Jyri Vähä-Pietilä

Realization of the Status Test for the German Periodical Technical Inspection at General Motors Using the Diagnostic Interface

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Abstract

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The objective of this bachelor's thesis was to document and design a concept for the upcoming electronic Status Test for the Periodical Technical Inspection. It will be required by the German law in year 2014 according to the legal amendment and it will work as an extension to the current visual inspection. The new inspection processes are introduced first in Germany for piloting and later in the European Union. This project was appointed by the automotive company Adam Opel AG and the concept was designed to use the General Motors Diagnostic vehicle Interface.

The thesis describes the basics of communication using the Controlled Area Network (CAN) protocol as well as CAN diagnostics and the Electronic Control Units (ECU) involved in automotive communications. Furthermore, all the phases for the concept design process have been explained from the analysis to the current situation to the final concept selection in order to give a good overview about the concept design process.

As a result of this project, the current situation was analyzed and documented, multiple concepts were designed and one out of the developed concepts was picked as the selected concept for further discussion. The concept will be introduced to the review board for discussion, go through a possible refinement, and later will get implemented in the future vehicles.

Keywords	PTI, CAN, Opel, General Motors, Diagnostics

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Tiivistelmä

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Opinnäytetyön tavoitteena oli dokumentoida ja suunnitella konsepti uudelle katsastusmenetelmälle, joka tulee pakolliseksi Saksan laissa vuonna 2014. Menetelmä on määritelty lakiehdotuksen vedoksessa ja se tulee toimimaan lisänä yhdessä nykyisen visuaalisen tarkistuksen kanssa. Uudet katsastusmenetelmät esitellään ensimmäisenä Saksassa, koska Saksa toimii projektin pilottina, ja tämän jälkeen mahdollisesti muualla Euroopassa. Tämä projekti toteutettiin autoteollisuuden yrityksen Adam Opel AG:n toimesta ja konseptit suunniteltiin käyttämään General Motors Diagnostic -rajapintaa.

Opinnäytetyö perehdyttää Controlled Area Networkin (CAN) perusteisiin keskittyen ajoneuvojen sisäiseen kommunikaatioon, CAN-väylän diagnostiikkaan sekä elektronisiin hallintayksiköihin (ECU). Myös konseptin kehitysvaiheet on selitetty tämänhetkisen tilanteen analysoinnista lopullisen konseptin valintaan, antaen hyvän kokonaiskuvan konseptin suunnitteluprosessista.

Projektin lopputuloksena saatiin kattava tämänhetkisen tilanteen analyysi ja dokumentointi sekä useampi kehitetty konsepti, joista yksi valittiin pohjaksi tulevaa kehitystä varten. Valittu konsepti esitellään muutoksenrevisiotyöryhmälle. Palautteen perusteella konseptiin tehdään mahdolliset muutokset, jonka jälkeen se otetaan käyttöön tulevissa ajoneuvoissa.

Keywords	Katsastus, CAN, Opel, General Motors, Diagnostiikka

Abstract

Contents

Abbreviations

Abbreviations

BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung
CAN	Controller Area Network
DEKRA	Deutscher Kraftfahrzeug-Überwachungs-Verein
DTC	Diagnostic Trouble Code
ECU	Electronic Control Unit
FSD	Fahrzeugsystemdaten GmbH
GM	General Motors
GME	General Motors Engineering
GMLAN	General Motors Local Area Network
GMW	General Motors Worldwide
GTÜ	Gesellschaft für Technische Überwachung
ID	Identifier
ISO	International Organization for Standardization
OBD	On Board Diagnostics
OEM	Original-Equipment-Manufacturer
OSI	Open Systems Interconnection
PCI	Protocol Control Information
PID	Parameter Identifier
PTI	Periodical Test Inspection
SID	Service Identifier
SAE	Society of Automotive Engineers
StVZO	Straßenverkehrs-Zulassungs-Ordnung
SW-CAN	Single Wire Controller Area Network
TI	Test Institute
TÜV	Technischer Überwachungsverein
USDT	Unacknowledged Segmented Data Transfer
UUDT	Unacknowledged Unsegmented Data Transfer
VDA	Verband der Automobilindustrie

1 Introduction

In the course of many years the amount of electronics in commercial vehicles has increased tremendously. This produces new challenges to the Periodical Technical Inspection (PTI) methods to ensure the reliability of the test process and the safety of a vehicle. At the moment, the German Ministry of Transport (BMVBS) is driving a legal amendment for the German Periodical Technical Inspection for improving the current PTI, especially in the field of safety relevant electronically controlled systems. To improve the current process, new electronic PTI test processes are introduced.

This final year project was appointed by the Adam Opel AG, a well-known German automobile company founded in 1862 in Rüsselsheim, Germany, by Adam Opel [1].
The goal of the final year project was to develop a concept for one of the new tests in the upcoming PTI test, called the Status Test, which will be used to electrically verify the status of test relevant features inspected in the current visual inspection. Furthermore, major part of the project was to analyze and document the current usage of driver indications in case of a failure of a feature.

The goal of this thesis is to explain the process of concept development, requirement collection, and to give a good overview on the steps and practices taken for a good concept development. In addition, the thesis will also provide a good understanding of the most essential technologies that were related to the development of the PTI Status Test. Furthermore, the scope of this project is to analyze the current situation, collect requirements in order to define concept rating criteria as well as the concept development. Finally, the thesis will describe the reasoning of selecting one concept which will be then used for further discussion and development.

2 Theoretical Background

2.1 Periodical Technical Inspection

The Periodical Technical Inspection is a mandatory procedure that is issued for all road vehicles to ensure the road safety of a vehicle and to verify that the vehicle complies with the national environmental regulation and standards. In addition, the technical inspections are usually mandatory when importing cars from abroad. As the amount of electronics inside a vehicle has grown, new test procedures are needed to ensure the quality of the PTI tests.

These new tests require information about the vehicle's initial setup, i.e. which electronic control units and features are implemented in the vehicle at the production line. Each original equipment manufacturer (OEM) will have to provide this data for each built vehicle, which will be then used for the test processes. This data will be used as the data which the current status of the vehicle is compared with.

The Fahrzeugsystemdaten (FSD) is an engineer company that will collect and store all the data for the manufactured vehicles from the OEMs and is defined by the law as the storage location of the PTI related vehicle data. For executing the tests, the test institutes will have to request the information about the vehicles initial setup from the FSD.

The Fitment Test is a comparison between the actual fitment of the features located at electronic control units in the vehicle to the target fitment. The goal of this test is to identify any electronic control units removed after the vehicle has left the factory.

The Status Test, which is the topic of this thesis, is executed in order to identify any defects or failures in the electrical system on feature level. In this test, safety relevant features are tested and defects are identified. In order for the vehicle to pass the technical inspection, it needs to pass all the tests. Nevertheless, in case any defects are detected, the test shall be extended by a visual test to verify the negative result.

The initial list of testable features was defined by the FSD in collaboration with the German Ministry of Transport (BMVBS) and then reviewed by the German Association of Automobile Industry (VDA). Moreover, the list of features consists of 38 entries which include test relevant features from the external lights to vehicle handling and other safety relevant systems. To give a good idea what kinds of features are included in the list, the draft of the whole feature list is shown in appendix 1. The new test procedures will extend some of the currently used methods. Moreover, the goal of the new test process is to increase the reliability of the PTI as well as to reduce the time consumption of the overall test.

These new test procedures will be introduced in Germany first, as Germany works as the pilot for this project, and later on in other parts of Europe. The current legal status of the new PTI tests is still a draft. Nevertheless, the initial estimate for the launch of the new test processes in Germany will start with the Fitment Test in July 2012 for initially registered vehicles. This is followed by the Status Test in January 2014 for Germany, also for initially registered vehicles.

2.2 Electronic Control Unit

Electronic Control Units, known as ECUs, are microcontroller-based modules which send and receive signals from sensors and other ECUs. An ECU controls one or more electrical system or subsystem in a vehicle and has the functionality programmed in its memory. The communication in the system is done between a sensor and an ECU, between multiple ECUs or between an ECU and an actuator.

Nowadays, the vehicles have lots of different features, e.g. Antilock Brake System and Adaptive Front Lighting for controlling the vehicles behavior in different situation. An ECU can have multiple features assigned to it and on the other hand a feature can be distributed to multiple ECUs. The basic function of an ECU can be as simple as to control the actuators, e.g. window lifters. However, ECUs can be used to perform complex calculations where the functionality includes usually reading sensor data or signals from other ECU, use the information provided to make decisions and carry out certain actions in the vehicle.

As an example for a complex functionality of an ECU the Traction Control which adjusts the Brake force applied to Brakes in order to keep traction without requiring any action from the driver. Figure 1 illustrates a simplified example of a system that controls the headlights according to the ambient light. This gives an idea of the communication chain between multiple ECUs, sensors and an actuator. [3]

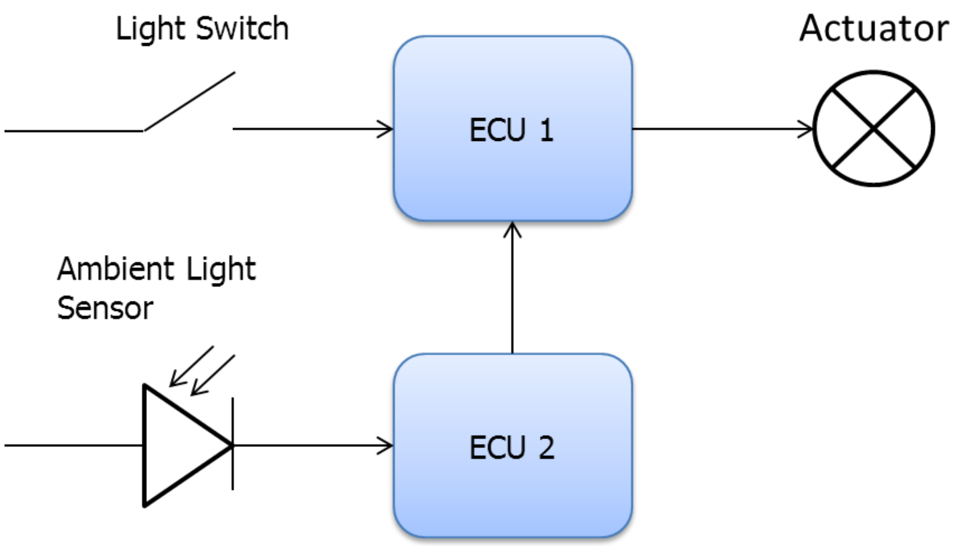

Figure 1. Simplified example of communication of the Adaptive Front Lighting.

