph from one vehicle. Two different measurement channels can be shown in the graph at the same time, one on the primary y-axis and the other on the secondary y-axis. The data show in the graph can be filtered with conditions presented in Figure 10. The figure also presents an example in which the vehicle speed is shown in the graph if it is less than 30km/h or greater than 100 km/h.

The graph in the Data Viewer tab displays the data from selected time period with 1 Hz time resolution. At the moment, the standard view shows data within ca. one minute period and a slider can be used for shifting the view back and forth. Therefore, it is difficult to get precise overview over a longer time period. To improve this, the graph will be updated so the x-axis scale can be freely adjusted to any desired time period.

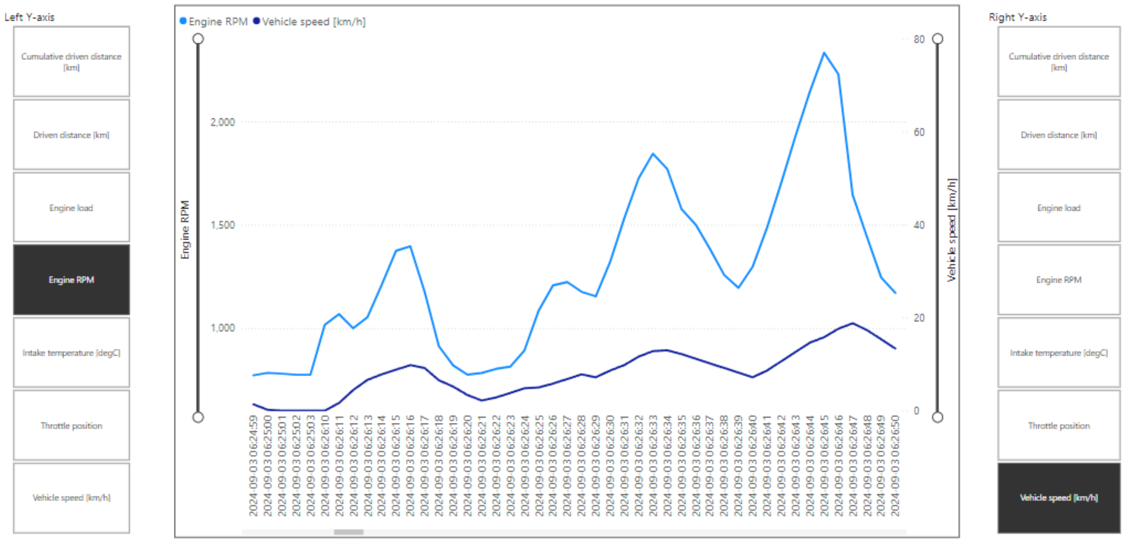

Figure 9. Data Viewer tab.

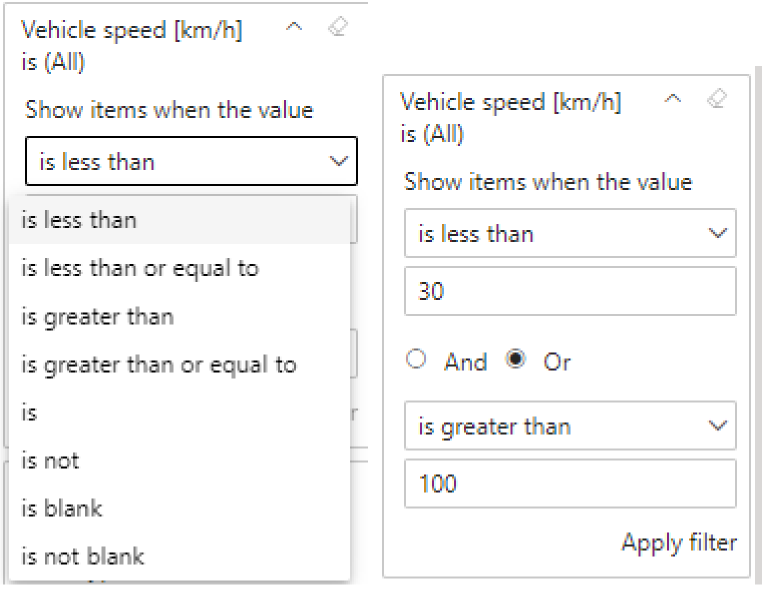

Figure 10. The filtering conditions and example of vehicle speed filtering.

