DEDICATE -
Dependability and Diagnostics Concept Assessment and Test

Project within FFI Fordonsutveckling

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

Automotive systems see increasing amounts of electrical and electronic systems with increased integration and interaction. This leads to increased complexity which, if not handled appropriately, decreases safety, quality and uptime by producing higher overall failure rates and more complex maintenance needs. This increases the overall cost of transports of goods.

The goal with DEDICATE is to develop solutions for the 2020 timeframe for increasing uptime, quality and safety by lowering the failure rate and shortening the time required for maintenance.

DEDICATE has developed and demonstrated new and improved concepts for increasing uptime, quality and safety by i) decreasing failure rate with better in-vehicle solutions for automatic detection, diagnosis and management of faults, and ii) facilitating repairs with better service solutions for diagnosis and maintenance, remotely and in workshops. This two year project is the continuation of a one year project started in 2009, and has in this endeavour produced the following results based on the results from the first year.

- **Fault type information:** We have collected information on which faults are the most common ones in operational vehicles, based on interviews and by studying relevant databases containing fault information. This has provided us with a comprehensive view on which the most problematic fault types are, how they are handled today and what could be improved. This fault type information formed the basis for our work on in-vehicle fault management systems and maintenance service concepts.
- **In-vehicle fault handling:** Building on our fault type information, we have selected a set of fault types for which we defined new and/or improved mechanisms for fault handling (including detection and recovery) targeting electrical faults, from conductor/node level up to the system (vehicle) level. The defined concepts and prototypes have been empirically evaluated to assess their weaknesses and strengths.
- **DEDICATE Framework:** In order to assess the in-vehicle fault management solutions defined in the project, we have put together an assessment and testing framework based on a test target in the form of an embedded distributed system resembling the technologies present in current and next generation automotive products from the Volvo Group, together with prototypes of the defined fault handling mechanisms. This framework also contains the DEDICATE Fault injEction and Analysis Tool (D-FEAT) for artificially recreating relevant fault types.
- **Maintenance service problem analysis:** Similar to the fault types study, we have conducted a study on what the perceived problems and bottlenecks are in today's maintenance service situation. By means of interviews with people working with or affected by maintenance services, such as workshop personnel, drivers and haulers, we have analysed the current situation and produced a comprehensive view on the current situation and what could be improved.
- **Maintenance service concepts:** Based on the problem analysis of current maintenance service solutions, we defined concepts for improved maintenance services. Using visualisations and other means we then evaluated those concepts.

2. Background

Quality and *Safety* are two of the corporate core values of the Volvo Group. There is a very close link between quality and safety in that it is virtually impossible to achieve safety without achieving quality and vice versa. Furthermore, uptime is an increasingly important factor for our customers, and both quality and safety are intimately linked to uptime.

The trend in automotive systems is increasing amounts of electrical and electronic systems with increased integration and interaction. This trend leads to increased complexity which, if not handled properly, works against safety and quality by producing higher overall failure rates. Furthermore, the increased complexity makes diagnosing faulty systems more difficult and thus generates more complex maintenance needs. Altogether, this results in decreased uptime, decreased perceived quality and, in the worst case, could lead to decreased safety.

In current product development efforts, these problems are of course being addressed, based on the needs and requirements at hand. However, the trend mentioned above is not showing signs of slowing down, so new needs and requirements are identified continuously. Thus, new ideas and concepts need to constantly be devised and assessed.

3. Objective

In Figure 1 a simplified view of the phases in which a vehicle can be during its lifetime is illustrated. The main three phases are: 1) operational, which is when a vehicle is performing actions necessary to fulfil its mission, 2) out of order, which is when the vehicle no longer can fulfil its mission due to some fault occurring in the system, and 3) in maintenance, which is when the vehicle is being repaired. After successful maintenance, the vehicle is once again in the operational phase.