As seen in figure 1, the functionality of a system in a vehicle can be distributed to multiple ECUs. In the figure, ECU 2 represents an ECU that takes the signal from ambient light sensor as an input and calculates the amount of ambient light with an algorithm inside the ECU. After the calculations, the ECU sends the data in a message to ECU 1 as an output. Finally, according to the information about the ambient light from ECU 2 and status signal from the light switch, the ECU 1 controls the headlights.

2.3 Controller Area Network

Controller Area Network, known as CAN, is a serial network technology that was at first designed for the demands of the European automotive industry but later became also a popular bus for industrial applications as well as for other embedded system applications. CAN was originally developed in 1985 by the company Bosch for in-vehicle networks and since 1993 it has been an international standard known as ISO 11898. The primary use of the CAN bus is in embedded systems and it is a network technology that offers fast communication links between microcontrollers for real-time requirements [4]. The advantages that made CAN so popular are durability, low cost, robustness as well as broadcast communication principle, message priority and error capabilities. [5]

CAN has a multi-master priority-based bus access which means that every node in the network can transmit messages in the CAN network as long as the bus is in idle state. Message priority will define the actions on situation where two nodes are sending data at the same time. In these situations, the message with higher priority will get transmitted and the message with lower priority will get postponed and later retransmitted. The priority of a message is defined in the identifier part of the frame which is also called as the CAN ID. Furthermore, in order to create a network without overlapping priorities, every node in the network must have unique CAN ID. [6]

The CAN network has no addressing scheme in sense of conventional addressing in networks such as Ethernet. Instead, the CAN network uses broadcast messaging to send out data between ECUs. All the messages from one node to another are sent to every node in the network. An example of communication with broadcasting and message filtering is presented in figure 2.

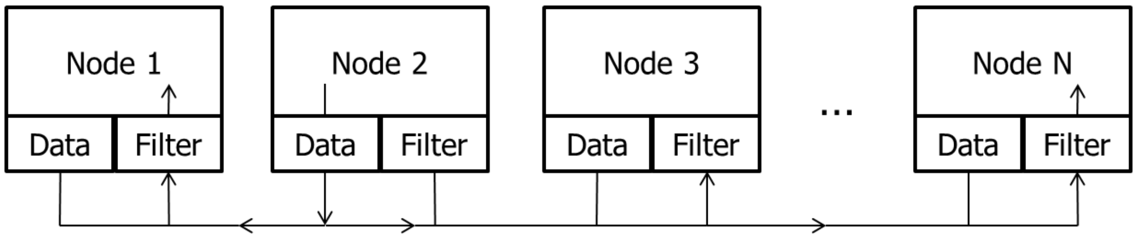

Figure 2. Example of communication in CAN network between nodes. Data gathered from Bosch. [6]

As illustrated in figure 2, in on-board vehicle communication, the node does not have to know the address of the destination node. Instead, the node sends out a broadcast message which will be picked up by all the ECUs that the message is relevant to. This functionality is implemented in the CAN-controller and is called message filtering. Message filtering means that each node has a register of identifiers which is compared to the identifier of the received message. The options for the CAN controller are either to accept and act on the message or just ignore the message. Furthermore, in a CAN network any number of nodes can receive and act simultaneously on the message. [6]

The error capabilities of CAN are included in the Cyclic Redundancy Code (CRC), which will perform error checking on the content of each frame sent to the network. If a sent frame has errors it will be ignored by all of the nodes in the network.

The standard CAN implementation uses only the two lowest layers of the International Organization for Standardization's (ISO) Open Systems Interconnection (OSI) model which are the physical layer and the data link. This is done in order to provide straight access to application software in order to save valuable memory resources and minimizing the overhead to gain more performance out of the limited resources that the embedded device has. [4]

There are different physical layer implementations of CAN. The most commonly used are the High-Speed CAN, Low-Speed CAN and Single Wire CAN. High-Speed CAN, which is implemented by using two wires, allows communication at a rate of up to 1 Mbit/s. The specifications for two wire can are specified in ISO 11898-2.

The Low-Speed CAN is also implemented with two wires but the transmit rates are lower, 125 kbit/s and it is also known as ISO 11898-3. It is mostly used for body electronics in automotive industry.

Single-Wire CAN is the most cost efficient implementation of CAN and it can transmit data with the rate of 33,3 kbit/s but also 83,3 kbit/s in the high-speed mode which is used for programming and external diagnostic communication. The Single-Wire CAN is specified in Society of Automotive Engineers (SAE) J2411 standard which is used in General Motors communication strategy called GMLAN. [5]

2.3.1 GMLAN

General Motors uses a specific standardized communication strategy for its in-vehicle communication for CAN, called General Motors In-Vehicle Local Area Network (GMLAN). GMLAN provides reliable, cost efficient, flexible, and modular message exchange in a serial communication network. Additionally, GMLAN also supports transfer of diagnostic services. As a difference from the standard CAN, GMLAN utilizes all layers of the ISO/OSI reference model but only in diagnostic communication. In normal communication between ECUs, GMLAN implements other layers expect the transport layer. The following table will show all the available bus speed in GMLAN and their use cases. [7]

Table 1. Available bit rates and purposes of different CAN busses. Data gathered from GMW3104 [8]

GMLAN Network	Bit Rate	Purpose
High-Speed bus	500 kbit/s	Periodical real-time data
Mid-Speed bus	125 kbit/s	Infotainment
Low-Speed bus	33,33 kbit/s (Normal communication) / 83,33 kbit/s (High Speed communication)	Event driven data / Programming

The High-speed bus is a two-wire differential bus which can have transmission rates up to 1 Mbit/s, thought in GMLAN the rate is set to 500 kbit/s. Because of the fast transmit rate, it is typically used to transfer real-time data such as information about the engine or steering. Therefore, the High-speed bus is mostly a periodically driven bus and the messages within this network are sent constantly. [8]

The Mid-speed bus is typically used for infotainment systems such as displays and navigation, where the system response time needs to be efficient for transferring large amounts of data in relatively short time such as updating a graphics display. The transmission rate of mid-speed bus is 125 kbit/s. [7]

General Motors Low-speed bus, also known as the Single Wire CAN (SW-CAN), standardized as Society of Automotive Engineers (SAE) J2411, was developed and standardized by General Motors as an alternative to SAE J1850. SW-CAN is used for event driven communications like controlling the motor of an electronic window lifter which does not need constant updating. The transfer bit rate of SW-CAN is 33,33 kbit/s for normal communication. SW-CAN utilizes also a high speed communication mode with the transfer rate of 83,33 kbit/s. This is used for diagnostics and programming electronic control units. The advantage of the SW-CAN is cost reductions and selective node sleep capability, which allows regular communication to take place among several nodes while others are left in sleep state. [9;7]

As stated before, the whole in-vehicle system consists of multiple networks with different bit rates. In case there are multiple networks with different transfer rates, an ECU with a gateway function is required. The gateway ECU will handle its own functions and in addition, forward CAN messages from one network to another. When forwarding the message from different networks with a different transmit rate, the transferred message can get reformatted into another message and then sent to the destination bus. [7]

2.3.2 CAN Data Frames

CAN data frames are used to send information between source node and one or multiple receiving nodes. Explicit addressing is not used but instead each receiving node will use filtering to receive only the frames that the node is interested in. The filtering is done based on the information content of the frame which is encoded in the identifier field in the frame. The identifier field has two purposes, to establish the frame priority and to identify the frame contents. CAN data frames have two types of frame formatting that differ from each other by the length of the identifier field and the data field. [6]

CAN Frame used for communicating on the bus is composed of seven different bit fields: Start of Frame, Arbitration Field, Control Field, Data Field, CRC Field, ACK Field and End of Frame. The two different formats of a CAN frame are illustrated in figure 3 and figure 4 where figure 3 represents standard CAN frame and figure 4 extended frame. [6]

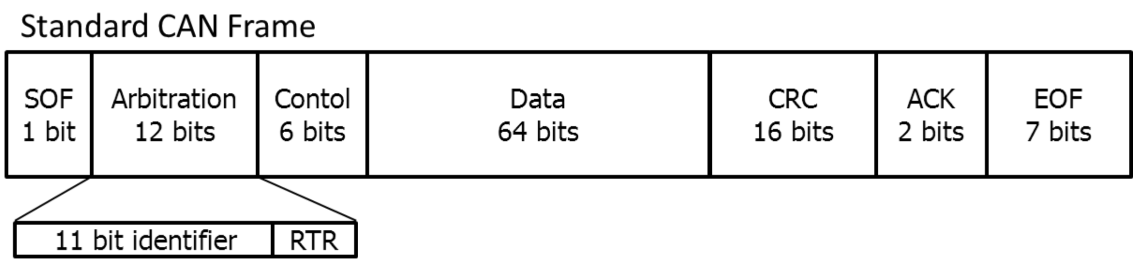

Figure 3. Format of a Standard CAN frame. Data gathered from Bosch [6]

Originally CAN supported only one type of frame, the standard frame. The address space of a standard frame has been defined by an 11 bit identifier field in the Bosch CAN specification 2.0A. Since the complexity of the vehicle systems using CAN has grown, the amount of addresses needed to be extended which led to the introduction of the Extended Frame that is illustrated in figure 4.