7.3.2 Overview tab

The Overview tab is used for comparing accumulated kilometres of two or more vehicles (Figure 11). This tab also presents the driven kilometres and average speed in numerical format. If the temperature sensor for ambient temperature measurement is connected, then the information of minimum, maximum and average ambient temperature is available. The overview tab is created to easily access information how kilometre accumulation is developing during the field trials.

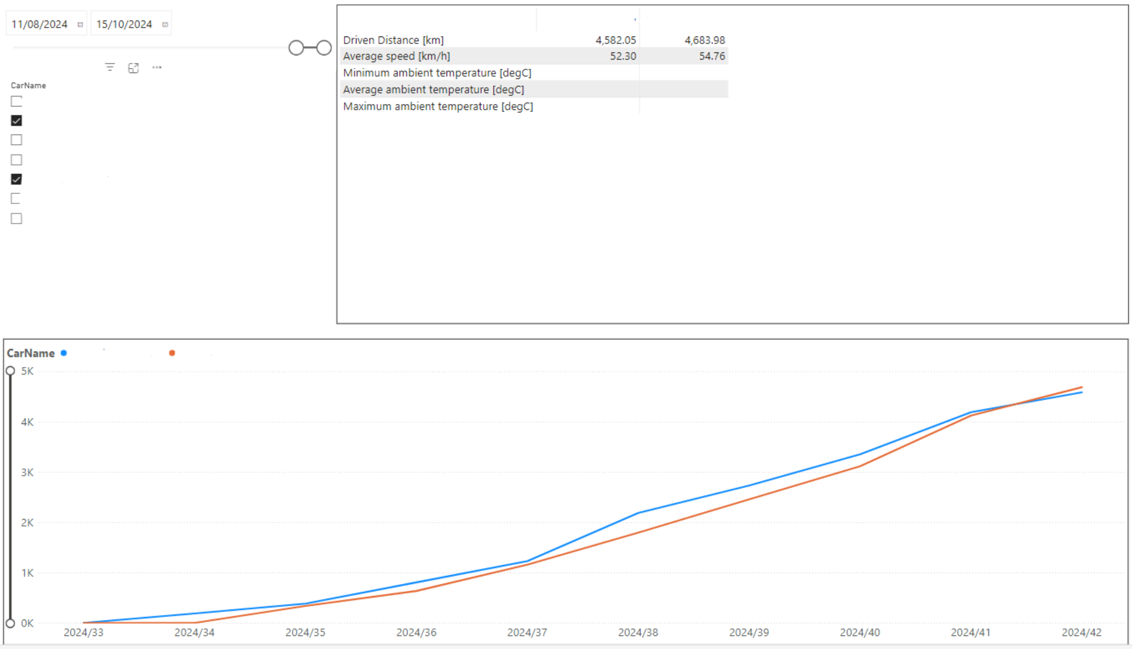

Figure 11. Overview tab.

7.3.3 Comparison tab

In the Comparison tab (Figure 12), it is possible to compare the speed distribution of two vehicles within a given time period. The pie chart presents how many kilometres have been driven with certain speed range. For now, it is not possible to choose what measurement channel is presented in the pie chart but the possibility for selection will be added in the future. The Comparison tab also presents the ambient temperature values on daily basis as well as driven distance and average speed.

