Japanese AD Safety Assurance Investigation for Global Industry Harmonization

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Proving AD safety is a great challenge for industry. Traditional safety approaches based on long driving distances insufficient. Innovative AD safety assurance methodologies are needed.
Development of an innovative methodology

Scenario Structure

Perception limitation
sensor malfunction

Traffic Disturbance
Traffic participants’ unsafe behavior

Vehicle Disturbance
Cause of vehicle instability

Road

Ego Vehicle

Traffic Participants

Surrounding Vehicle
- position
- behavior
So as to achieve the globally common approach, the key is harmonization of 1) scenario structure, 2) parameter range, and 3) acceptance criteria.

Blue: needs harmonization
Green: share to clarify region/country difference
Red: potentially share (needs clarification of benefit)

Multi pillar approach
- Pre Production: Proving ground tests
- Post-Production: market severance
- Real-traffic tests
- Virtual tests

AD Safety Assurance Process based on scenario
Certification Test Scenario Derivation Process

Safety requirement

UN

EU

JP

AV, under their OD, shall not cause any traffic accidents resulting in injury or death that are rationally foreseeable and preventable

Field data

All possible traffic scenario type in the ODD

Accident Taxonomy

Traffic flow observation data

Scenario Structure (Functional Scenario)

Scenario structure with realistic parameter range

Iteration Process

Foreseeable scenario (Logical Scenario)

Scenario (No illegal and No extreme conditions)

Preventable scenario

Test Scenario Catalog (No illegal and No extreme conditions)

Discussion points in VMAD

A Foreseeable: empirically predictable scenario w.r.t observed field data

B Preventable: No illegal and No extreme conditions

Output of IWG

Validation method

Consider validation method

Track tests

Simulation

On road tests

Test scenario

Selected scenario for certification
Safety Argumentation Matrix

<table>
<thead>
<tr>
<th>Foreseeable</th>
<th>Scenario Base Approach</th>
<th>Unforeseeable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AD functionality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>To minimize the accident</td>
<td>[Goal: Mitigation]</td>
</tr>
<tr>
<td></td>
<td>(EM, Driver Monitor)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>[Goal: No Collision]</td>
</tr>
<tr>
<td></td>
<td>Learning Process</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Based on Field Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resilience Support for Residual Social Risk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preventable</td>
<td>Unpreventable</td>
</tr>
</tbody>
</table>

Test Scenario Catalog

Field monitoring
Development of SOTIF Safety Structure based on the safety requirement

[Vision] In bringing down the number of road fatalities, reducing harmful emissions from transport and reducing congestion

[Vision] To realize society where traffic accidents caused by automated driving system resulting in injury or death become zero

[Safety Requirement] Within ODD, AD shall avoid accidents resulting in injury or death wherever foreseeable and preventable

G1: The ODD shall be clearly defined.

E1.1: ODD

5 Definition of function and system

Layer 1

G2: Within ODD, the potential unacceptable level of risk shall be systematically identified and eliminated.

6 SOTIF Identification and evaluation of hazard

G2.1: All rationally foreseeable scenarios are extracted

G2.2: Among foreseeable scenarios, all rationally preventable accident scenarios are extracted

G2.3: The foreseeable and unpreventable accident resulting injury or death needs to be compensated by the social resilience support.

E2.2: Driving Policy

E2.3: Learning Process

G2.4: AD functionality to minimize the accident (EM, Driver Monitor)

[Goal: No Collision]

[Goal: Mitigation]

Layer 2

SOTIF Function change to reduce risk

Layer 0

E2.2.1: SOTIF Analysis

E2.2.2: SOTIF Metrix

G2.1: Within ODD, AD shall be confirmed to avoid the all foreseeable and preventable accident in field test, track test, or simulation

G2.2: AD shall have the function to mitigate foreseeable and unpreventable accidents resulting in injury or death

G2.3: AD shall be updated based on the observation by authority and industry in order to avoid recurrence of the foreseeable and preventable accident resulting injury or death.