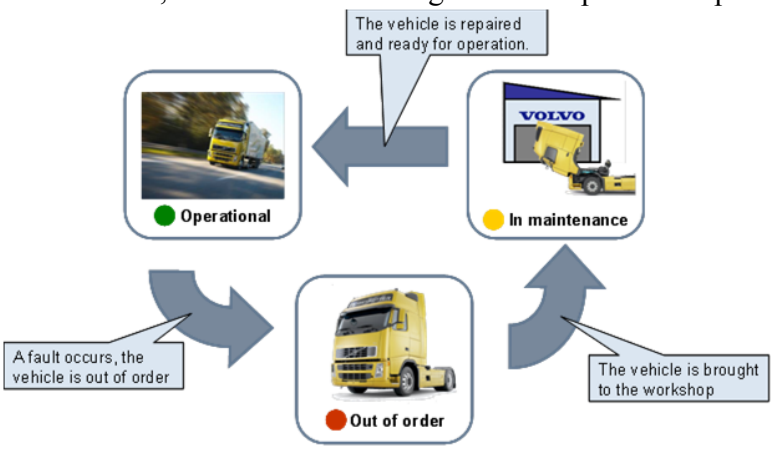

Figure 1. Simplified view of vehicle phases

In DEDICATE we have developed solutions for the 2020 timeframe for increasing uptime, quality and safety by lowering the failure rate and shortening the time required for maintenance. We address this with a two-pronged approach: 1) new and improved in-vehicle solutions for automatic detection, diagnosis and management of faults, i.e.,

increasing the time in which the vehicle is in the operational phase, and 2) new and improved service solutions for diagnosis and maintenance, i.e., decreasing the time the vehicle is in the out of order or in maintenance phases.
The new and improved in-vehicle solutions will equip the vehicle with the improved ability to automatically detect abnormal situations, i.e. the existence of a fault which prevents the vehicle from operating normally, and subsequently handle these faults such that the mission can still be safely completed, as well as store information pertinent for the improved maintenance services.
Improved service solutions for diagnosis and maintenance are important, as the perceived quality of a vehicle is not only based on the capabilities of the vehicle, but also on external services, e.g., extended diagnostic abilities in some central Back Office, as well as easy and swift maintenance locally at the workshops.
DEDICATE aims at developing a concept assessment and test framework related to dependability, such that new solutions and technologies can be demonstrated and visualised and their feasibility and effectiveness assessed. Using the DEDICATE framework will enable assessment and validation of new concepts for improved dependability, diagnostics and maintenance for incorporation into next generation vehicle platforms and the generations beyond. A proven and validated concept is easier to incorporate into products as we will know how to incorporate it efficiently and we know what the benefits are. This will lead to *increased cost-efficiency for dependability and diagnostics solutions*.
Improved dependability and diagnostics capabilities, both in terms of in-vehicle systems and external services, will lead to *safer vehicles and increased uptime* and thus *even better perceived quality and safety* of Volvo Group products.

4. Project realization

The overall work flow in the DEDICATE project is illustrated in Figure 2.

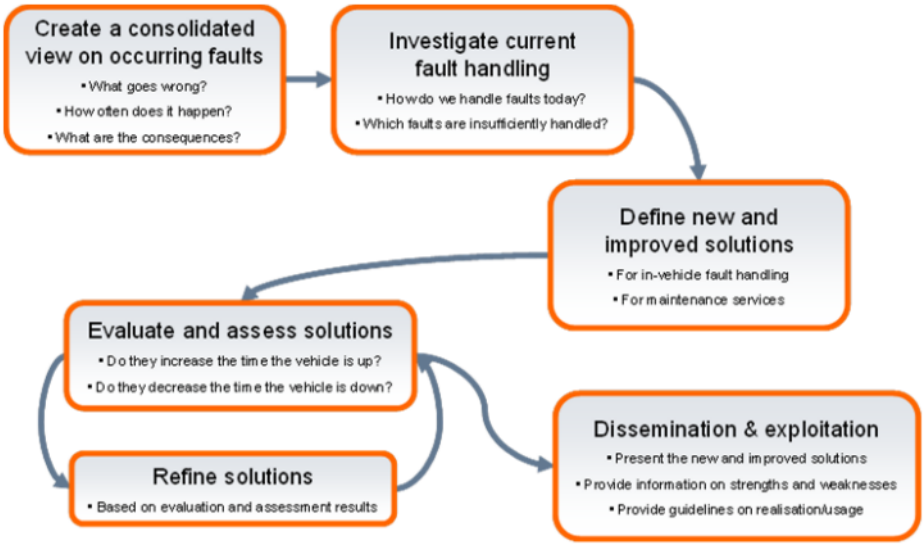

Figure 2. Overall workflow in DEDICATE

The project realization is described based on the two parts of the project: 1) In-vehicle fault management; 2) Maintenance service concepts.

