Enabling simulation technologies for on-board diagnostics development

Technische Universiteit
Eindhoven
University of Technology

/ Department of
Mathematics and
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/ PDEng Automotive
Systems Design

Enabling Simulation Technologies for On-Board Diagnostics Development:

A System Architecture Design

Executive Summary

October 2019

Sergio Fajardo Quintero

Where innovation starts

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Eindhoven University of Technology
Stan Ackermans Institute - Automotive/Mechatronic Systems Design

PDEng Report: 2019/084

Public Executive Summary

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Date	October 2019	

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The design that is described in this report has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct.

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Partnership: This project was supported by Eindhoven University of Technology and DAF Trucks N.V.

Published by: Eindhoven University of Technology
Stan Ackermans Instituite

PDEng-report: 2019/084

Preferred reference: Enabling Simulation Technologies for On-Board Diagnostics Development: A System Architecture Design. Eindhoven University of Technology, PDEng Report, October 2019 (2019/084)

Abstract: This project studies possibility of using simulation technologies for On-Board Diagnostic development. The types of simulation models and the way they can be used for the different stages of OBD development is presented as well as the needed additions in terms of expertise and facilities to implement the new process in full. The process followed to collect the system requirements and the way these are satisfied by an architecture design is also presented. Finally a proof of concept for a misfire situation is presented.

Keywords: OBD, Engine Emissions, Simulation, MiL, HiL

Foreword

Continuously increasing requirements from legislator, customers and internal targets let me to believe a change in our used technology and used process is necessary. Creating confidence in our product early in the development cycle is of key essence here. This also reduces the lead time of development (due to less rework loops) and improves customers satisfaction. Simulation based data analysis vs hardware based data analysis is an important contributor here.

Sergio helped us to look at current possibilities and establish a frame work to identify the gaps on where we want to be and currently are in his PD-Eng Thesis project.

He proved to be a quick learner who embedded in the team and technology very quickly. I liked working with him as he is communicating clearly, but with respect and humor. He has a pleasant personality. Sergio, wish you the best with your next steps in your career and personal life, where ever this may be!

John de Graaf
Supervisor OBD development
DAF Trucks N.V.
October 2019

Preface

This report is the culmination of the final project of the Automotive Systems Design (ASD) Professional Doctorate in Engineering (PDEng) program at the Eindhoven University of Technology (TU/e). The project was done in collaboration with DAF Trucks N.V.

The ASD program focuses on developing skills needed to design high tech systems for the automotive industry. During two years the trainees involved in the program are taught technical and non-technical skills that have been identified as key for product development in a technological environment. The first 14 months are divided into three different projects where trainees have the ability to work with industry in tackling current challenges and fulfill different roles. The final 10 months are reserved for a final project in a designated company to be done individually by each trainee.

In this case DAF Trucks N.V. wanted to study the possibility of replacing or complementing experimental development with simulation for On-Board Diagnostics development. The main idea was to find if and to what extend a simulation could be used to develop OBD systems.

The project was an exercise in translation of customer needs into functional and non-functional requirements as well as a system architecture design in SySML. The report is meant for an audience that has basic knowledge of diesel powertrains and system engineering.

Sergio Fajardo Quintero
October 2019

Acknowledgements

I would like to thank all the people who in some way or another contributed to this project.

Firstly, I would like to thank John de Graaf for giving me the opportunity to work on this project as well as supporting it through all the way. I would also like to thank Bram Hakstege for his support and guidance, I believe his key questions steered the project in a positive direction.

Special thanks to Jan Gillot, Petter Smit and Thomaz de Sousa who helped me to understand the general inner workings of the OBD system from DAF as well as giving me their support with their technical knowledge.

Jaap van Deventer, Niek Hermans, Roger Saane and Kevin Rademakers who supported me in the test cell and with the simulations in order to produce the data used as proof of concept.

Henk Nijmeijer and Peter Heuberger, for their valuable feedback and help in all aspects of the project and for allowing me to take part in this two year adventure called Professional Doctorate in Engineering. Ion Barosan for his guidance with System Engineering and SySML overall.

To all my colleagues from the ASD, MSD and ST PDEng programs from TU/e, thank you for the support, the laughter, the discussions and the beers. Special shout to Gurbey Çeken and Sina Sarneizehdoost for all the good times and endless whisky nights and to “Alim” Alosta and Arne Laponin for all the inappropriate jokes and awk-ward laughs.

Finally but not least to my family and my girlfriend who have supported me in more ways that I can described since this journey started, I couldn’t have done it without you.