Preventable

Unforeseeable

Unpreventable

DRAFT
Traceability between ODD and scenario

**View from outside of system**
- Needs to be understandable for users

**View from inside of system**
- Needs to be scientific and holistic

**Test Scenario**
- e.g. Influence on recognition by the raindrop adhesion to a sensor.
  - Cause A
- e.g. Influence on car dynamics by low $\mu$ with the puddle.
  - Cause B

**Perception**
- vehicle stability

- Traffic

**ODD**
- Sensor 1
- Sensor 2
- Sensor 3
- Fusion
- Route/Path Plan
- Control
- map
- localize
Traffic Scenario Structure

Extract the most demanding parameter from real environment data for each road geometry classification based existing laws and regulations.

Define 8+1 position around ego-vehicle and movement which can invade the ego trajectory.

Road geometry

<table>
<thead>
<tr>
<th>Road geometry</th>
<th>Ego-vehicle behavior</th>
<th>Traffic participants’ position</th>
<th>surrounding vehicle behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main roadway</td>
<td>Lane keep</td>
<td>Lane change</td>
<td></td>
</tr>
<tr>
<td>Merge</td>
<td>Merging in front</td>
<td>Merge</td>
<td></td>
</tr>
<tr>
<td>Branch</td>
<td>Branch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp</td>
<td>Free Driving</td>
<td>Lane change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Following</td>
<td>Overtaking</td>
<td></td>
</tr>
</tbody>
</table>

Road Structure Ordinance

- Main roadway
- Merge
- Branch
- Ramp

Ego-vehicle behavior

- Lane keep
- Lane change
- Free Driving
- Following
- Overtaking

Traffic participants’ position

- Cut in
- Cut out
- Acceleration
- Deceleration
- Sync
Traffic Data collection

Third party is collecting the driving data and establishing the data processing technique so as to extract the foreseeable critical parameter combination and range.

### Instrumented vehicles

- **Data Source:**
  - TUAT Driving Recorder Data (~2018~)
  - JAMA Driving Recorder Data (2008)
  - Driving Database (2017)
  - On road Recognition Database (2017)
  - Instrumented Vehicle Data Correction (2018~)
  - Fixed Location Camera (2018~)

<table>
<thead>
<tr>
<th>Parameter available (Mobileye/Lidar)</th>
<th>Video only</th>
<th>Visible</th>
<th>Not recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔ / ✔</td>
<td>△</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

### Fixed camera

- **Logging Device:**
  - 60 vehicles
  - 30 vehicles
  - 6 vehicles
  - 3 vehicles
  - 3 cameras / each location

- **Driver:**
  - Taxi driver
  - Ordinal driver
  - Ordinal driver
  - Staff
  - Staff
  - -
We adopted the parameter selection methodology, which is investigated with NFF Henze and Znamiec. The paper has been submitted to ITSC2019 (Under revision)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>① Ve0</td>
<td>Ego vehicle velocity</td>
</tr>
<tr>
<td>② Vo—Ve0</td>
<td>Relative velocity</td>
</tr>
<tr>
<td>③ dx0</td>
<td>Initial distance</td>
</tr>
<tr>
<td>④ dy0</td>
<td>Initial lateral distance</td>
</tr>
<tr>
<td>⑤ Gx</td>
<td>Deceleration</td>
</tr>
<tr>
<td>⑥ Vy</td>
<td>Lateral velocity</td>
</tr>
</tbody>
</table>

**Figures:**
- **Ve0 (Ego vehicle velocity) [km/h]:**
  - 5%
  - 95%

- **Vo—Ve0 (Relative velocity) [m/s]:**
  - 5%

- **dx0 (Initial distance) [m]:**
  - 5%

- **Vy (Lateral velocity) [m/s]:**
  - 5%
3D cloud of correlated parameters

The relationship between the parameters that correlate (ego-vehicle velocity, initial distance, and relative velocity) needs to be considered when generating concrete scenarios.
Case study 1: Generation of concrete scenario

