Generating Test Cases from Real Field Data to ensure V2X Interoperability

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Motivation – Need for Testing

- V2X is one of the main parts of traffic system’s digitalization,
- It is feature-rich and complex,
- Many stakeholders are involved in the system, (Automaker, Infrastructure-Supplier and –Manager, Authorities, etc.)
- Conformity and especially Interoperability/Compatibility are crucial for the system’s function,
- Although not yet in operation, safety-critical use of V2X is a must to increase road-traffic's capacity (e.g. Signal Phase and Timing),
- The situation gets even more critical when it comes to automated and co-operative driving.

→ Comprehensive Testing, especially in-lab testing is one of the most-common methods to ensure interoperability, conformity and (functional-) safety.
Motivation – Need for Testing

Abbildungen: acatech Studie – Neue autoMobilität II
Motivation – Lab Testing

• Due to digitalization in-lab testing for V2X is simple. At least the interface between car and road is standardized (ETSI). Of course, backside between communication unit and car/infrastructure-components is manufacturer-dependent.
• Common and applicable testing-setsups are Hardware/Software-in-the-loop.
• In combination with a test-adapter to interface between communication unit and the system behind (car/traffic light/etc.) the technological setup is complete and available.
• But what about the test specification?
Return of Experience: Functional testing in the railway domain

- In the railways there has to be a communication between track and train due to high masses and low friction.
- In the past there was a (more or less) dedicated and specialized system for every track.
- Today cross-borderer traffic across Europe is needed and the system has been standardized and harmonized (called ETCS: European Train Control System).
- Tech: max. 830 Bit per message, safe.
- Interoperability became one of the main issues during the deployment of ETCS.
- Lab-Testing the Eurocab in independent Laboratories has been put into the law, to resolve the interoperability issues.
Return of Experience: Functional testing in the railway domain

• Main issue:
  • Creating the test specification.

• Why?
  • Moving target (continuous upgrade of the system specification),
  • Has been created manually,
  • Complex but in-adequate toolchain,
  • Hardware has been put into service in parallel to the development of the test specification,
  • Many stakeholders involved.
  • Today there are more than 70,000 test steps per test campaign…

• Sounds familiar?
  → Back to V2X.
Focus: Cooperative Awareness Message (CAM)

- Probably the CAM message will be the first message implemented by many vehicles.
- Specification is available (ETSI EN 302 637-2),
- Main purpose: Inform other road users about each others position, dynamics and attributes.

A.28  DE_ExteriorLights

B.19  referencePosition

B.37  exteriorLights

B.22  speed
Existing test specification

- TTCN-3 Test cases from ETSI:

- Advantages:
  - formal
  - TTCN-3, simple execution, more or less human-readable.

- Is there a need for more test cases?
  - Depends on the current coverage:
    - Checkout the current test cases,
    - Search, sort the referenced requirements,
    - Check the coverage.
Coverage in the CAM specification

• Example CAM, based on ETSI EN 302 637-2.

• Documented coverage::
  • Annex B.1, 6.1.3, 5.2, Annex B.11, B.12, B.13, B.14, B.15, B.16, B.17, 5.3.4.1,6.2.2.1,4.2.2

• Important note: Only documented requirements have been take into account.

• Currently only few requirements are covered. There is no parameter set to invoke the test cases in different scenarios. Even the covered requirements are only tested in certain situations.
Approach

• Several test tracks (C-Roads, AIM, Test bed lower saxony, TAF, etc.) are available, equipped with road-side-units.
• First manufacturers are rolling out on-board-units in their production lines.
• Furthermore there are sophisticated simulations (e.g. SUMO) for traffic simulation available, which can be validated with the data from the real test tracks.
• Collecting all received/sent messages in a database leads to more and more growing database of real V2X-communication.
  • Certain scenarios will appear with a lot of different constraints,
  • Different manufacturers are involved in the communication
  • In the beginning there will be almost no safety-criticality
Approach – in detail.

• Assumptions:
  • All cars are emitting CAM messages,
  • Frequency 5Hz,
  • No packet loss,
  • Data Stream of every car is recorded.

• First example: Overtake maneuver, especially first lane change.

• Steps:
  • Generating Test Data
  • Pattern matching for maneuver trigger, analyzing trajectory,
  • Collecting all different occurrences of the maneuver,
  • Inspecting constraints,
  • Creating scenarios / test cases.