Sergio Fajardo Quintero
October 2019

Executive Summary

1.1 Problem Context

On Board Diagnostics is a procedure by which powertrain health and operating status is monitored in real time. The system is in charge of informing the driver, service technicians and engineers of any failure to comply with emission limits setup by legislators. There are different processes around engine operation that have an impact on emissions, each of these processes (or a combination of them) is associated with a type of failure. The occurrence of these failure is what the OBD system monitors.

The task of the OBD department is to develop, test and validate on board diagnostics relevant to up-to-date emission legal limits. In order to do this, powertrain operational data such a temperatures and pressures are needed. The needed data varies widely across the different needs for each diagnostic and getting relevant data is currently limited by the availability of hardware.

1.2 Problem description

Currently a complete and operative powertrain becomes available for testing very late during the development process. Thus OBD developers do not have enough time to perform all the needed tests and gather valuable data to develop a complete OBD system.

Hence there is a need to provide the OBD developers with relevant data earlier in the development cycle of a new powertrain. The company is looking for a solution that is aligned with its current capabilities, know-how and development cycles.

1.3 Project Aim

The aim of this project is to design an architecture for a virtual environment that will allow DAF Trucks N.V. and specifically the OBD department to simulate powertrain operational curves with the ability to change component tolerances within and outside manufacturer specification and introduce partially broken or totally damaged components.

The architecture should provide simulation capabilities of a powertrain as a system of systems with the ability to select and alter individual powertrain components and sensors. The simulation shall provide emission relevant parameters which are aligned with the variables currently used by the OBD department to develop diagnostics.

Finally the requirements of the designed architecture should be measured against the current virtual capabilities and DAF Trucks N.V. in order to establish a recommendations needed to breach the gap between the Virtual Environment design and current status.

1.4 Project Solution

High level requirements have been created following the CAFCR framework for system engineering. The framework breaks down the development of a product into six viewpoints; the Customer objectives, the Applications given to the end product, the Functionalities the product must have, the Concept design to fulfill those functionalities and the Realization of the concept design. Together they shape a product from customer needs and desires up to the realization of the final product.

The high level requirements have been broken down into smaller and subsystem specific requirements. This information has been used to create the simulation processes which use Model in the Loop and Hardware in the Loop methodologies to generate relevant data for OBD development.

The Model in the Loop process is aimed at simulation of powertrains with failures in OBD relevant subsystems while the Hardware in the Loop process is aimed at identifying OBD sensitivity to powertrain system tolerances. In the first step, powertrain simulation is used to understand the features and trends present in relevant powertrain signals when a failure is inputted. The second step is used to study diagnostic response to deviation of nominal values of components and sensors within the powertrain.

Both methodologies use different modeling solutions. The Model in the Loop exploits 1D simulation while the Hardware in the Loop uses real time models coupled to control strategies that are to be delivered to the real powertrain. The simulation models for both methodologies are align with the current modeling techniques available at the company.

1.5 Project Conclusion

The Model in the Loop methodology was tested for a selected diagnostic with positive outcome. A nominal 1D powertrain model was used to emulate the experimental setup used to capture data for the selected diagnostic. The simulated data contained the features needed to identify the failure under test. Furthermore the data was used as an input into the current algorithm of the selected diagnostic with a positive identification of the failure.

This shows that the simulation approach is useful for initial OBD development. The model was able to simulate the features that a monitored signal should contain in the presence of a failure. Investigation into other failures, failure modes and diagnostics still needs to be done.

The sensitivity analysis was not tested. This was because the complete system to perform this study is not ready at DAF Trucks N.V. Nonetheless the components needed to perform this sensitivity analysis as well as the way a simulation architecture can be used to perform it was described.

Finally an evaluation of the current coverage of the requirements used to create the simulation environments was done. A clear definition between the currently covered requirements and the ones that need work to be completed covered has been done. Recommendation on ways to have a complete coverage of the system requirements and system architecture has been provided.

1.6 Stakeholder Analysis

The stakeholder analysis provides an overview of the different people that were directly involved or impacted by the development and result of the project. It also provides information about the different concerns that must be answered in order to have a successful completion of the assignment.