For pre-set initial ego-vehicle velocity of 80 km/h and lateral velocity of 1.45 m/s, initial distances of 12.3 to 61.1 m and their respective correlating relative velocity values need to be considered.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>① Ve0 (Ego vehicle velocity)</td>
<td>km/h</td>
<td>80</td>
</tr>
<tr>
<td>② V0-Ve0 (Relative velocity)</td>
<td>m/s</td>
<td>see table</td>
</tr>
<tr>
<td>③ dx0 (Initial distance)</td>
<td>m</td>
<td>see table</td>
</tr>
<tr>
<td>⑥ Vy (Lateral velocity)</td>
<td>m/s</td>
<td>1.45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>dx0 Initial distance (m)</th>
<th>Ve0 Ego vehicle velocity (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>y = 0.16 x + 47.92</td>
<td>R² = 0.57</td>
</tr>
<tr>
<td>y = 0.04 x + 8.76</td>
<td>R² = 0.68</td>
</tr>
<tr>
<td>12.3 20 30 40 50 60 61.1</td>
<td>assumed 2m/s pitch</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>③ dx0 (Initial distance)</th>
<th>[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>② V0-Ve0 (Relative velocity)</td>
<td>[m/s]</td>
</tr>
<tr>
<td>Min</td>
<td>-7.49 -6.50 -5.21 -3.93 -2.64 -1.35 -1.21</td>
</tr>
<tr>
<td>Max</td>
<td>0.19 1.58 3.39 5.21 7.02 8.83 9.03</td>
</tr>
</tbody>
</table>

assumed 10m pitch
Case study 1: Precondition and Results

Exemplary safety criterion (0.5G braking)

AD vehicle function

Systems braking

Detection area of avoidance maneuver

TTC = 2s

Ve0=80km/h, Vy=1.45m/s

Table: Simulation results

<table>
<thead>
<tr>
<th>③dx0 (Initial distance) [m]</th>
<th>12.3</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>61.1</th>
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</table>

Detection area of avoidance maneuver

TTC = 2.0 [s]

Width 0.5m

Exemplary safety criterion (0.5G braking)

Simulation results

Within the parameter ranges defined and incorporated to the simulations, some cases could not prevent a crash based on the applied (example) safety criterion with mid-level performance braking capabilities.
Case study simulation results (videos)

<table>
<thead>
<tr>
<th>dx0 (Initial distance) [m]</th>
<th>12.3</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>61.1</th>
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<tbody>
<tr>
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<td>1.58</td>
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<td>3.39</td>
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<td>9.03</td>
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</tbody>
</table>

Relative velocity [m/s]

Ve0 : 80.0 [km/h]
Vo : 79.3 [km/h]
dx0 : 12.3 [m]

Ve0 : 80.0 [km/h]
Vo : 61.2 [km/h]
dx0 : 40.0 [m]

Ve0 : 80.0 [km/h]
Vo : 47.5 [km/h]
dx0 : 61.1 [m]
Exemplary safety criterion (0.9G braking)

AD vehicle function

Simulation results

Ve₀=80km/h, Vᵧ=1.45m/s

<table>
<thead>
<tr>
<th></th>
<th>12.3</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>61.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>①dₓ₀ (Initial distance) [m]</td>
<td>✔</td>
<td>✔</td>
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<td>✔</td>
<td>✔</td>
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</tr>
<tr>
<td>②V₀-Vₑ₀ (Relative velocity) [m/s]</td>
<td>✔ 1.9</td>
<td>✔ 1.58</td>
<td>✔ 2</td>
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<td>✔ -7.49</td>
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</table>

✔ : Success (non-crash), ✗ : Fail (Crash)

This case study illustrates the process we are applying to generate cases that can be applied to design AD systems with the potential to prevent all possible foreseeable scenarios.
JAMA is developing, in continuous communication with the Japanese authorities and related research and standardization institutions, a comprehensive strategy to tackle AD safety-related challenges.
JAMA and JARI, under the auspice of the Japan Ministry of Economy, Trade and Industry, are collecting data and developing engineering methodologies and processes for specific AD safety assurance purposes.

Socially acceptable top safety goals defined by authorities

Test Scenario

Data Driven Approach

Real world data → Trajectory → Distribution (Statistics) → Parameter Search Engine

Search Based Test

Functional scenario → Convert → Logical scenario → Convert → Concrete scenario

Safety evaluation

Real-traffic tests, Proving ground tests, Virtual tests

Safety Criteria
We are **willing to continue collaborating** with our international industrial partners to harmonize the activities that will lead to a safer and global AD society.

Thank you!

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