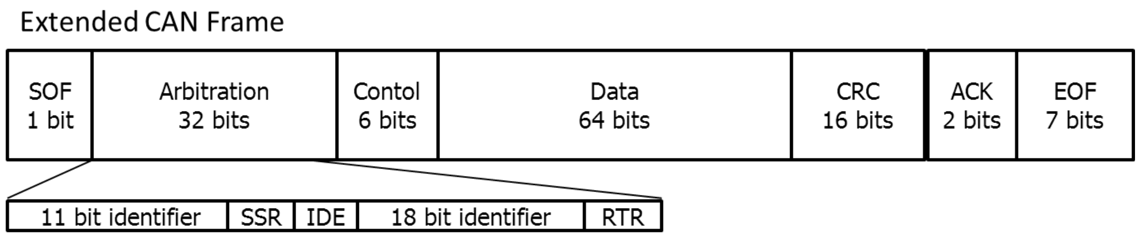

Figure 4. Format of an Extended CAN frame. Data gathered from Bosch. [6]

The Extended Frame was introduced as the Bosch CAN specification 2.0B and it has a 29 bit identifier field which is split in to two parts. The base identifier which is the same as the standard identifier has a length of 11 bits and, in addition, the extended identifier has a length of 18 bits. Therefore, this removes the compromises that needed to be made for the system because of the limited address range provided by the standard frame. Furthermore, the messages with either extended format or the standard format can coexist within the same network without causing any conflicts. [6;9]

2.4 Diagnostics

Any data communication between external test device and automotive electronic control units which uses the diagnostic protocol is called diagnostic communication. Diagnostic communication works with the request-response-principle where the client is requesting diagnostic services from the ECU and the ECU provides a response to the request. Thus, the difference between diagnostic communication and normal communication is that the normal communication consist ECUs communicating to each other with multi-master principle. The diagnostic communication is executed between an external diagnostic device and the ECUs and takes place using the request-response-principle.

Diagnostic services are requests sent by the tester to an ECU or responses from an ECU to the tester. Therefore, to identify the services, all requests and responses have well defined service identifiers, referred to as SIDs. Diagnostic communication requires the nodes to have unique Diagnostic CAN identifiers in order to separate diagnostic messages from normal CAN messages. A diagnostic frame is illustrated in figure 5 below. [3]

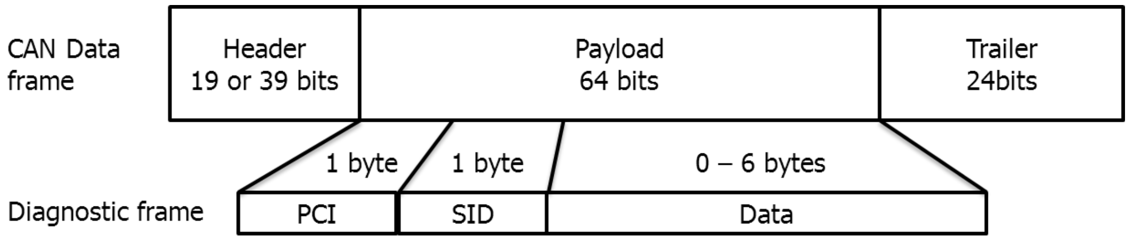

Figure 5. Format of a diagnostic USDT Single Frame in GMLAN. Data gathered from GMW3110. [10]

The diagnostic frame contains three fields. The Protocol Control Information, known as the PCI byte, which consists of two parts. The first four bits of the PCI byte define the length of the data field including the SID field from one to seven bits and the bits four to seven represent the type of the frame. There are four different frame types which are the following: Single Frame, First Frame, Consecutive Frame and Flow Control Frame. Each frame type has a different use case. The last three frames are used in messages that require multiple frames to be sent.

The service identifier represents the diagnostic service requested. Likewise, this field also has the size of one byte. When sending a service request for an ECU, the data field can contain one or more data identifiers.

2.4.1 Data Segmentation

In some situations the response or the request message does not fit into a single CAN frame. The message gets split into two or more parts in order to get the message fully transferred. Messages that do not fit in a single CAN frame will be handled by a process called data segmentation. This process is provided by the transport layer and the network layer of the OSI model. [3]

The data segmentation is controlled by the first byte of the CAN data field which is the PCI byte. In a diagnostic communication the data segmentation process is called Unacknowledged Segmented Data Transfer (USDT). If the response fits into one CAN frame, for optimization reasons, the PCI byte can be left out which will save one byte from the transfer. This type of transfer is called Unacknowledged Unsegmented Data Transfer (UUDT). [3]

2.4.2 Responses

There are two different types of responses either positive or negative response. Otherwise, a missing response indicates a hardware malfunction. A positive response is sent from an ECU to the tester in case that the ECU has successfully processed the request from the tester. In detail, a positive response contains response service identifier, which will specify the exact type of response. The value of the SID field in positive response is the request service identifier added by 0x40 and the data field contains the requested data.

In case the ECU is not able to process the request, it will send out a negative response. A negative response will have a fixed response service identifier with a value of 0x7F. Also, every negative response uses the USDT format and the ECU will not send a negative response to functional request. [10]

2.4.3 Addressing

There are two different types of addressing ECUs in the diagnostic communication. Physical addressing is used to define each individual node in the network. Each node in the CAN network has a unique physical request CAN ID and a physical response CAN ID. For contacting a single node, the external device sends physical request which will be broadcasted to the CAN network and then gets picked up by the node that the CAN-ID belongs to. Likewise, the response works the same way as a request by broadcasting the response message to the network and afterwards, the response message will be picked by the external testing device. [3]

Functional addressing allows contacting a group of ECUs and requesting information from different nodes with a single functional service request. The addressing groups need to be predefined in order to contact multiple ECUs with a functional request. As a response for the functional request, it is likely that the client will receive more than one physical response because multiple ECUs are contacted. In GMLAN the functional addressing contacts every ECU in the CAN network. [3]

2.4.4 Data Identifier

Data Identifier (DID) is used when requesting data from an ECU or writing data to an ECU. The data parameter indicates to the diagnostic application which specific information is being requested by the tester in a request message, e.g. specific ECU input or output status variables, calculated variables, etc. The size of a DID is two bytes and it is located inside the data field of a diagnostic frame. The DID is present in the request frame as well as in the first response frame. [10]

2.4.5 Diagnostic Trouble Codes

Diagnostic Trouble Codes (DTCs) are used for indicating problems in the vehicle. DTCs have a unique identification number which is stored in the fault memory of an ECU as soon as an ECU detects a fault. There are different types of diagnostic protocols for defining the DTCs and services that are used for requesting the DTCs. On Board Diagnostic (OBD) DTCs are emission related trouble codes and they are standardized in ISO 15031-6 and used by all the manufacturers. OBD is used for monitoring the emission related data such as exhaust emissions of a vehicle or to protect the components of a vehicle and report any problems. [12]

Unified Diagnostic Services (UDS) is a standardized diagnostic protocol which is defined in ISO 14229. Moreover, this standard defines all services used for UDS diagnostic which is becoming widely used standard within the industry. However, this standard does not take any stance on DTCs which will be left as for the OEMs to define. The difference between OEMs on the implementation specifications can consist differences in e.g. error handling, reaction on certain invalid requests, security access, fault memory instances, trouble code assignment, or set/reset conditions of trouble code status bits. [14;11]

3 Requirements

In order to create criteria for the comparison of developed concepts, requirements from all stakeholders needed to be collected. This chapter will introduce all the stakeholders and list all the requirements defined for each stakeholder. Also, the following chapter will provide a small amount of information about the stakeholders in order to give an idea of the goal what the stakeholder is trying to achieve with the requirements, following with a list of requirements defined for the specific stakeholder.

Three stakeholders were identified and the requirements for each stakeholder were defined from where later on, the final concept selection criteria were refined. These three stakeholders were the German Association of Automobile Industry (VDA), General Motors Engineering (GME) and the Test Institute (TI).

The Association of the Automobile Industry (VDA – Verband der Automobilindustrie) consists of more than 600 companies involved in the production of the automotive industry in Germany having members from automobile manufacturers to automobile suppliers [13]. The VDA requirements for the execution and implementation of the PTI Status Test are defined in table 2.

Table 2. Gathered requirements for the VDA.

Requirement ID	Requirement
ST_1	The end result of the Status Test shall be indicated with OK or NOK.
ST_2	The vehicle manufacturer shall provide the description of reading feature states in the Open Diagnostic Data Exchange format (ODX).
ST_3	The status information shall not be provided using an OBD diagnostic service.
ST_4	The test shall be designed so that several electronic control units can be contacted.
ST_5	The test shall cover the total cause and effect chain using self-diagnostics.

GM Engineering convers service engineering and product engineering of General Motors. This consists of the data collection and provision for the test institute as well as the ability to check the readiness of the vehicle for the PTI in the dealership. The following requirements were collected in respect of General Motors Engineering, and are presented in table 3.

Table 3. Gathered requirements for the GME.

Requirement ID	Requirement
ST_6	The test procedure shall not use DTCs for indicating the status of the PTI system because the trouble codes could trigger fault indications even though they are not relevant for the tested PTI system, like calibration error or just irrelevant DTC.
ST_7	The implementation of the concept shall be done with low development effort.
ST_8	To be able to provide the status for the test relevant systems, the Status Test shall distinguish the features specified in the PTI system list.
ST_9	Future vehicles shall be supported by the developed tests.
ST_10	The test shall be applicable for as many vehicles as possible, including joint-venture vehicles.
ST_11	The developed test shall not increase product cost.
ST_12	The process shall be reliable.
ST_13	The test shall make use of standardized exchange formats.
ST_14	The telltales of the Instrument Panel Cluster shall indicate the same result as the result of the status test.