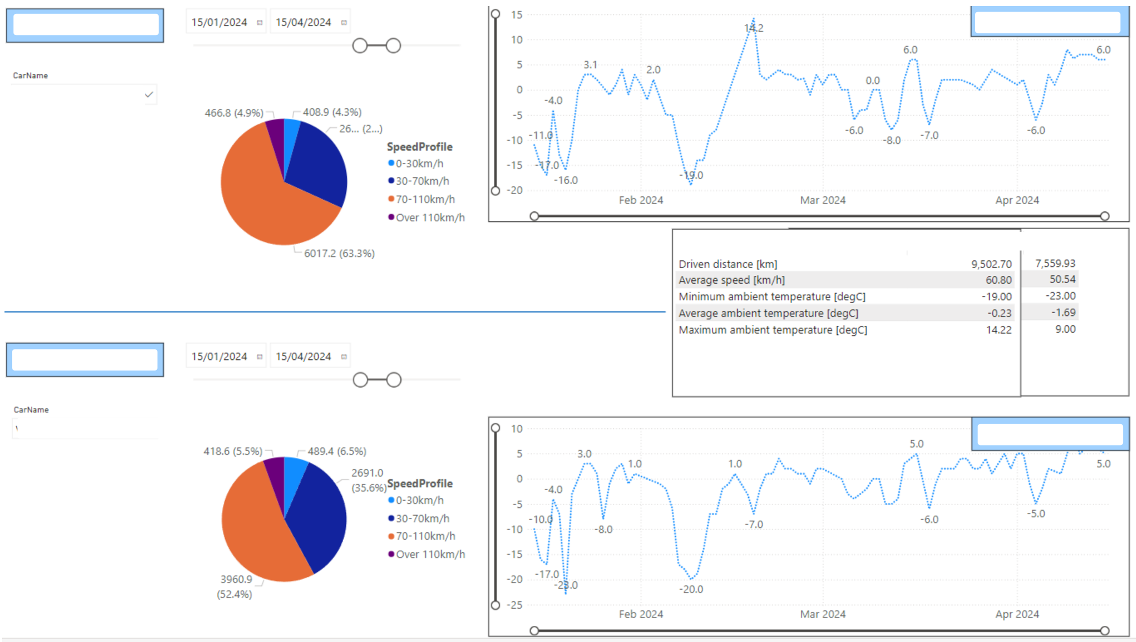

Figure 12. Comparison tab. For confidential reasons, the vehicle identification information has been covered.

8 Summary

The purpose of this work was to find a solution for field trial car’s data acquisition. The work included definition of the system requirements, comparison of the available systems, trial measurement with the most promising system, final decision of the system and preliminary plan for the data flow from device to cloud storage service.

The technical requirements of the system included the possibility to measure vehicle data via OBD-II service socket, measure analog signals from external sensors and transfer the measured data automatically to cloud storage service. Emphasis was also put on the physical size of the devices and easy-to-use configuration tools.

Based on the discussions and email conversations with multiple vendors, the system from CSS Electronics was selected for trial period. Based on the trial period the decision was made to continue the discussions with CSS Electronics.

They had very robust product, user-friendly software tools and easily accessible technical support. It was decided to acquire nine identical measurement setups from CSS Electronics. Seven of those were installed to field trial vehicles and two sets would be for temporary measurement needs.

The installation to the vehicles was done by a summer trainee and a Bachelor’s thesis was written based on that work. The data acquisition systems are in active use. So far no problems have been noticed with the installed systems.

Neste IT experts were used for creating the data flow from CANedge2 module to data dashboard for visualizing the collected data. The data is stored and converted in a cloud service using Python code. The dashboard is created with data visualisation software.

The data acquisition system has been in use for ca. 1,5 years without any major problems. Therefore, it can be concluded that the selection of the system provider was successful. There are some development ideas for the dashboard, which will take place in the near future.

References

1 Johansson, Karl Henrik; Törngren, Martin & Nielsen, Lars. 2005. Vehicle Applications of Controller Area Network: Handbook of Networked and Embedded Control Systems, p. 741–765. Birkhäuser Boston. https://doi.org/10.1007/0-8176-4404-0_32.

2 Kiencke, Uwe; Dais, Siegfried & Litschel, Martin. 1986. Automotive Serial Controller Area Network: SAE Technical Paper 860391. https://doi.org/10.4271/860391.

3 Voss, Wilfried. 2005. A Comprehensive Guide to Controller Area Network, 2nd edition. Copperhill Technologies Corporation. Amherst.

4 ISO/IEC 7498-1:1994. Information technology - Open Systems Interconnection - Basic Reference Model: The Basic Model.

5 Walter, Richard P; Walter, Eric P. 2019. Data Acquisition from Light-Duty Vehicles Using OBD and CAN: SAE International. Warrendale. http://dx.doi.org/10.4271/R-458.

6 Bosch Automotive Electrics and Automotive Electronics. 2014. Automotive Net-working. E-book. Robert Bosch GmbH.

7 ISO 11898-1:2024. Road vehicles - Controller area network (CAN) Part 1: Data link layer and physical coding sublayer.

8 Corrigan, Steve. 2016. Introduction to the Controller Area Network (CAN): Application Report. Texas Instruments.

9 ISO 15765. Road vehicles — Diagnostic communication over Controller Area Network (DoCAN).

10 ISO 15031. Road vehicles - Communication between vehicle and external equipment for emissions-related diagnostics.

11 Flygare, Niklas. 2023. Nesteen kenttäkoeautojen tiedonkeruujärjestelmän asennus ja käyttöönotto. Bachelor Thesis. Metropolia University of Applied Sciences. Helsinki.