Table 1. Stakeholder Interest and Concerns

Stakeholder	Project Role	Interests and Concerns
John de Graaf	Project Owner / Project Supervisor	Define a way to maximize the use of facilities and tools
		Having an operative and accurate OBD system
		Investigate the possibility of using simulation for OBD development
Abraham Hakstege	Project Supervisor	Have a system that can be adaptable in time and used with future powertrains
OBD Developer	End product user	Getting data for diagnostic development
		Getting accurate data
		Create a robust diagnostic against powertrain tolerances
		Compare diagnostic strategies in an efficient way
Niek Hermans	End product user	Develop accurate powertrain models
		Maximize powertrain model usability
Peter Heuberger	ASD Program Director	Ensure the trainee meets educational requirements for the completion of the ASD PDEng program
		Establish positive and long-lasting collaboration with ASD PDEng program and DAF Trucks N.V.
Henk Nijmeijer	ASD Program Scientific Director / Project Supervisor	Guide the trainee in the correct direction to fulfill project goal
		Promote trainee professional development

1.7 Communication Strategy

Weekly progress meetings

Open and continuous communication was important in order to steer and complete the project. From the beginning of the project it was stablished that a weekly meeting with the company supervisor and supporting OBD developers would take place. The information discussed in this meetings was around current status, the direction the project was taking and the discoveries that were made during it. For each of these meetings, a presentation was prepared beforehand and meeting minutes were taken during the meeting. These two documents were shared with the people involved in the meetings and the ASD program director.

Project Steering Group Meetings

Five Project Steering Group Meetings (PSGM) were organized and completed during the duration of the project. These meetings were used to inform supervisor from the TU/e and DAF Trucks N.V. about the direction and progress of the project. Henk Nijmeijer (TU/e supervisor) , John de Graaf (DAF Trucks N.V. supervisor) and Sergio Fajardo Quintero (ASD Trainee) took part in all of these meetings. Peter Heuberger (ASD program director) was also invited and joined a couple of them.

As with the weekly progress meetings, a presentation was prepared beforehand by the trainee and meeting minutes were sent after the meeting to the people who attended.

Things like deliverables and extended project goal where discussed during these meetings. The overall satisfaction of both supervisors was assessed at these meetings to ensure that progress was being done in the correct direction. The PSGM meeting dates were the following:

- PSGM # 1: February 28th 2019
- PSGM # 2: March 1st 2019
- PSGM # 3: May 16th 2019
- PSGM # 4: July 9th 2019

Special meetings

In addition to the scheduled meetings mentioned above, meetings with simulation developers, function developers, HiL engineers, calibration engineers and external partners were done.

These meetings helped to gather important information about the companies way of working, the different capabilities of simulation models and simulation systems like the HiL and powertrain subsystem interaction. Without these meetings it would have been impossible to gather a system overview. The information gathered from the different people involved in these discussions also helped to improve the overall goal of the project by providing critical information about things available in the company.

1.8 Risk Management

In the early stages of the project a risk assessment was presented to the supervisors. Risks involving the project scope, people availability and (lack of) knowledge were identified and evaluated in terms of their perceived impact. The chance of occurrence and the impact of occurrence was evaluated on a scale of 0 to 4 per risk. The impact evaluation was obtained by multiplying the chance and impact of occurrence.

The complete risk assessment and management can be found in Table 2.

Table 2 – Risk Assessment and Management

Risk	Chance of occurrence (0-4)	Effect of occurrence (0-4)	Impact (C * E)	Mitigating Actions	Responsible
Lack of knowledge about domain needs.	2	2	4	Increase literature review and ask both company and university staff for support.	Trainee

TU/e supervisor not available for discussion / consultation.	3	3	9	Find optional professor / consultant from TU/e that can solve an specific issue.	Trainee / ASD management
Supervisors (TU/e and/or company) not available for PSG meetings and others.	3	3	9	Schedule meetings via Outlook calendar so that availability can be check beforehand. Perform an assistance check 2 days before meeting, if someone is not available either reschedule or find suitable substitute.	Trainee / ASD management / Supervisors
Project scope too long to be achieved in the given time.	2	4	8	Have a clear Project Management Plan document with proper project planning based on scrum methodologies that enable adaptation and merging with current DAF working methodologies.	Trainee
	2	4	8	Have clear communication with client and manage expectations from the beginning of the project.	Trainee
Lack of knowledge about cost related deliverables.	4	2	8	Ask for help on approximate costs on HW needs from TU/e experts.	Trainee / ASD management
Alignment with existing teams, knowledge and tools	2	3	6	Gather model information from various departments in order to incorporate current capabilities from the complete organization into the architecture.	Trainee
				Check with model owners from different areas to adjust architecture where possible.	
Testing facilities not available / Impossible to get experimental data	3	4	12	Plan testing with the person responsible for testing in due time	Trainee
				Maintain constant communication with the person responsible for testing	Trainee
				Keep a clear scope for the test	Trainee

1.9 Project Planning

The project was divided into five different phases from the beginning. These were kept for the entirety of the project but their duration varied as the project progressed. The changes in schedule were mainly a response to the appearance of new information or an extension of the tasks needed to complete a phase.