Test institute is responsible for the technical requirements. The engineering company FSD (Fahrzeugsystemdaten GmbH) represents the test institutes on defining the technical requirements for the Periodical Technical Inspection test. The following requirements, defined by the FSD, are shown in table 4.

Table 4. Gathered requirements for the Test Institute

Requirement ID	Requirement
ST_15	The execution of the status test as well as the data provision for the status test shall be process reliable.
ST_16	The test process shall have increased efficiency and reliability.

4 Concept Selection

4.1 Criteria

For rating concepts, concept selection criteria are needed to be derived from the requirements that were defined by the stakeholders. In this chapter, all the criteria are listed and explained and, in addition, the reasons behind the rejected requirements are explained.

In order to keep the number of criteria reasonable, requirements were combined. The full list of criteria will present the requirements for the concepts which then will be used for the rating of the concepts. The criteria can be found in table 5.

Table 5. Table of the concept selection criteria

Criteria	Customer	Requirement ID
Low development effort	GME	ST_7
Minimum information about the system outside the vehicle	GME, VDA	ST_1, ST_6
Concentrate only for the specific features	GME	ST_6, ST_8
Process reliability	GME	ST_12, ST_15
Test result correctness	GME, TI	ST_5, ST_14
Efficiency of the test process	TI	ST_16
Usability for as many vehicles as possible	GME	ST_9, ST_10

As seen in table 2, most of the requirements could be combined as one, generalized criteria. Due to several reasons, some of the requirements were not taken into account when building the concept selection criteria table. Every requirement that was not included in the concept selection criteria is listed in the following section explaining the reasons of the rejections.

4.2 Rejected Requirements

Requirement ST_2 "Vehicle manufacturer shall provide the description of reading feature states in the Open Diagnostic Data Exchange format (ODX)" and ST_13 "The test shall make use of standardized exchange formats" was rejected because the format of the exchanged data was irrelevant for the concept development at this point.

Requirement ST_3 "The status information shall not be provided using an OBD diagnostic service." will be used in all concepts so it was discarded from the concept rating criteria.

Requirement ST_4 "The test shall be designed so that several electronic control units can be contacted" was not considered because particular requirement was not mandatory but more of a recommendation.

Requirement ST_11 "The developed test shall not increase product cost" was rejected as a concept criterion because it was not possible to predict the costs of each concepts with enough accuracy in such an early stage.

5 Concept Definitions

5.1 Initial Situation

At the moment the periodical technical inspection is done with a manual and visual inspection to the vehicle. This includes a visual inspection of the telltales of the Instrument Panel Cluster (IPC), visual inspection of the lights and also manual inspection for the other functionalities of the vehicle. As the vehicles depend more and more on electronics, it has come even harder to identify the failures in the system which can have a significant impact on the vehicle's safety.

The current way of determining the status of the electrical systems is done by means of telltales. The inspector will check the telltale lights in the IPC and detect all the active telltales or messages which indicate a malfunction in the system. The goal for the analysis of the initial situation was to identify the relation between the GM features and features in the PTI system list. Furthermore, all the PTI feature relevant signals and messages that indicated a failure in the feature were mapped. This information will be used for the implementation of the functionality of the status provision to the tester.

The analysis has shown that the use of telltales alone is not adequate for the PTI because not all of the features have a proper telltale or some of the features have shared telltale. This makes it hard to distinguish which of the test relevant features are defected. As said in the introduction, the PTI Status Test shall be used to support the current visual test.

5.2 Concept Development

In order to develop a concept that would be used as the selected concept for further discussion, initial steps needed to be taken. The following steps were necessary for generating the best possible result in the end.

To analyze the current system and find out what could be achieved with the current on board diagnostics available. The goal for this was to guarantee the best compatibility for previous vehicles and to have consistency with the Instrument Panel IPC telltales. Also, define all the possible parts of the system that could be reused in the future design.

To define the requirements from different stakeholders that will be used for refining the concept selection criteria for the comparison of the concepts which was carried out in chapter four.

One of the last steps is to define the concept variants which will then lead into a table that is used to generate different concepts. After all these steps, several concepts could be generated and rated against each other. The result of this rating will lead to one selected concept that is superior to the other generated concepts for further discussion and development.

5.3 Concept Variants

In order to develop concepts for the Status Test, several concept variants had to be identified which would be used to generate the concepts. These variants present the different possibilities of approaching the problem. The concept variants are the following:

- The implementation location of the decision algorithm on vehicle level.
- The implementation location of the decision algorithm on component level.
- The parameter used to represent the status.
- The method for requesting the status data.

All the developed concepts were generated by creating all possible combinations of the variants. As a result, all concept variants and combinations generated for the concepts are shown in figure 6.

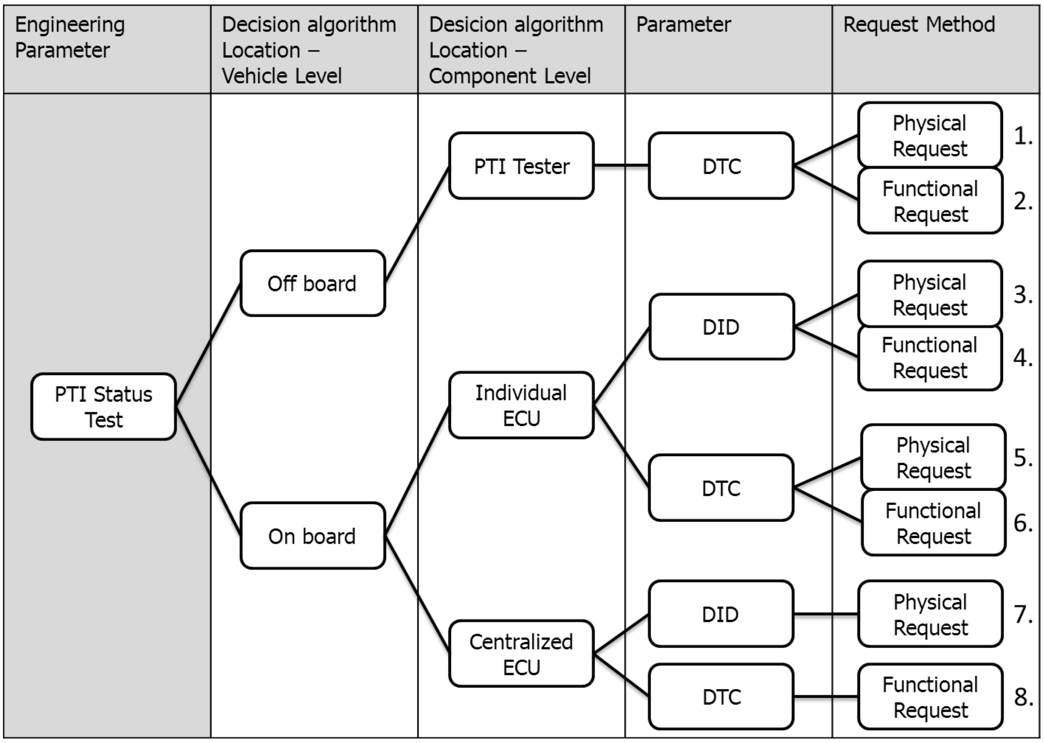

Figure 6. Concept generation chart.

In figure 6, all the possible paths through different concept variants are illustrated and each generated concept is numbered. This figure was created to give a more lucid overview of the variants and how they affected in the concept generation process. Additionally, the figure provides an easier way to perceive the developed concepts described in the following chapters.

5.4 Developed Concept

5.4.1 Concept 1 – Off Board Implementation with Physical Request

The attributes of the first possible concept were the off board implementation where the tester requests the DTCs that already exist in the vehicle with a physical request by contacting each related ECU separately. When receiving all the DTCs the tester would filter out the unnecessary DTCs from the received ones. The tester would decide the status of the tested feature and then provide the information to the end user if the feature is functioning correctly or not. This concept requires only implementing the whole PTI system to the testing device and would not need modifications to the current in-vehicle system. Therefore, reducing the effort and cost from the OEMs and ensuring the compatibility with the older vehicles. The request sequence is illustrated in figure 7 below.

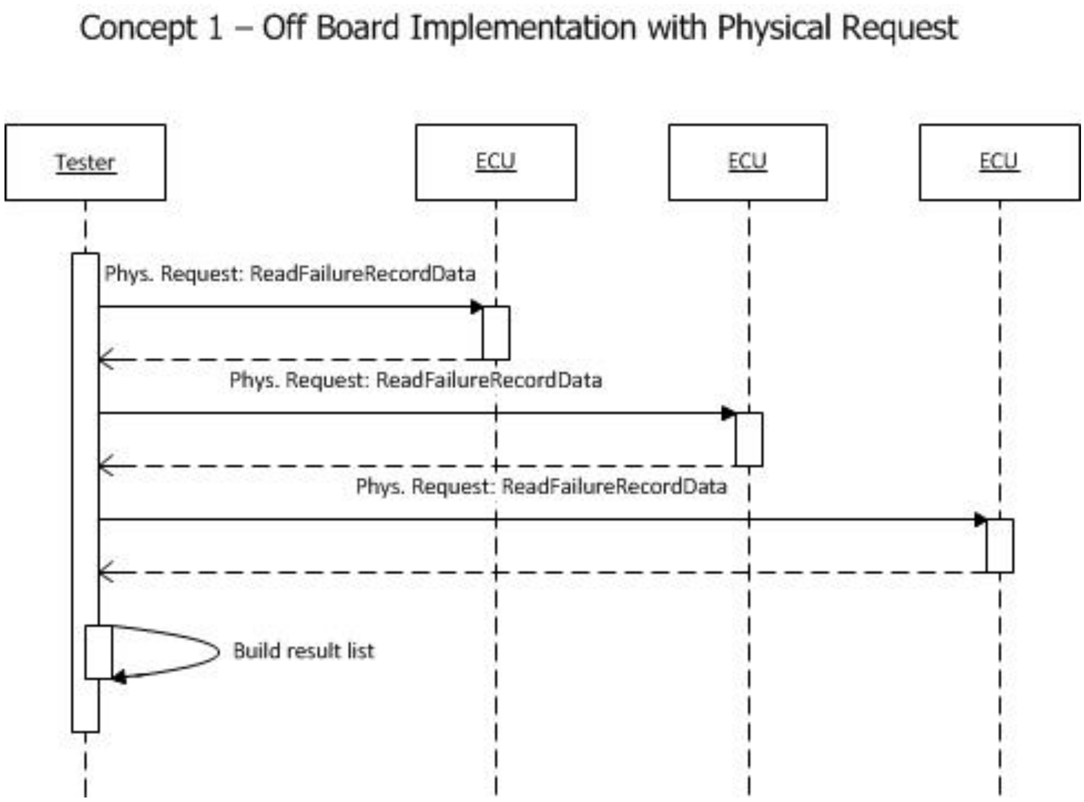

Figure 7. Request sequence of the first concept for the PTI status test.

