Design and Evaluation of a Customizable Multi-Domain Reference Architecture on top of Product Lines of Self-Driving Heavy Vehicles – An Industrial Case Study

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Abstract: Self-driving vehicles are of high interest for academia and industry at the moment. Particularly, in the transportation domain they exhibit a huge potential to increase companies’ competitiveness by automating delivery tasks or construction work. This industrial case study reports on the process of developing and evaluating a multi-domain reference architecture concerned with commercial transport mission planning, execution, and tracking for self-driving vehicles. Therefore, internal and external stakeholders as well as development documents were consulted. The resulting reference architecture is evaluated based on its underlying non-functional requirements ensuring early confirmation of compliance with stakeholder needs. A concrete variant of the architecture was also deployed on a Volvo FMX truck and practically evaluated in an exemplary construction site setting. This paper summarizes our work Schroeder et al. [Sc15] published at 2015 ICSE.

Keywords: self-driving vehicles, reference architecture, design, evaluation, variability, case study

1 Goal and Research Questions

Preliminary research revealed that so far no industrial case studies showed the successful elicitation, integration, and validation of functional requirements (FR) and non-functional requirements (NFR) for a multi-domain reference architecture supporting transport mission planning, execution, and tracking. Consequently, the main goal of this study to design and evaluate such a reference architecture. This goal was divided into the following two research questions:

1. What are FRs, NFRs, and design patterns for a multi-domain reference architecture that supports transport mission planning, execution, and tracking?

2. How can the resulting reference architecture be evaluated regarding how well it accords with the elicited requirements?

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2 Resulting Process, Architecture Design, and Evaluation

The process starts with an extensive data collection during stakeholder interviews, document reviews, and literature reviews. This resulted in unprioritized FRs from customers and domains, and unprioritized NFRs on the self-driving heavy vehicle systems concerned with transport mission planning, execution, and tracking. Prioritization in multiple stakeholder workshops led to concrete functionalities expressed as variations and commonalities necessary for the reference architecture design. The design was expressed in component diagrams and feature models enabling automatic product variant generation. The prioritized NFRs matching the domain needs were incorporated as architectural design patterns.

The resulting design was evaluated using three methods based on scenarios and mathematical models. Evaluation was performed at two distinct stages throughout the process, assessing adaptability, changeability, and stability. The first evaluation was done in an early phase of the architectural design and the second one at the end. The evaluations finalize the architecture development process and ensure that stakeholders’ expectations towards the architecture design are fulfilled. Finally a practical evaluation was performed on a test track using a concrete variant of the reference architecture deployed on a Volvo FMX truck.

3 Contributions and Conclusions

The reported industrial case study contributes with a complete process for developing and evaluating reference architectures in the domain of self-driving transport vehicles. It furthermore lists results for each step including functional and non-functional requirements, and resulting design patterns for a reference architecture for this domain. The resulting design of the reference architecture is described in form of component diagrams and feature models. Finally, architectural evaluation is reported for assessing changeability, adaptability, stability, and interoperability. The resulting reference architecture expresses stakeholder requirements as well domain needs in both functional and non-functional terms. It proved itself being useful in theory and applicable in practice. The development process and the resulting reference architecture can be considered as role model for comparable industrial settings. More detailed information on this study can be found in [Sc15].

References