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Software-Related Challenges of Testing Automated Vehicles

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***Abstract*—Automated vehicles are not supposed to fail at any time or in any situations during driving. Thus, vehicle manufactures and proving ground operators are challenged to complement existing test procedures with means to systematically evaluate automated driving. In this paper, we explore software-related challenges from testing the safety of automated vehicles. We report on findings from conducting focus groups and interviews including 26 participants (e.g., vehicle manufacturers, suppliers, and researchers) from five countries.**

I. Introduction

The advancements of software triggered a paradigm shift in the automotive domain, slowly enabling vehicles to gradually support automation, moving to (conditionally) automated driving. While automated vehicles provide many advantages, their safety has to be guaranteed. Since the recent introduction of conditionally automated driving, we have seen several accidents involving such vehicles [1], [2], [3]. Hence, thorough testing of such safety-critical functionality is required to reduce accident rates.

In this paper we investigate **RQ:** *What are the current software-related challenges of testing (conditionally) automated vehicles?* We conducted an empirical study using two different kinds of data collection – focus groups and interviews. The focus groups included eleven practitioners from Sweden, the interviews included 15 practitioners and researchers from Sweden, Germany, US, Netherlands, and China. The participants have between five and 30 years of experience with automotive safety, 66% of them hold management positions, they are from eight different companies (e.g., five of them premium automotive OEMs), seven research institutes and universities, and one proving ground. The major question for focus groups and interviews was: "What are the future trends on vehicle automation? How will testing have to change to address these future trends?". The lengths of the focus groups and the interviews were 60 and 45 minutes, respectively.

II. Related Work

Testing, verification, validation, and certification pose a challenge for the successful introduction of automated road vehicles [4], [5], [6], [7], [8], [9]. Only a few studies on testing automated vehicles exist. Relevant and suitable test scenarios and metrics to assess such systems have to be defined. Furthermore, simulation testing will be inevitable [10], as the vehicles need to cover a certain high number of kilometers. Simulations can also be used to identify a catalog of relevant test cases [11]. Proving grounds must support testing with coordinated automated vehicles and objects [12].

III. Challenges of Testing Automated Vehicles

Fig. 1 gives an overview of the identified challenges of testing automated vehicles. The challenges are sorted based on the amount of participants discussing a given challenge.

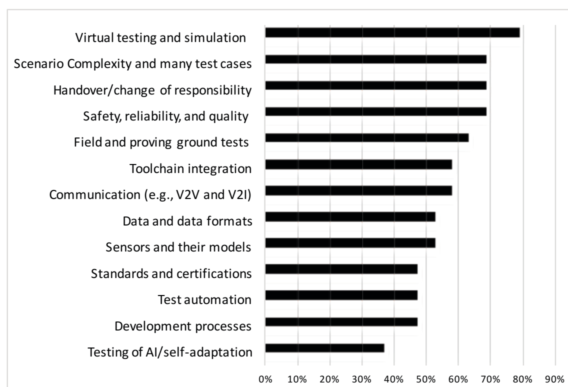

Fig. 1. Overview of identified topics and the corresponding percentage of participants that mentioned the topic.

In the following, we report the challenges with most implications for software engineering:

Virtual testing and simulation – will have an increased importance: Virtual testing and simulation were discussed as a promising technique that will get more attention with the increase of automation levels. "Massively shifting from practical to virtual testing (as practical testing is too expensive)". Challenges related to virtual reality testing as mentioned by the participants are:

- Legal aspects: Can simulation be used as one kind of testing to receive certifications? Based on the interviews there were indications that testing authorities might move towards virtual testing as it is very efficient.
- Mixed reality testing requires an infrastructure to enable such kind of testing.
- The use of these techniques requires better integration into the rest of the testing processes.
- Finding the right data sets or collect real traffic data to be used for simulation testing: For example, collected

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field data can be fed back into the simulation to test with run-time data.

Change of responsibility – increased need to test non-functional aspects: While an active safety system is intended to help the driver, it is however, relying on the driver as the last instance when the system might miss something. However, for fully automated driving the vehicle cannot miss anything. New functions for automated vehicles should be robust (i.e., not supposed to fail at any point at run-time) as the vehicle is responsible for every part of driving.