As the figure 7 shows, each ECU is contacted individually with a physical request by requesting the failure record data. For this request, the ECU will respond with error codes that the tester needs to filter. However, the use of DTCs was not advised because of the unreliability and the possibility of misinterpretation. Also, as a downside, the list of CAN IDs needs to be maintained because it can differ between vehicle models and model years. Also, the list of relevant DTCs needs to be maintained and cause work in the long run.

5.4.2 Concept 2 – Off Board Implementation with Functional Request

Attributes for the second possible concept implementation would be the same as the previous concept with a difference on the method for requesting the DTCs. In this concept the request would be sent out as a functional request. This request is sent to all of the ECUs in the vehicle which increases the received data, thus requiring more filtering on the tester side. As for the previous concept, a list of the relevant ECUs needed to be maintained unlike for this concept. The request sequence is illustrated in figure 8.

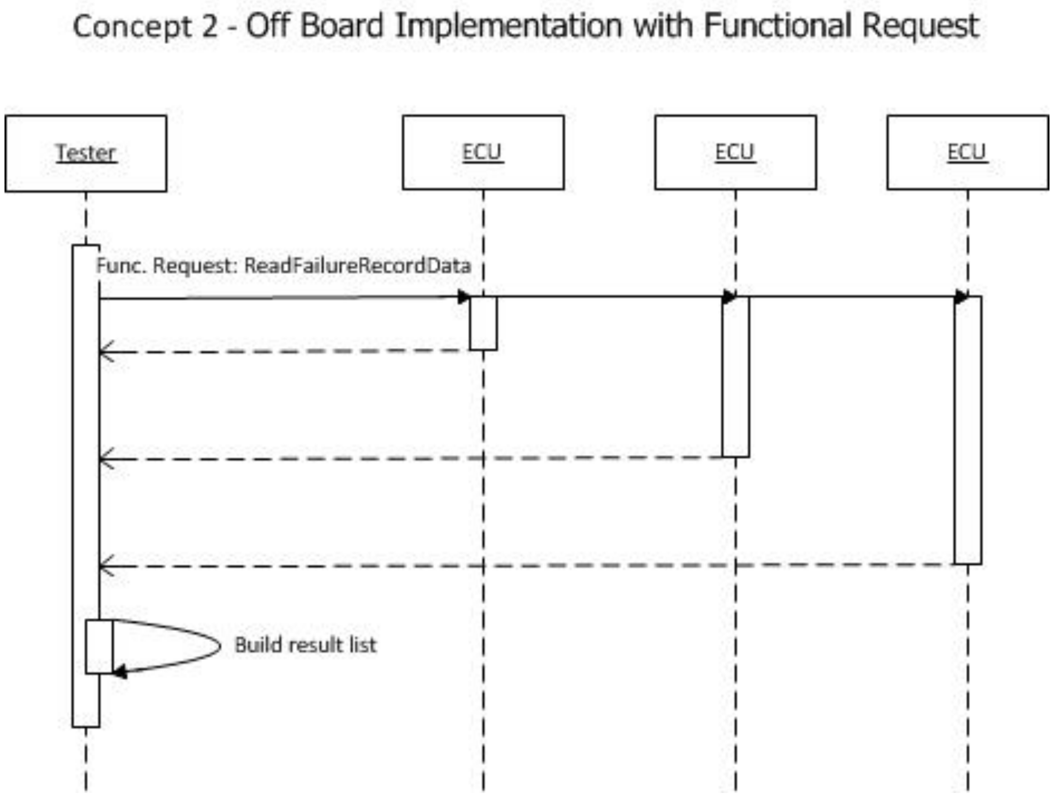

Figure 8. Request sequence of the second concept for the PTI status test.

As seen in figure 8, the functional request can be done with one service request and the service is requesting DTC information and then filtering out the irrelevant DTCs for the status report. This concept also requires maintaining the list of relevant DTCs. However, the greatest advantage of this concept is that nothing has to be implemented in the in-vehicle system, thus providing low development effort for OEMs and the compatibility for previous vehicle models.

5.4.3 Concept 3 – PTI Parameter with Physical Request

The third concept will provide a different approach compared to the two previous concepts. The main difference is that it introduces a new, so called "PTI parameter" DID. This will be used to store the status of the system in a parameter for the status test. Moreover, the new parameter would represent the status of the system with either OK or NOK. This requires changes to the current in-vehicle system which basically means that it is not compatible with the older vehicles. Also, it produces more development effort on the OEM side but on the other hand it reduces the complexity of the test device and the risk of errors. The request sequence is illustrated in figure 9.

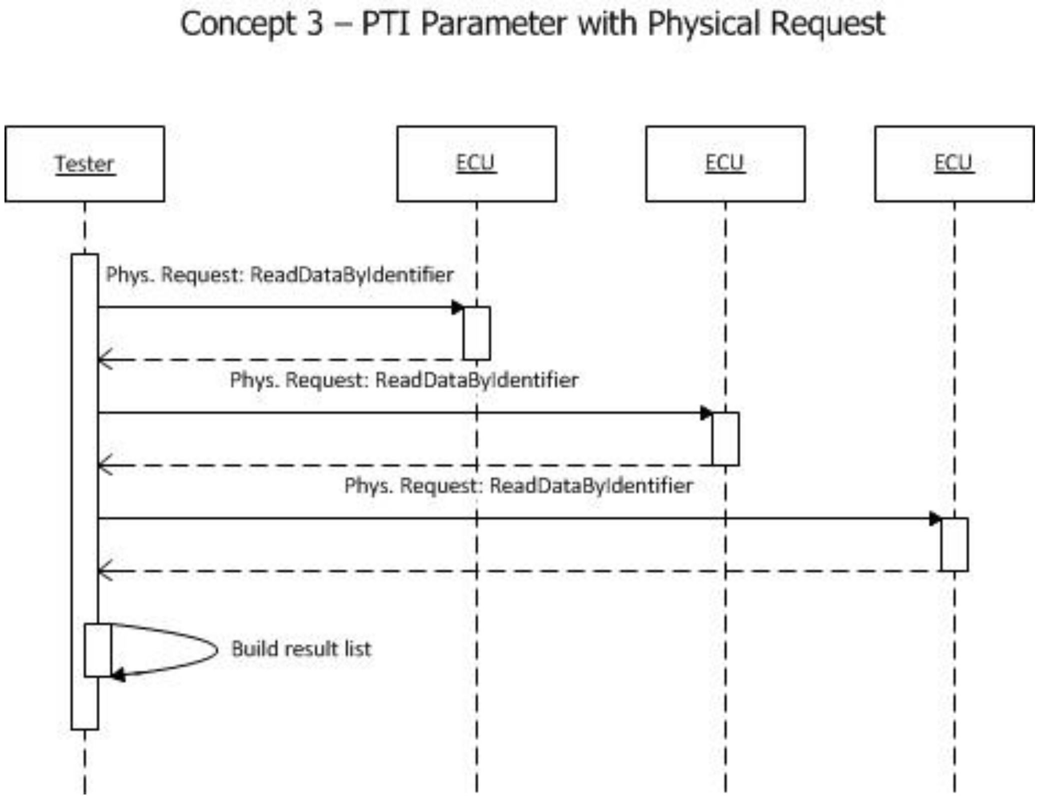

Figure 9. Request sequence of the third concept for the PTI status test.

As shown in figure 9, this time the service request is requesting data identifier. Moreover, the main attribute for this concept is in-vehicle diagnostics providing the status of the system to a certain parameter which then will be requested by the tester. This removes the issue of misinterpretation of the test result that was present on the two previous concepts because only the parameter value is transmitted to the tester. Each individual ECU will have a list of parameters every test relevant feature. Each ECU will only report the status of the features implemented in the ECU. Tester will use physical requests to request the parameters from ECUs which requires maintaining a list of CAN IDs.

5.4.4 Concept 4 – PTI Parameter with Functional Request

Overall the fourth concept is much like the previous concept, concept number three. The key difference which makes this concept better than the previous concept is the use of functional requests which in this case means that no list of DIDs needs to be maintained for different vehicle models and model years. As a result, this provides an easy access to the status data of the system while offering reliable result for the request because of the implemented status parameter. The DID needs to be implemented in each test relevant ECU and the responsibility of defining the errors that trigger the parameter as well as maintaining the DID could be assigned to the ECU owner. The request sequence is illustrated in figure 10.