In-vehicle fault management

The investigation on current fault types was conducted as a field study, where interviews and data analysis from existing databases where used. The same interviews were also used to gather information regarding current use of fault handling mechanisms, forming the basis for performing the fault handling gap analysis (revealing the gaps between available fault handling mechanisms, FHMs, for current fault types). Where we in the gap analysis found that it would be beneficial to improve or create new FHMs a more applied method was used. Here mechanisms were first conceptually developed and described and then later realised in prototypes which were experimentally assessed. A simplified development process was followed for the prototype development. In this process requirements, use cases and modelling were performed prior to commencing the actual implementation in hardware and software which was followed by validation in assessments.

For the evaluation of the prototypes, fault injection was used for validation and verification. In fault injection, faults are artificially injected into the target system and its behaviour is studied. Based on the expected behaviour the target system is classified as being able to handle the faults or not. In DEDICATE the faults injected were based on the fault types collected from the field (to be realistic) as well as those from standards (such as IEC 61508/ISO 26262). A fault injection tool, DEDICATE Fault injEction and Analysis Tool (D-FEAT), has been developed for injecting faults and collecting result data automatically.

Maintenance service concepts

When developing the service concepts, the work has included interviews, observation studies and co-creation workshops aimed to explore customers' (haulers') needs related to maintenance and repairs. Maintenance and repair suppliers (workshop personnel) together with Volvo Trucks were also included in the study to get a holistic picture of the current maintenance and workshop situation.

To understand how customer's expectations are met in the workshop we have performed studies and interviews in two workshops in Sweden, one in UK and one in the U.S.

The methods used are shown in Figure 3.

Interviews

Semi structured interviews were conducted with various people from service suppliers and customers

Observations

Observational studies were performed at service suppliers were the customers and workshop personnel were observed rather than questioned

Co-creation workshops

Co-creation workshops were set-up based on methods developed within Volvo Technology and methods developed together with Chalmers University of Technology and held together with haulers, workshop personnel and Volvo Trucks

Figure 3. Three methods for service development used in DEDICATE

The results from the co-creation workshops were further enhanced by the project team at Volvo Technology into the Volvo Non-Stop Concept. In addition, the concept was visualized through Adobe Flash to make it tangible and easy to understand. This was showed at an open Volvo seminar where the concept was evaluated by the audience.
To get a deep understanding of what happens to a vehicle during a workshop visit we have performed value stream mapping on three different workshops. This means that we have followed a number of vehicles from the time they enter a workshop until they are finished. All activities that occur around the vehicle were clocked and categorised as either value adding, not value adding but necessary and waste. In the end, we have looked at the total throughput time of the vehicle through the workshop and how much time is spent on each category of activities.

5. Results and deliverables

DEDICATE is internally at Volvo handled as a three year project, where 2009-04159 (summarised in this document) constitute year two and three. Year one has been constituted by 2009-00260, and the results described here are a direct continuation on the results from 2009-00260. The presentation of results and deliverables in this section focuses on the activities performed during year two and three. Please refer to the reporting of 2009-00260 for more detail from the results of the first year of the project.

Fault type information

The fault type information has been used to form a comprehensive picture of the faults pertaining to electric and electronic subsystems of Volvo products. This comprehensive picture is useful in several aspects: a) it provides quantifiable justification for the need to handle common faults and thus guidelines for research on new and improved fault handling mechanisms; b) it provides input to assessment of fault handling mechanisms; and c) serves as an “eye-opener” to engineers and researchers within the field.
The method used is two-folded, both an interview study and a database study have been performed. The interview study was mainly performed in the first year of the project and finalised during the last two years. In the database study, information from existing databases containing fault information were compiled and studied. The aim of the database study was to further substantiate the results from the interview study (which was a qualitative study with information on what faults people in the Volvo organisation “think” occur in the products), trying to verify/falsify the results using significant amounts of statistical data from the field.
In all the information in three different databases were analysed. The result from the database study supports the results from the interview study in general.
The following main conclusions were drawn from the interview- and database studies:

1. Sensors, cabling and connector faults are the most frequently faults appearing in our products. Problems related to software have also been identified as one failure source.
2. Transient and intermittent faults occur and they are difficult to handle at workshops
3. The diagnosis time for electrical faults is high compared to other faults
4. Data link faults occur and there could be many reasons for such faults to be reported

Recommendations for how to proceed with the findings, i.e. how to proceed with investigations in order to improve the handling for these fault types, have also been compiled.