Current Status // Gathering the data

- Right now, there is no direct access to real data:
  - Only very few cars are equipped with V2X technology and are emitting any messages.
  - Not all test tracks are already in operation or are in upgrading procedures.
- To show the basic function of the method and for later extension of the test-data a simulation based approach is necessary.
- DLR’s traffic simulation SUMO has been configured to simulate a certain part of the Test Bed Lower Saxony.
- In a first step only CAM messages have been evaluated, they will be available first.
- The simulation has been configured with real traffic data, acquired by the BAST.
- Simulation time 1 hr.
Current Status // Gathering the data

- V2X CAM Information has been emulated, reduced to:
  - stationID,
  - exteriorLights,
  - speed (w/o accuracy),
  - position.
- Important assumption: stationID stays unchanged for the maneuver.
- Due to performance reasons no live processing has been executed but the data has been stored file-based as floating car data.
- The simulation output has been acquired for approx. 8km between Exit 30 (Cremlingen) and Exit 28 (AK Wolfsburg/Königslutter). **Why this selection?**
Current Status // Gathering the data (selection)

- Test Bed Lower Saxony (opening 08.01.2020).
- Between exit 30 and exit 28 a very accurate traffic acquisition will be available:
  - Accuracy better than 25cm
  - Every vehicle will be detected
- For every detected vehicle a V2X-Message (CAM) can be emulated in real time.
- The resulting data stream will be very close to future situations with V2X equipment in every car.

High precision acquisition system between (1) and (2)
Current Status // Maneuver Extraction

- Time-based Floating Car Data has been converted to vehicle-based trajectories (gpx-format),
- Data has been analyzed for Overtake on the highway.
- Exterior lights have been filtered for left flasher.
- Vehicles using the left flasher and changing lane (gradient of trajectory) are selected for EGO-vehicle in the scenario.
- The entire scene with all cars in a certain time scope (e.g. +/- 5 secs), within a certain distance (e.g. 100m) have been selected and added to the maneuver.
Current Status // Maneuver Extraction

- All vehicles in the scene are analyzed for their trajectories in relation to the EGO vehicle:
  - Are overtaken by EGO,
  - Overtake EGO,
  - Traffic behind EGO,
  - Traffic in front of EGO.
- Relevant parameters are extracted:
  - Speed,
  - Distance,
  - Exterior Lights.
- Border identification leads to a limited number of scenarios.

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>EGO</th>
<th>Overtaking</th>
<th>Overtaken</th>
<th>Traffic behind</th>
<th>Traffic ahead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>10.73</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>58.91</td>
<td>59.89</td>
<td>59.91</td>
<td>58.88</td>
<td>59.93</td>
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<tr>
<td>Median</td>
<td>25.69</td>
<td>11.45</td>
<td>30.72</td>
<td>0</td>
<td>25.55</td>
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<tr>
<td>Average</td>
<td>28,5019683</td>
<td>14,3743175</td>
<td>30,7541587</td>
<td>2,93177778</td>
<td>29,4564762</td>
</tr>
</tbody>
</table>
Current Status // Maneuver Extraction

- Tool-chain has been executed with one hour simulation time (including warm-up phase), 200ms sample rate (~ 5 CAM/s).
- 231 maneuvers have been identified.
- For verification purpose for every SCENARIO a graphical representation has been generated.
- Scenarios have been exported to OpenSCENARIO (v 0.9.1).
Current Status // Test Case Format

• OpenSCENARIO:
  ✓ Well known in the automotive domain
  ✓ Toolchain for creating and editing is currently under development, many projects ongoing/done (Pegasus/SETLevel4to5).
  ✓ Can be read by many simulators (VTD/Carmaker/etc.)
  ✓ Lot of potential / human-readable / text base (for easy versioning)
  ✓ first version available (incl. scheme definition)
  ✗ **Not a real test case format**: Difficult to describe expected reactions of System-under-Test
  ✗ really complex
Summary

Open Points:
• Simulation is not yet calibrated,
• Almost no co-operative behavior (by intention),
• Some drawbacks by using openSCENARIO,
• Coverage not yet available.

Done:
• Simulation results usable,
• Maneuver detection works,
• Parameters can be extracted,
• Scenarios are created in openSCENARIO,
• Ready for real data (when available).
Potential of the scenarios

• Maybe there is not only V2X-testing possible, is it possible to use the scenarios also for testing automated driving functions?

• Many parameters are known in good or at least medium quality, e.g. coming to Galileo the quality of the position signal will enhance significantly.