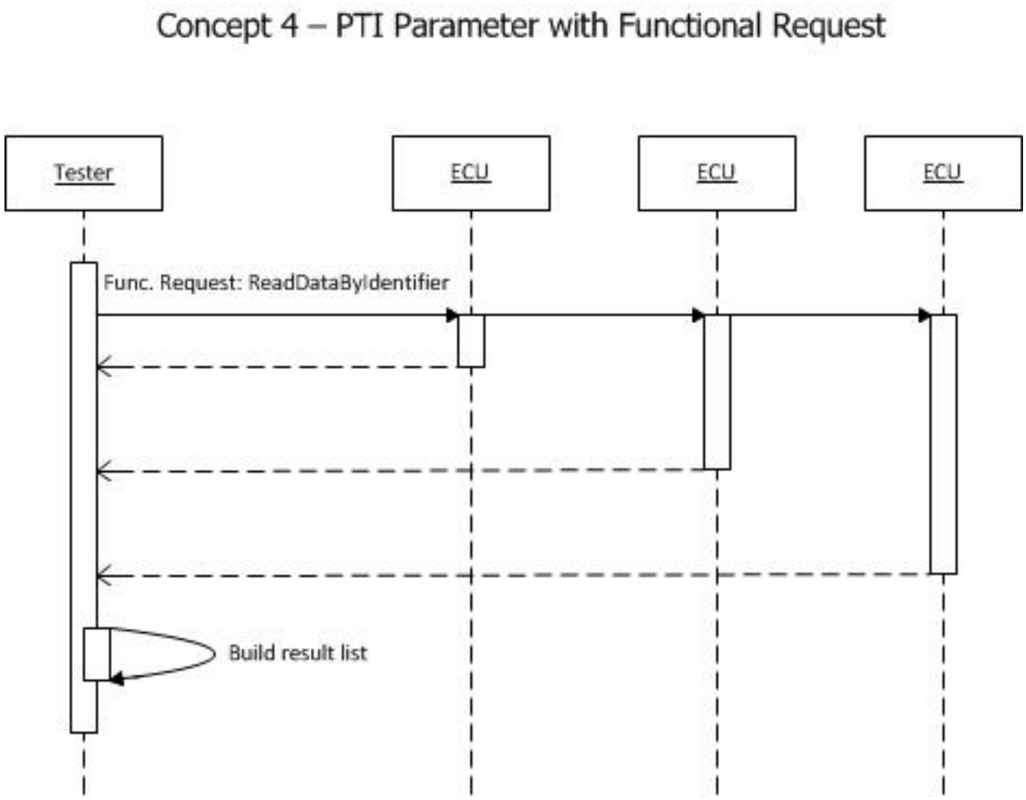

Figure 10. Request sequence of the fourth concept in the PTI status test.

In summary, the attributes for this concept are in-vehicle implementation which requires a new parameter to be implemented on each individual ECU which provides more precise and efficient development, resulting in more reliable results for the end user, and functional request for the status of the vehicle which is the easiest and most effortless way to maintain the addressing.

5.4.5 Concept 5 – PTI DTC with Physical Request

The fifth concept uses another way of storing and representing the vehicle status. This concept introduces a new diagnostic trouble code for indicating the status of the system. This DTC would require in-vehicle modifications like concepts three and four. As DTCs are generally created for indicating failures in the system, this would be an obvious way of implementing a parameter to the system. Nonetheless, the use of DTC, also in this case, brings out the same issues as before on concepts one and two, including the effort to maintain a list of CAN IDs. The request sequence is illustrated figure 11.

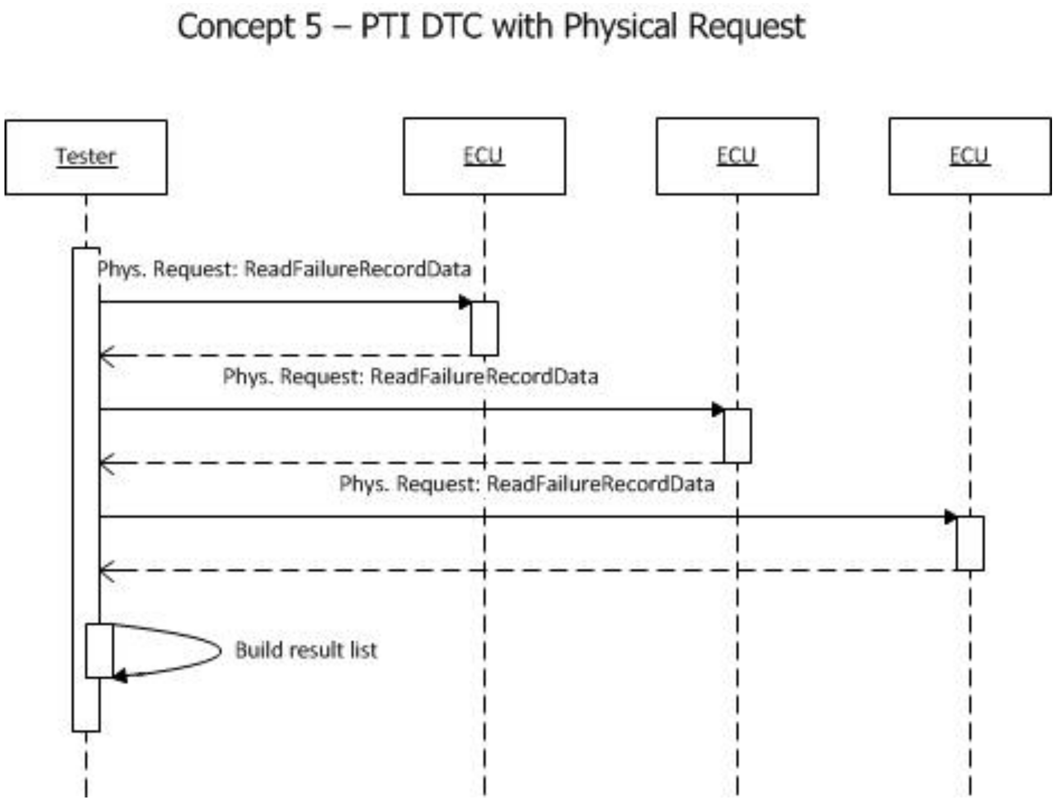

Figure 11. Request sequence of the fifth concept in PTI status test.

The main attributes of the fifth concept are the introduction of new DTCs to indicate the vehicle status which is implemented for each feature for the responsible ECU. This requires changes in the in-vehicle system because of the added DTCs. The request method used is physical request which contacts only the ECUs that are related to the required features. In addition, each PTI feature would have its own indication DTC which would be assigned to the responsible ECU.

5.4.6 Concept 6 – PTI DTC with Functional Request

The sixth concept is much like the previous concept. The only difference between these two concepts is that this concept uses a functional request instead of physical requests. This concept also implements a new DTC for indicating the status of the system. As stated in the previous concepts, where DTCs were used, the DTCs introduce a risk of misinterpretation of the trouble codes. Nevertheless, the advantage of this concept is that it uses a functional request for requesting the trouble codes. The request sequence for this concept is illustrated in figure 12.

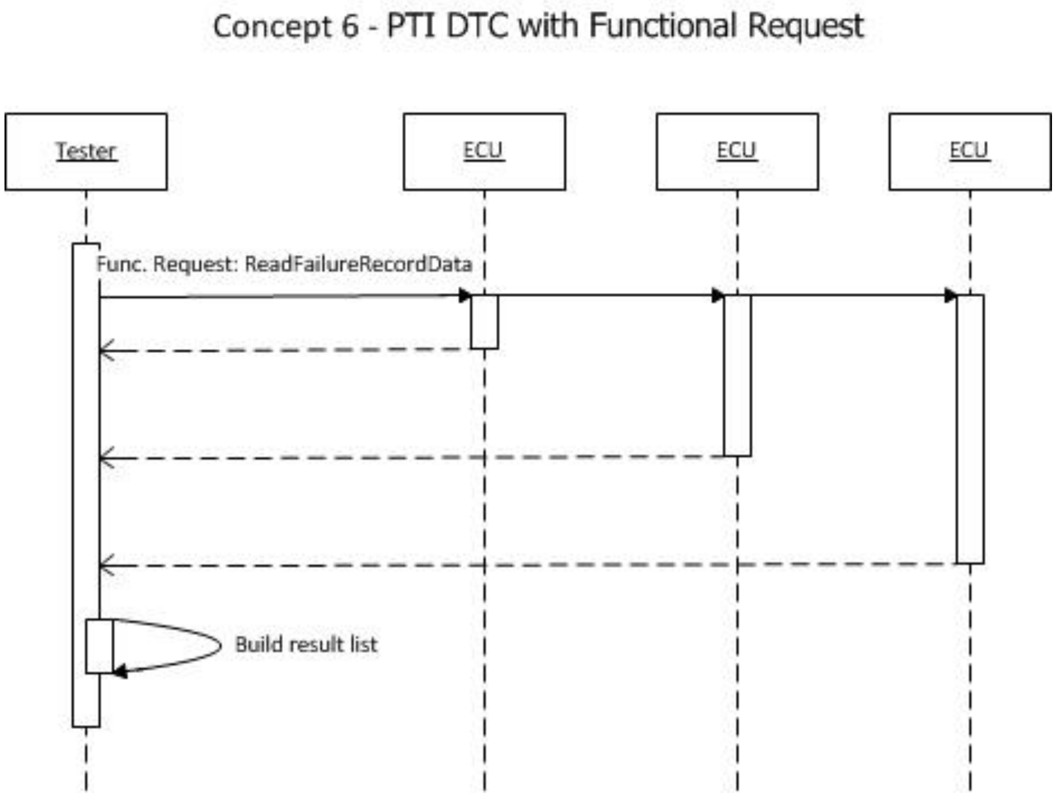

Figure 12. The request sequence of the sixth concept for the PTI status test.

As for summary of the attributes, this concept requires an implementation of the DTCs to in-vehicle system which means that it is not usable in earlier vehicles where the DTC is not implemented. The tester uses a functional request for requesting the status of the vehicle from all of the ECUs and has the DTCs implemented for every test relevant feature.

5.4.7 Concept 7 – Centralized Storage with PTI Parameter

The seventh concept differs from all the other concepts by introducing so called centralized storage ECU. This centralized ECU will have a list of so called "PTI parameters", introduced in the earlier concepts, which will be set by the ECUs which have the related feature implemented. This setting of the parameter is done by normal communication messages.