In-vehicle fault handling

In this part of the project, in-vehicle fault management solutions have been elaborated. In a literature study, available fault management solutions for electrical faults have been compiled in to a comprehensive collection of mechanisms and techniques available for incorporation into Volvo Group products. Furthermore, the usage of fault management solutions in the Volvo Group has been studied in an interview study. Two different gap analyses have been performed to investigate: a) if there are available fault management solutions for the frequently occurring faults found in the project, and b) how the available fault management solutions are used within the Volvo Group for the frequently occurring faults.

The main result from the first gap analysis was that there are available fault management solutions for sensors, cabling and connectors, and transients. However, in order to improve the diagnosis time, approaches for better pin-pointing on fault localisation are required. For data link faults, a more system wide approach to diagnosis, i.e. going from an ECU-level to vehicle level when drawing diagnostic conclusion, is needed. Such an approach would also be useful decreasing the diagnosis time.

The second gap analysis showed that the knowledge of available fault handling mechanisms is good within the Volvo Group and it also showed that many of the mechanisms are also being used.

Based on the result from the gap analyses, we have chosen to study a number of different fault handling approaches further. These approaches are described here below:

PADS

Proactive and Accurate Diagnostic System (PADS) is a concept using the principle of continuously monitoring both voltage and current of a connected load (power line or sensor signal etc.) in order to detect and handle faults. This concept was developed during the first year of the project. During the second year it was thoroughly evaluated in an assessment using fault injection in the DEDICATE framework (see below). Based on the result from this assessment improvements in the implementation were performed and another assessment was performed showing good improvements.

The general conclusions from the assessments are that PADS can detect and handle faults (for example short circuit faults) on cables and connectors and PADS can be used for better localisation of faults compared to using only the built-in capabilities of modern ECUs.

TDR

The measuring technique called Time Domain Reflectometry (TDR) was studied during the first year of the project and this study continued during the second year of the project. It was found to have a great potential of being able to increase the precision on pin-pointing the fault localisation.

4-wire measurement

Another fault handling mechanism that has been studied is the 4-wire measurement approach. 4-wire measurement is used to eliminate the influence from the series

resistance in the supply voltage cables. It was found that compared to a conventional measurement setup, the 4-wire measurement technique makes it possible to detect more fault types and the precision in the fault localisation is also better.

DEDICATE Error Management concept

When it comes to the system wide approach we have been working on different approaches and the result is the DEDICATE error management concept.

The DEDICATE error management concept is a software design concept, with a hierarchal and distributed approach, that reaches beyond the classic ECU encapsulation in order to view the vehicle as a functional architecture instead of a network of stand-alone systems with regards to diagnostics and error reactions. The concept provides support for vehicle-wide error handling and diagnosis and enables analysis of the health of the entire vehicle rather than analysis being limited to ECUs (or functions). It presents a dual view for the error model, a functional view and a physical view, which interact in order to handle the complexity in modern E/E-architecture. Furthermore, the concept seeks to provide support for more elaborate and more systematic error handling strategies.

The DEDICATE error management concept is built around the notion of Error Managers (EMs) which encapsulate all error management strategies. The Error Managers allow a high degree of separation of error management from nominal functionality, when this is possible. There will be multiple Error Managers in the vehicle and they have inputs and outputs, as illustrated in Figure 4, which are used to make diagnostic decisions.

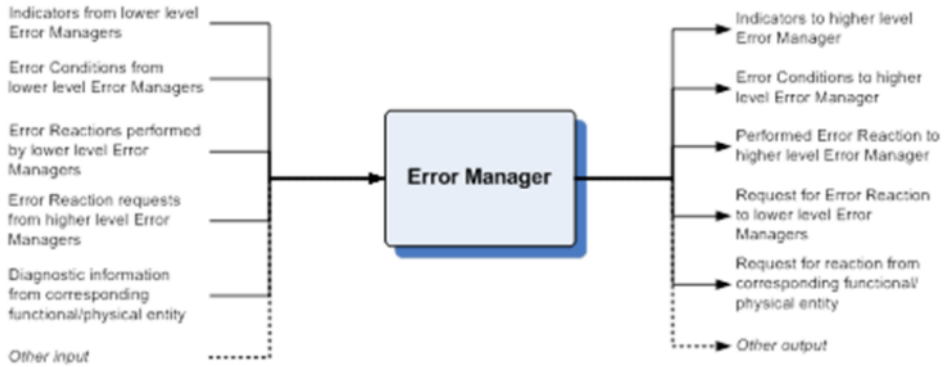

Figure 4. Input and output of an Error Manager.