1.9.1. *Initial Project Planning*

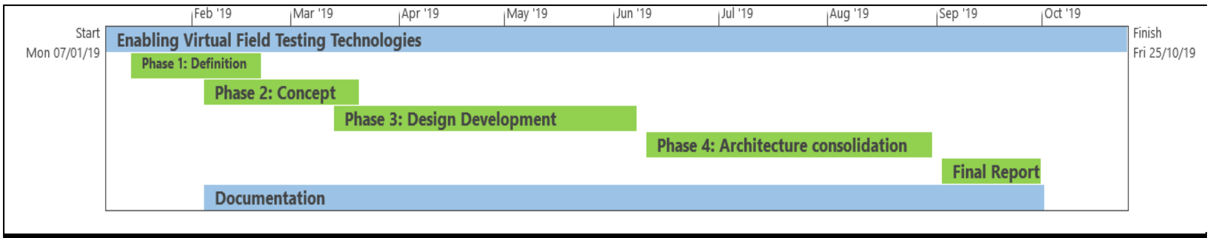

Figure 1 – Initial Project Planning

Figure 1 shows the initial planning. The phases identified to complete the project were the following:

Phase 1: Definition

The first part of the project was set to focus around information gathering about the problem that the company wanted to resolve. Identifying and stating clear objectives, scope and deliverables. All of these in consultation with the project owner. The boundaries of the project were also identified in this phase.

Phase 2: Concept Design

The second phase focused on gathering information about the current OBD system, the way developers worked, the way OBD systems are tested and validated and overall a general understanding of what kind of information is used by the different diagnostics to monitor the powertrain. Identification of high level requirements for the virtual environment was also done during this phase.

Phase 3: Design Development

During the design phase the high level requirements were broken down into simplified requirements. These would dictate the direction and shape the way the virtual environment would have to be design plus how it would have to be used.

Phase 4: Architecture Consolidation

The next phase was about the satisfaction of the different requirements created in phase 3. Different systems and system interactions were designed to cover all the requirements. The existing systems in the company like the powertrain simulation software and engineers were taken into account in the design. Facilities like the HiL test bed was also added to the architecture consolidation.

Phase 5: Final report

Phase 5 was reserved for the final report. Documentation was done along the whole duration of the project, but a time slot was reserved in order to complete the report in a comprehensive way and to adjust to the different feedback from the supervisors.

1.9.2. *Adjusted Project Planning*

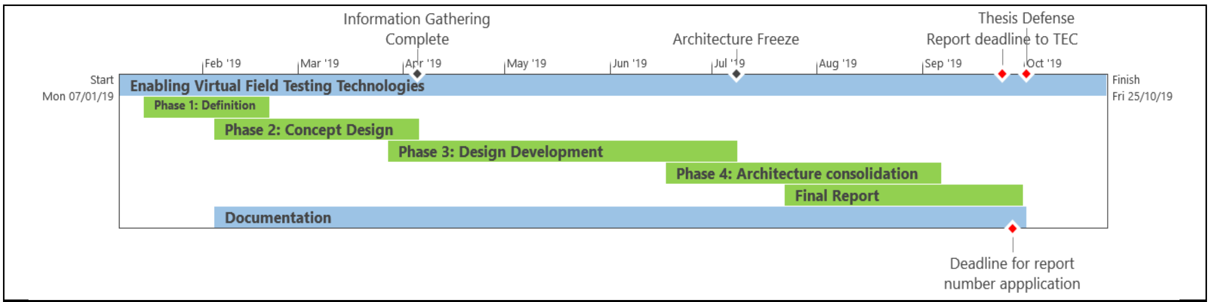

Figure 2 – Adjusted Project Planning

As the project moved forward it became clear that some phases needed to be extended as well as when overlapping could begin Figure 2 shows the adjustments that were done to the project planning after the first phase was complete and during the second phase.

The overlapping between phase 2 and phase 3 was the result of starting the decomposition of the high level requirements earlier than planned. The requirement elicitation was an iterative process that resulted in various modifications to the final requirements. The overlapping of these two phases was the result if the first iterations which resulted in a clear division of the high level requirements across the MiL and HiL systems.

The overlapping of phase 3 and phase 4 was the result of starting the architecture design in parallel to the decomposition of the high level requirements. As soon as the requirements were enough to describe the functionalities of a block needed in the system architecture, the design of such block started. The iterative process around the requirements decomposition also made the design process an iterative one.

Once phase 2 was completed and the architecture started to take shape, the final report (phase 5) was started. This produced a live document which was adjusted as the design process evolved.

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