By storing all the parameters in a centralized place, this concept provides easy access to the information about the features. A downside of centralizing the test status DID for one ECU means that the development and maintaining work will be concentrated only for the centralized ECU owner. This can result in much bigger development effort than the others because of the need of additional gathering of information about the features. The request sequence for this concept is illustrated in figure 13.

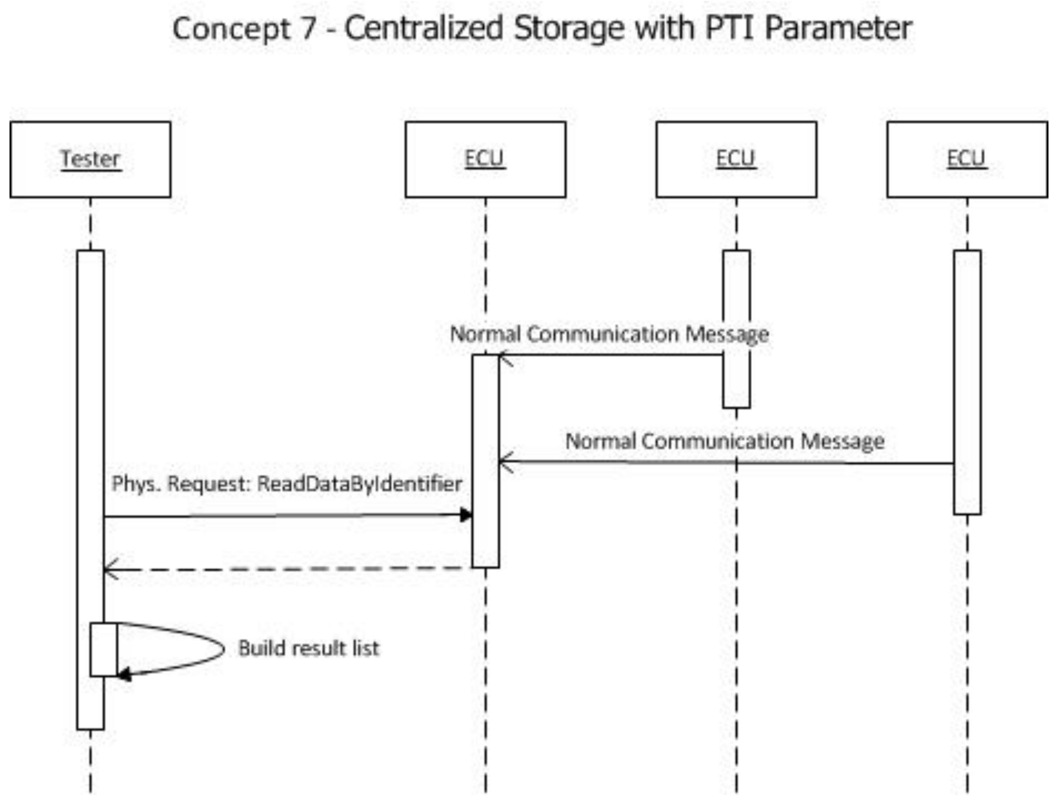

Figure 13. The request sequence of the seventh concept for the PTI status test.

The attribute summary for this concept is that it introduces the use of centralized ECU with the new parameters. The list of parameters is requested with a physical request which is an efficient way of requesting because only one ECU needs to be contacted in order to get the required information.

5.4.8 Concept 8 – Centralized Storage with PTI DTC

The final concept implementation combines the use of DTCs with a centralized ECU that will hold the trouble codes. All the DTCs are stored in one ECU which will provide an easy access to the status data in case of a request. The centralization has the same downside as the previous concept and in addition the use of DTCs, even though considered as a good way to indicate failures in the system, is not clear and reliable enough to be considered as the best solution for this concept. The request sequence for this concept is illustrated in figure 14.

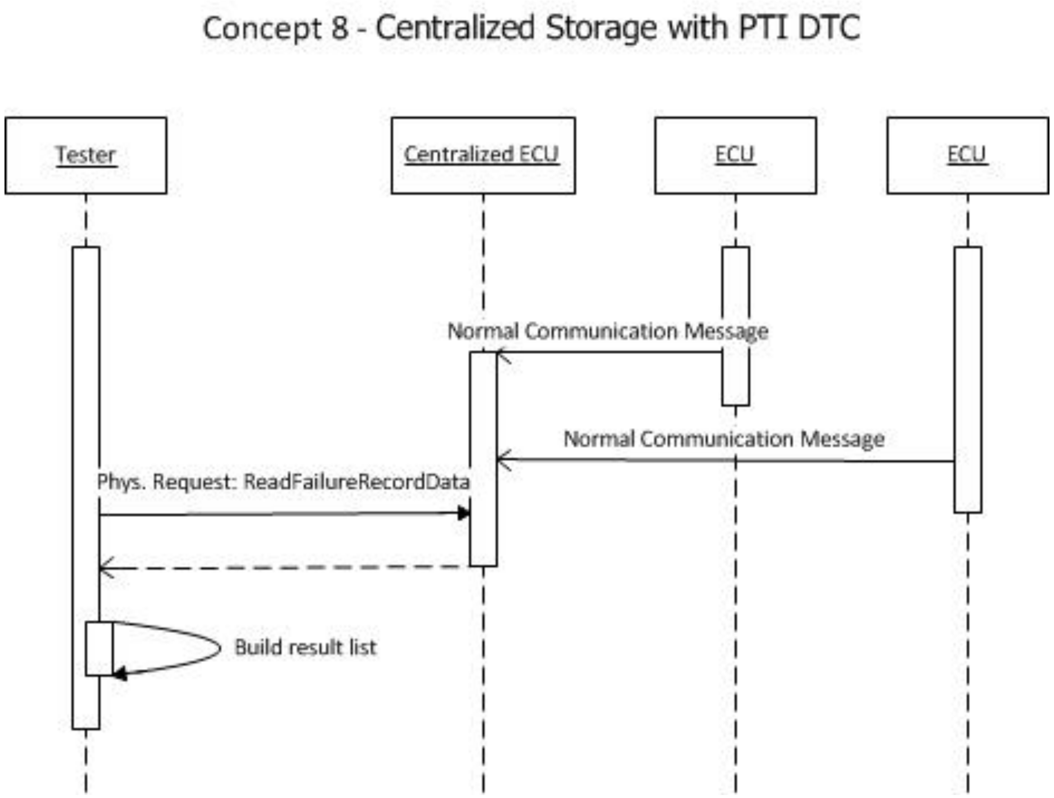

Figure 14. Request sequence of the eight for PTI status test.

As in summary for the attributes of this concept, on board implementation for the concept requires modifications for the system, thus preventing the use of this concept as it is in current vehicles and also a centralized storage ECU is used for removing the need for maintaining a list of addresses. DTCs are used as a way to indicate the status so the centralized ECU will monitor the relevant ECUs and set a DTC flag in case of a failure or error. The DTCs are requested by a physical request because only one ECU needs to be contacted.

6 Concept Selection

Now that the concepts are created and requirements are refined as criteria, the rating of the developed concepts can be carried out. As for the first part of concept selection, all of the concepts were rated against the initial situation to define which of the concepts will be selected as the best one according to the ratings.

Because of the comparison of the concepts to the initial situation resulted in a score where all the concepts rated equally, an additional round of comparison needed to be done. For this, one concept out of the eight generated concepts was selected as the datum and the comparison was done between the selected concept and the other generated concepts to distinguish the concept with the best rating. This situation can happen when developing concept for totally new system because the initial situation does not implement the feature that the developed concepts do.

The concept selected as a datum for the ratings was concept three, "PTI Parameter with Physical Request", which was the concept that utilized the use of the "PTI parameter" and distribution of the status parameters for each ECU. The request method being physical request, the test process can be sure that each individual ECU will be contacted with the request.

For the concept selection, a Pugh decision matrix was used. Each criterion was compared with the datum and then given either the value plus one (i.e. better), zero (i.e. the same) or minus one (i.e. worse) and in the end the sum of ratings was calculated for each concept. If the sum of the ratings is higher than 0, then the concept scores higher than the selected datum concept and if lower the selected concept is stronger that he compared one.

Table 3 will show the full Pugh matrix with the compared scores. The reasoning for each of the ratings can be found in appendix 2 which provides information related to every given rating.

Table 3. Concept ratings with Pugh decision matrix while concept three being the datum.

Criteria	0	1	2	4	5	6	7	8
1. Low development effort		1	1	0	0	0	-1	-1
2. Minimum information about the system outside the vehicle	D	-1	-1	0	0	0	0	0
3. Concentrate only for the specific features	A	-1	-1	0	0	0	0	0
4. Process reliability	T	0	1	1	0	1	0	0
5. Test result correctness	U	-1	-1	0	-1	-1	1	-1
6. Efficiency of the test process	M	0	0	0	0	0	0	0
7. Usability for as many vehicles as possible		1	1	0	0	0	0	0
Sum of ratings	**0**	-1	0	1	-1	0	0	-2

As a summary for the concept selection, as seen in table 3 above, one of the concepts rated higher that the initially picked concept. This concludes that the concept number four, "PTI Parameter with Functional Request", is the best concept according to the defined criteria. As seen also in the table 3, the criterion number six, "Efficiency of the test process", resulted with the same rating on each concept so we can assume that there is no significant difference on the efficiency of the concepts, at least not at this point.

7 Results

7.1 Selected Concept

As a result of the comparison that can be seen from table 3, the initially picked concept which was thought as the best options, did not qualify as the best concept selection. The criterion which made the difference between the two highest rated concepts was the process reliability which is a result from using different types of request methods.

The functional request, which broadcasts the request in the CAN network, provides more cost efficient and reliable access to each of the relevant ECUs because there is no need for maintaining different lists of CAN IDs for different vehicle models and model years. Furthermore, these attributes make the selected concept an obvious pick as the concept selection for further discussion.