There are Error Managers for each item in the system decomposition, implementing the specified error handling strategies. In order to define the error handling strategies, we have within the concept suggested roles and activities to be incorporated in the development process for the development organisation.

The error management concept has been assessed using a prototype implemented in the DEDICATE framework (see below). The assessment was performed by executing a number of implemented use cases, selected to illustrate important features of the concept, and analysing the results from executing the implementation while injecting faults. The main purpose of the assessment was to verify the feasibility of the concept and to identify possible overlooked issues or weaknesses. Another purpose was to create a design pattern which could be used as a practical guide when implementing the concept in a vehicle architecture. The assessment was performed iteratively with the possibility to influence the concept after each of the iterations.

The results from the assessments showed that the DEDICATE error management concept is a promising approach for system wide error management, but it is necessary to evaluate the concept further to be able to better support an implementation in a real product.

DEDICATE framework

The DEDICATE framework is our setup for testing and assessing the concepts we develop for fault management. Two different versions have been developed, one for evaluating PADS (built during the first year of the project), and another one for evaluating the DEDICATE error management concept built during the last two years of the project. The first version of the framework is described in the reporting of 2009-00260 and therefore only the second version is described here.
The largest difference between the requirements for the versions is that the DEDICATE Error Management concept includes many more software oriented requirements whereas the requirements for version one are more focused on hardware. The second version of the framework also provides a larger distributed system with the ability to explore advanced network applications compared to the first version.
The framework consists of five ECUs, a brake pedal, an accelerator pedal, indicator and warning light switches, brake and indicator lights, power supplies and cables as shown in the simple schematic in Figure 5.

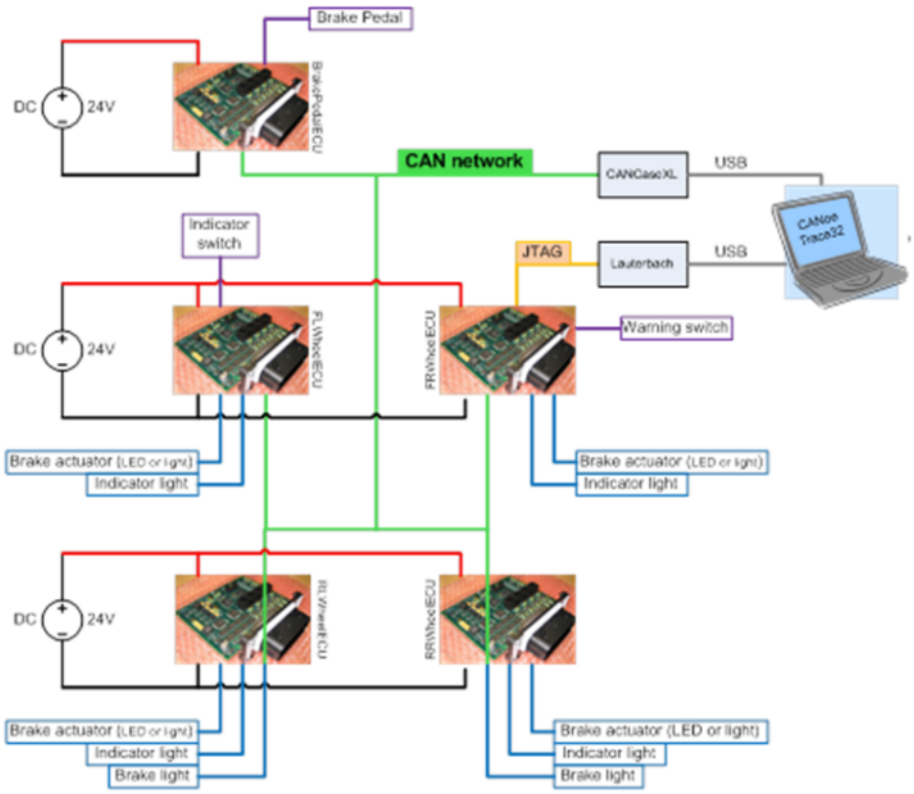

Figure 5. Overview of the second version of the DEDICATE framework

A number of distributed applications have been implemented on the framework ECUs. The main application is a BBW (Brake-By-Wire) application running on all five

framework ECUs. Other implemented applications are Brake Light controller as well as Indicator and Warning Light controller. All the implemented applications are distributed over several ECUs.