The transition from driver in charge to vehicle in charge will shift the limitations concerning functionality: Non-functional aspects become increasingly important as for example the driver's comfort plays an important role in the success of automated vehicles: "We need to test more with driver's perspective". Trust is another very important aspect when the vehicle takes over responsibility. In such vehicles the driver has to feel safe as the safety depends on the automated vehicle. Based on the interviewees, testing for the safety feeling poses a challenge. Another aspect of an important non-functional property is the user interface. As the amount of software in vehicles increases, the vehicles should also ensure software-related non-functional properties like being easy to use.

Standards and certifications – have to be defined for automated vehicles: From the legal point of view, the vehicles that drive on the streets are supposed to be robust. New quality criteria, regulations, standards, and certifications are required to ensure this. Several participants mentioned that it is necessary to accept virtual testing as part of the (re-)certification. Additionally, testing in real traffic might be important as well – however, it is not entirely clear how this will be designed. Furthermore, legal aspects should also cover continuous software engineering aspects, like does the vehicle have to be re-certified if updates are uploaded to the vehicle at runtime? Or do we need to re-certify vehicles having self-adaptation capabilities? Or will machine learning be accepted as part of certification?

Test automation – will be a necessary step to increase the efficiency of testing: The amount of resources needed for testing of automated vehicles increases steadily. To decrease the costs, testing steps could be automated as for example:

- Processes for automated processing of data.
- Equipment to automate testing on proving grounds, for example, automated targets which can be used to create complex scenarios.
- Adaptive testing that can be used to test the system adaptation: This is necessary as automated vehicles will be self-adaptive and are dynamic at run-time, with the possibility of learning and adapting to different tests.
- For fully automated vehicles, the system itself must learn how to test certain criteria, to facilitate the testing process: "Testing is not supposed to ever stop"
- Infrastructure for automated data collection and labeling of data during drives of automated vehicles to reuse it for testing of the next generation of automated vehicles.

Development processes – continuous software engineering vs. agile methods vs. V-model: Different development processes exist. However, it is unclear whether one of the development processes or a combination thereof is the suitable solution for automated vehicles. Based on these, the testing is integrated in different ways in the development processes. Requirements of automated vehicles are not entirely known during the design of the vehicle – requirements need to be updated after the vehicle is delivered. Hence, the development processes have to be flexible and the ability to move more efficiently between the different development activities is needed. Hence, only following the V-model seems not to be suitable for automated vehicles. Combining V-model with continuous software engineering might be a viable way forward. However, challenges arise e.g., concerning continuous experimentation where functions are delivered with the vehicle but are disabled and run-time data is collected; for example, privacy concerns, or the missing feedback *what would have happened if the function would have acted* as inert functionality is not supposed to have access to a vehicle's actuators.

Furthermore, experts assess that the life cycle will become shorter.While parts might become shorter, larger processes might remain V-like. Additionally, test-driven approaches will gain importance, requiring to start testing at the beginning of the life cycle. Agile methodologies seem to provide the advantage of having testing in focus and allow for an increased quality. Testing should become a permanent activity, starting already at component level.

Testing of AI/adaptation: Automated vehicles include software that makes the system smart. Having the driver in charge provides the advantage of having him as the fallback who can execute any kind of driving tasks, whereas the automated vehicle only executes the functionality that is implemented. It has to be ensured that the vehicle is not missing any major functionality at runtime, but also that the functionality implemented is executed as it should be and in no other way. Two different properties characterize this kind of systems and makes the testing of these systems a challenge: Self-adaptive capabilities and the use of artificial intelligence using a variety of data. Vehicles will learn at run-time and improve their *skills*. However, the current processes are not set up for testing automated systems, especially not for testing of machine-learning techniques that are used at run-time and which evolve the system over time. New toolboxes are needed, which provide AI and optimization tools, respectively.

IV. Conclusion

We have reported about an empirical study on the challenges of testing automated vehicles. We reflected on challenges related to 1) virtual testing and simulation, 2) change of responsibility, 3) standards and certifications, 4) test automation, 5) development processes, and 6) testing of AI.

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