The following paragraphs will give a deeper look at the ratings of the selected concept, thus providing more detailed explanation about the advantages and disadvantages of the concept compared to other developed concepts.

The selected concept scored lower rating on three different criteria against other concepts which means that other concepts were better on those specific fields. The disadvantage of this concept is the need of modification in the in-vehicle system which creates a lot of additional development effort when comparing to the first two concepts that required none.

The implementation of a new parameter reduces the amount of vehicles that the PTI status test can be executed because all the previous vehicles will not have the parameter implemented. Again, the first two concepts surpassed the selected concept on this criterion as well. Lastly, the concept seven provides an implementation, almost like the current telltales, which would make it easier to be consistent with the IPC. Nevertheless, the difference of this concept and the selected one on result correctness makes only a slight difference.

The advantages of this concept over the other ones was the functional request which will provide responses even without having to maintain a list of the CAN IDs and the feature mappings distributed to each feature owner. Moreover, the use of DIDs instead of DTCs will increase the reliability for the test result and opportunity to concentrate only on the PTI relevant features.

The distribution of the data decreases the development effort compared to the centralized concepts because the work will also be distributed to the feature owners who know how the feature works. This decreases the amount of work required. Furthermore, there is no need for providing interface for the other ECUs like in the case of the centralized concepts. Also, the possibility to assign the responsibility of maintaining the DID to each ECU owner increases the reliability of the whole process.

7.2 PTI Parameter

The concept selection resulted in a selection where the so called "PTI parameter" will be introduced. The following chapter will explain the structure of the parameter in detail. The parameter DID itself will contain a list of one bit Boolean values, one for each system, providing information about the status of the feature. The default value for the status parameter of each feature is "NOK".

The decision for the status of the parameter is done mostly by the same principle as the current telltales. The DTCs that are used for setting the trigger signal for telltales are used for the parameter as well. The difference between the functionality of telltales and the parameter is that the DTCs are remapped for the features. This helps to distinguish every single feature, even in the case that the features share a telltale. The content of the DID is shown in figure 15 below.

Bit	Name	Conversion
0	S001 - Cornering Light	0x00 = Not OK 0x01 = OK
	. . .	
37	S038 - Hydrogen System	0x00 = Not OK 0x01 = OK

Figure 15. Sample of the PTI DID list.

All the statuses of the PTI relevant features are assigned to one DID. In order to implement status for all features, at least 5 bytes needs to be reserved. For future expansions, some extra space should be also assigned for the DID. These expansions could possibly be new PTI relevant features or extended information required by the PTI test.

The DID will be implemented in every ECU that holds the main algorithm for one or more features. Each feature will have a set of failure codes that will trigger the parameter in the respective ECU. The ECUs take stance only for the features where the ECU holds the main algorithm for the feature. When requesting the list of parameters with a functional request, each ECU that has the DID implemented will response to the tester with a full list of features, indicating either “OK” or “NOK” depending on the status of the features that are implemented in the ECU. In the end, when all the ECUs have sent their responses, the tester will collect all this information and build a list of the overall final condition of the vehicle.

8 Discussion

The scope of the project was to analyze the current situation and create a concept for further development. The part of the project that was assigned for me was executed in time and as the result of the project a final concept suggestion was created.

The outcome of the concept development process resulted in a concept that was not the one thought to be the best. Even though the datum concept and the selected concept shared many similar attributes, the ratings revealed the most suitable concept and gave some idea of the strengths and the weaknesses of the selected concept for further discussion.

The initial analysis suggested that something similar like the telltale activation will be required, so a DID for the Status Test was defined. The DID takes the functionality of telltale activation methods and extends it to utilize more accurate results for the PTI relevant features. In the end, the project yielded good results as a solid base for further development of the PTI Status Test.

While carrying out this project, the lack of previous concept design experience caused some difficulties in the beginning. However, this enabled the possibility to absorb lots of knowledge on a theoretical level as well as on practical level about concept design, concept development and methods used in the process. The analysis of the initial situation also proved to be hard and time consuming because of the complexity and indistinctiveness of the documentation. Nevertheless, it turned out to be a good situation to build understanding of the functionality of the electronics in a vehicle and self-diagnostics.

9 Conclusion

The goal of this final year project was to analyze the current system and to develop a concept for Germany's upcoming test process. The analysis was done in respect of the current inspection method, which is executed via visual inspection of the IPC telltales. The goal of the analysis was to identify the possibilities with the current system. This thesis explains all the phases in this particular concept development from requirement collections to selection of a concept.

The objective of developing a concept for Status Test of the Periodical Technical Inspection that will be used for testing the electronics of a vehicle was met. The current situation of the capability of self-diagnostics was analyzed and found insufficient for implementing the test procedure. Furthermore, the requirements for the concepts were defined from different stakeholders and concept selection criteria were refined according to the defined requirements for further observation of the developed concepts. Finally, several concept suggestions were created and those concepts were rated with the criteria which resulted in selection of a concept for further discussion, which included defining the PTI parameter DID.

The results will be used as a base for further development of the concept giving enough information about the methods and reasons behind concept realization process. As the end result of the project, a new test procedure will be introduced to extend the current visual test. This will lower the cost and increase the efficiency of the test process. Comparing to present-day test methods, the new test procedure increases the overall road safety of future vehicles by taking more in-depth look to the functionality of the electronics and control units of a vehicle on feature level.

The logical next step for the process will be introducing it to the review board for further discussion and approval. The development of the Status Test will be continued until the final decision of its introduction is available. As the status legal amendment progresses, more pressure will be added for the project to drive the project forward towards the goal of creating new ways to test the safety relevant electronics in current and future vehicles.

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PTI System List

PTI System ID	PTI System Name
S001	Cornering Light
S002	Adaptive Cruise Control
S003	Adaptive Air Guide Device (Spoiler)
S004	Adaptive Front Lighting
S005	Airbag
S006	Active Head Rest
S007	Active Hood
S008	Automatic Vehicle Hold
S009	Automatic Headlamp Leveling
S010	Automatic Emergency Brake
S011	Antilock Brake System
S012	Automatic Light Control
S013	Hill Descend Assist
S014	Electric Vehicle Drive
S015	Electronic Park Brake
S016	Electromechanical Power Steering
S017	Electronic All Wheel Drive Control
S018	Electronic Damping Control
S019	Electronic Brake System

PTI System ID	PTI System Name
S020	Electronic Stability Program
S021	High Beam Assist
S022	Speed Limiter
S023	Belt Pretensioner and Belt Force Limiter
S024	Tail Lights Switching
S025	Hybrid Drive
S026	Curve Light
S027	Steering Assistant
S028	Level Control
S029	Emergency Brake Signal
S030	Preventive Safety Systems
S031	Tire Pressure Monitoring System
S032	Lane Keep Assist with Braking Intervention
S033	Lane Keep Assist with Steering Intervention
S034	Lane Change Assistant with Steering Intervention
S035	Traction Control
S036	Superposition Steering
S037	Rollover Protection (active)
S038	Hydrogen System

Arguments for the Concept Ratings

Reasons	3	1	2	4
1. Low development effort		Using already existing DTCs will not require any modifications to the current in-vehicle system.	Using already existing DTCs will not require any modifications to the current in-vehicle system.	In-vehicle modifications also required for this concept.
2. Minimum information about the system outside the vehicle	D	Using already existing DTCs might provide additional information that can be misinterpreted.	Using already existing DTCs might provide additional information that can be misinterpreted.	Uses the same PTI parameter as the datum.
3. Concentrate only for the specific features	A	DTCs available are not precise enough for concentrating specific features.	DTCs available are not precise enough for concentrating specific features.	Feature specific DID.
4. Process reliability	T	Requires maintaining list as does the datum.	No need for maintaining address list.	No need for maintaining address list.
5. Test result correctness	U	Using DTCs may cause misinterpretations which leads to incorrect test results.	Using DTCs may cause misinterpretations which leads to incorrect test results.	No major difference between this and the selected concept.
6. Efficiency of the test process	M	Cannot see any real difference at this point of the development.	Cannot see any real difference at this point of the development	Cannot see any real difference at this point of the development
7. Usability for as many vehicles as possible		DTCs already exist on current vehicles and could be used in the future also.	DTCs already exist on current vehicles and could be used in the future also.	Requires in-vehicle modifications. Not available for previous vehicles.
Sum of ratings	**0**	**-1**	**0**	**1**

Reasons	3	5	6	7	8
1. Low development effort		In-vehicle modifications also required for this concept.	In-vehicle modifications also required for this concept.	Additional work on gathering the necessary information about other features.	Additional work on gathering the necessary information about other features.
2. Minimum information about the system outside the vehicle	D	Uses a specific DTC assigned for the feature.	Uses a specific DTC assigned for the feature.	Uses the same PTI parameter as the datum.	Uses a specific DTC assigned for the feature.
3. Concentrate only for the specific features	A	Feature specific DTC.	Feature specific DTC.	Feature specific DID.	Feature specific DTC.
4. Process reliability	T	Requires maintaining list as does the datum.	No need for maintaining address list.	Does not need a list but required additional development for the centralized ECU.	Does not need a list but required additional development for the centralized ECU.
5. Test result correctness	U	Using DTCs may cause misinterpretations which leads to incorrect test results.	Using DTCs may cause misinterpretations which leads to incorrect test results.	Consistency with the IPC telltales would be assured.	Using DTCs may cause misinterpretations which leads to incorrect test results.
6. Efficiency of the test process	M	Cannot see any real difference at this point of the development	Cannot see any real difference at this point of the development	Cannot see any real difference at this point of the development	Cannot see any real difference at this point of the development
7. Usability for as many vehicles as possible		Requires in-vehicle modifications. Not available for previous vehicles.	Requires in-vehicle modifications. Not available for previous vehicles.	Requires in-vehicle modifications. Not available for previous vehicles.	Requires in-vehicle modifications. Not available for previous vehicles.
Sum of ratings	**0**	**-1**	**0**	**0**	**-2**