Maintenance service problem analysis

The purpose of this part of the project was to develop solution concepts that meet customer and market needs related to uptime, taking into account current needs and those envisioned for the 2020 time frame.
In order to better understand what happens from the time an error occurs until a truck is repaired we followed a number of vehicles through this process. The result is shown in Figure 6.

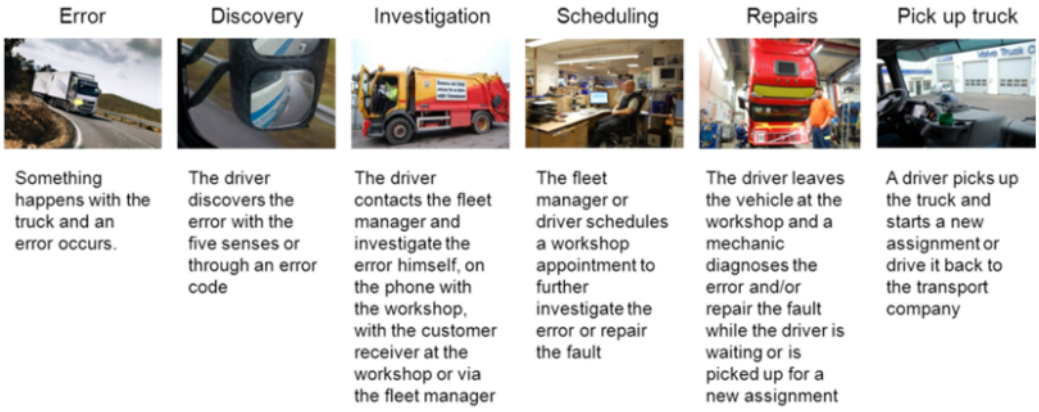

Figure 6. The process from which an error occurs until the truck is repaired

In co-creation workshops a comprehensive list of current problems was developed, agreed upon and boiled down to three main problem areas: 1) Identification of the fault; 2) Planning for repairs; 3) Customer relationship.
In order to understand what happens to the vehicle during service and repairs we performed a value stream mapping by following a number of vehicles from the time they arrive to the workshop until they leave and documented all executed activities. More specifically we measured value adding time, necessary time and waste time from a vehicles perspective during the workshop visit. The data from the measurements were compiled into three categories: 1) Lead time; 2) Efficiency; 3) Waste.

Maintenance service concepts

To set the stage for the 2020 workshop we have created a vision that shows an uptime experience of the customer in the future. It has been based on the interviews, the value stream mapping and the co-creation workshop. The vision has been visualised as a comic paper illustrating and highlighting the future requirements and needs regarding maintenance solutions.
Furthermore, for each of the five largest waste categories (Fetch tools, Unnecessary diagnostics, Movement, Administration work, and Wait at parts counter) found in the value stream mapping, estimates on potential internal savings have been made.

A vision will not be realised without tangible solutions and therefore we have created 19 different concepts based on our studies and co-creation workshop. The aim with the concepts is to reduce the top five waste categories from the value stream mapping.
A concept for the future workshop has also been developed. It focuses on giving the customer receiver more tools to identify a fault on a vehicle, to improve the planning process through a pre-work order and to grow the customer relationship, see Figure 7.

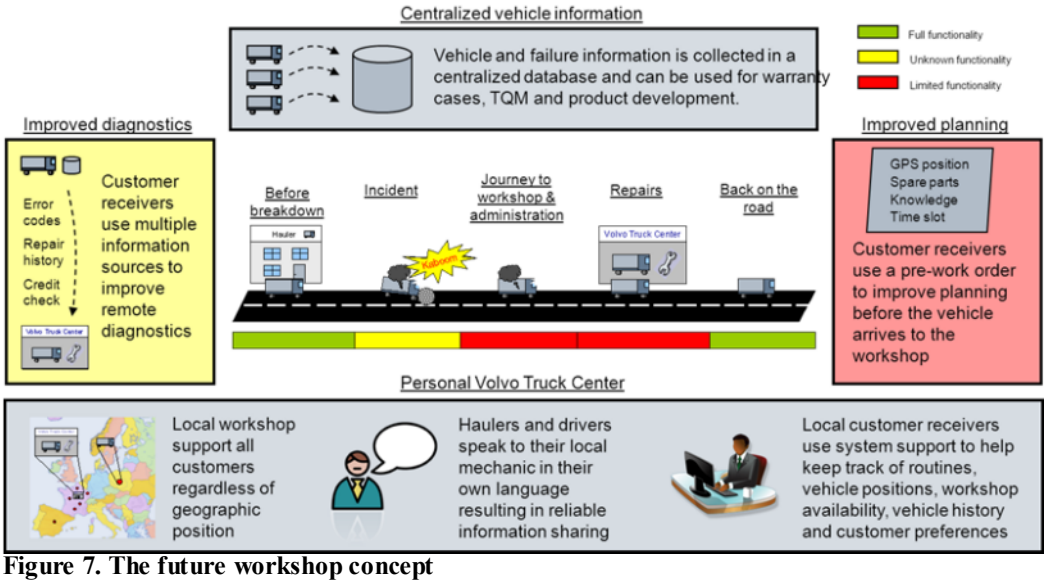

Figure 7. The future workshop concept

The developed concepts have been assessed at internal seminars and also at the DEDICATE seminars where valuable feedback have been given. This feedback has been considered in the final versions of the concepts. Furthermore, the concepts have been assessed through discussions with people at Volvo Bus and Volvo Trucks and internal seminars with people from different parts of the Volvo organisation.

Deliverables

The results described in the previous sections have been documented in a number of deliverables, in addition to other project relevant information:

- D1.1 Project plan
- D1.2 Project summary
- D2.1 DEDICATE Framework (first version)
- D2.2 DEDICATE Framework documentation (first version)
- D2.3 DEDICATE Framework (second version)
- D2.4 DEDICATE Framework documentation (second version)
- D3.1 Fault model
- D3.2 Fault injection tool
- D3.3 Fault injection tool documentation
- D4.1 FHM overview and gap analysis
- D4.2 FHM prototypes – electrical level
- D4.3 FHM documentation – electrical level
- D4.4 FHM prototypes – system level
- D4.5 FHM documentation – system level

- D4.6 FHM assessment – electrical level
- D4.8 FHM assessment – system level
- D5 Maintenance service concept
- D6.2 Visualisations
- D7.2 DEDICATE Seminar 2
- D7.3 DEDICATE Seminar 3
- D7.4 Future directions

These deliverables are in general not available for public access. Please contact us for further questions about the project results.

Delivery to FFI-goals

Here follows our opinion of how DEDICATE contribute to the targets set forth in the programme FFI Fordonsutveckling.

Further development of base technologies of strategic importance

Being able to quickly and accurately diagnose and deal with errors is a basic skill needed to maintain quality and safety in vehicles. Quality and safety are two of the Volvo Group's core values, and thus the areas that DEDICATE is working in include strategically important basic technologies. The project has developed new and improved ways to detect and handle errors that arise in the electrical parts of the vehicle platform, with a high potential to eventually find its way into the Volvo Group's products and/or aftermarket system. In the project, we have listened to our customers (haulers, drivers and engineering staff) to find out what areas are considered as problematic and as bottlenecks, and developed service concepts that address the key issues to improve the perceived quality. This has, in the same way as with the on-board solutions, a high potential to impact the services that will be offered by Volvo Group to its customers in the future.

Development of innovative concepts in areas such as vehicle electronics

The concepts developed for the improved error management, on both electrical and system level, represent a skill level that has not been achieved in today's products. You could say that the diagnosis and error handling in today's products is near-sighted, that focuses mostly on a single electronic unit (ECU) and its components and peripherals. With the error handling concepts we develop in DEDICATE, we take a step up to the vehicle level and can create a better picture of the entire vehicle's condition, and not just individual units' condition.

Development and introduction of more efficient development methods

Development methods have not been a primary focus in the project. However, we believe that the fault injection methods we have used for evaluating the error-handling mechanisms can be used to improve development methods used for next generation safety-related embedded systems (in accordance with the requirements in ISO 26262). Furthermore, our concept for system wide error management supports a structured way to work with error handling that is a necessary building block in an efficient development method.

Contribute to a global leadership in vehicle electronics and software

The Volvo Group core values safety and quality are also important to our international competitors for whom these aspects have become more and more important over the past 15-20 years. In order to maintain Volvo's leadership in safety and quality, new and

improved methods for fault management and maintenance are of the utmost importance, and our solutions are in our opinion a high potential to contribute to these.

Increase competence to efficiently develop new vehicle concepts

We have at for example the DEDICATE seminars actively spread knowledge from the project. All the project reports are also available for the whole Volvo Group via the intranet which facilitates the access to the project result. We have also disseminated our results and solutions at external automotive events as well as for applicable parts of the Volvo organisation by giving project presentations. Furthermore, results from DEDICATE are being used in other on-going research projects such as BeSafe and VeTeSS. In addition to this, the project has hosted a master's thesis which has contributed to increasing the competence within the field for young Swedish engineers.

Relevance to other parts of manufacturing industry

Apart from the maintenance service solutions, the in the project elaborated solutions could be used in other parts of the industry within the field of electrical and electronic systems. The solutions could for example be employed in the industries of personal cars, avionics, and rail where there also is an increasing amount of electrical and electronic systems in the products.

6. Dissemination and publications

Knowledge and results dissemination

On April 27 2011 and June 19 2012 we held the second and third DEDICATE Seminars. These events were open to all Volvo Group employees and to invited guests from Volvo Car Corporation, from Chalmers, and from the haulers we have collaborated with. Furthermore, DEDICATE was presented at the Volvo Group Tech show in May 2011. More than in total 2000 persons from Volvo, universities, suppliers, media etc. visited this event. DEDICATE was also presented at the FFI conference 2011.

Additionally, DEDICATE has been presented at other external automotive events and also a number of internal presentations have been held to related Volvo Group bodies for research and technology strategies.

Driving forces which will speed up the dissemination of the project result is for example the need for fault management solutions due to the trend of increasing amounts of electrical and electronic systems with increased integration and interaction which leads to increased complexity which, if not handled properly, works against safety and quality by producing higher overall failure rates. Furthermore, recent research shows that the fault rate in semiconductor circuits is increasing, mainly due to process variations, shrinking geometries, and lower power voltages. Faults in semiconductors include transient and intermittent faults that need to be handled by suitable mechanisms to avoid failures. Since the semiconductor geometry sizes will be even smaller in future, this is an increasingly important factor to consider. In addition to this, the applicability of the second edition of the ISO26262 standard for commercial vehicles will place additional focus on functional safety, which will require improved dependability and diagnostics capabilities.

BeSafe is an on-going FFI-funded project that uses results from the project and the same goes for VeTeSS which is an ARTEMIS project. We are also working on several project proposals, both for internal and external funding, which are based on the results from DEDICATE, for example the EU FP7 project SafeAdapt.

Publications

No publicly available documents have been produced in this project.

7. Conclusions and future research

Using interviews and studying data from databases was found to be a good way to find the most frequently occurring fault types. The knowledge of these fault types was essential for the work creating new and improving already available in-vehicle fault handling solutions. These solutions (both on electrical- and system level) were among other things found to improve the pin-pointing abilities finding the root cause of a fault used in order to decrease diagnosis time.
Using fault injections as a technique for validating our in-vehicle fault management solution concepts implemented in prototypes was a powerful way to assess the ability of the solutions. Furthermore, building frameworks as a foundation for the assessments has been shown to be an efficient way to save cost by re-using result in other projects.
Value stream mapping was a suitable method to analyse what happens to a vehicle during service and repairs and from this information valuable conclusions on for example time spent on non-adding value activities could be drawn.

Results from the project is already being used in on-going research projects, and we are also working on new project proposals which are based on results from DEDICATE. In particular we would like to elaborate more on our concept for system wide error management in order to take it to the next Technology Readiness Level (TRL).

8. Participating parties and contact person

DEDICATE is a so called vertical project in the FFI programme, and thus only involves Volvo Group companies. The main work of the project has been performed by Volvo Technology. During the project, we have cooperated with personnel from just about all other Volvo Group companies.

Contact persons

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