Key Ideas: UL 4600 Safety Standard for Autonomous Vehicles

June 2023

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Overview

- UL 4600 standard for AV safety cases
  - Automated driving (SAE Levels 3-5)
  - First published April 2020
  - 3rd Edition published March 2023

- Key 4600 ideas:
  - System-level safety case provides direction
  - Vehicle as well as infrastructure and lifecycle processes all matter
  - Safety metrics used for feedback loops
  - Third party component interface protects proprietary info
  - 4600 helps you know that you’ve done enough work on safety
Traditional safety standards are prescriptive
- “Here is how to do safety” (process, work products)
  - ISO 26262, ISO 21448, IEC 61508, MIL-STD 882, etc.

UL 4600 is goal based
- “Here is what a safety case should address”
  - Do NOT prescribe any particular engineering approach
    » Use other safety standards within the safety case context
- Standard for how to assess a safety case
  - Minimum coverage requirement (what goes in the safety case?)
  - Properties of a well-formed safety case
  - Objective assessment criteria
Example 4600 Clause

12.3.1 V&V shall provide acceptable coverage of safety related faults associated with the design phase.

12.3.1.1 MANDATORY:
   a) Systematic design defects
   b) Design consideration of faults, corruption, data loss, and integrity loss in sensor data
   c) Requirement gaps/omissions and requirement defects
   d) Response to violation of requirement assumptions
   **EXAMPLE:** Response to exceptional operational environment
   e) Identification and description of the intended ODD
   f) Acceptable mitigation of aspects of the defined fault model for each component and other aspect of the item

12.3.1.2 REQUIRED:
   a) Maintenance procedure definitions
   **NOTE:** While maintenance occurs during the lifecycle, the definition of procedures needs to correspond to design requirements and assumptions made in design regarding maintenance.
   b) Operational procedure definitions (including startup and shutdown) and operational modes
   c) Faults, corruption, data loss, and integrity loss in data from external sources
   d) Faults and failures associated with exceptional conditions that impair risk reduction functionality
   e) Hardware and software errata and other third-party component design defects
   f) Other faults in safety related functions, component designs, and other designed properties

12.3.1.3 HIGHLY RECOMMENDED – N/A

12.3.1.4 RECOMMENDED – N/A

12.3.1.5 CONFORMANCE:
Conformance is checked via inspection of design and V&V evidence.
Flexible Approaches

6.4.1 Each identified hazard shall be given a criticality level and assigned an initial risk assuming the absence of mitigation.

6.4.1.1 MANDATORY:
   a) Hazard Log records criticality level and initial risk for each hazard

6.4.1.2 REQUIRED:
   a) Use of at least one of the following risk evaluation approaches:
      1) Risk table
      2) Risk equation (weighted probability times severity)
      3) Fault Tree Analysis (FTA)
      4) Event Tree Analysis (ETA)
      5) Preliminary Item Safety Assessment (PSSA)
      6) Hazard Analysis and Risk Assessment (HARA)
      7) Bowtie diagram
      8) System-Theoretic Accident Model and Processes (STAMP)
      9) Field engineering feedback
     10) Other relevant risk evaluation approaches

b) Use of integrity level and related techniques

EXAMPLES: Integrity level and related techniques from ISO 26262, IEC 61508; development assurance level from DO-178

6.4.1.3 HIGHLY RECOMMENDED:
   a) Use of integrity levels defined in an accepted domain-relevant functional safety standard

NOTE: It might not be practical to use such integrity levels for all aspects of an autonomous systems, but it is highly recommended to do so to the extent reasonable.
Safety Case

- **Claim** – a property of the system
  - “System avoids pedestrians”

- **Argument** – why this is true
  - “Detect & maneuver to avoid”

- **Evidence** – supports argument
  - Tests, analysis, simulations, ...

- **Sub-claims/arguments address complexity**
  - “Detects pedestrians” // evidence
  - “Maneuvers around detected pedestrians” // evidence
  - “Stops if can’t maneuver” // evidence
Everything needed to independently assess safety

- Hazards and mitigation approaches
- Claims traced: arguments to evidence

Scope includes:

- **Technology**: HW/SW, machine learning, tools, ...
- **Lifecycle**: deployment, operation, incidents, maintenance, ...
- **Infrastructure**: vehicle, roads, data networks, cloud computing, ...
- **Road users**: pedestrians, light mobility, emergency responders, ...
- **Environment**: Operational Design Domain (ODD) definition
- ... and more ...
Example ODD Prompts (§8.2.2)

- Behavioral rules
  - EXAMPLES: Traffic laws, vehicle path conflict resolution priority, local customs, justifiable rule breaking for safety

- Compliance strategy of traffic rules and regulations
  - EXAMPLE: Enumeration of applicable traffic regulations and corresponding ego vehicle behavioral constraints

- Vulnerable populations including number, density, and types
  - EXAMPLES: Pedestrians, motorcycles, bikes, scooters, other vulnerable road users, other road users

- Special road user rules, if applicable
  - EXAMPLES: Bicycles, motorcycles, lane splitting, interacting with construction vehicles, oversize vehicles, snowplows, sand/salt trucks, emergency response vehicles, street sweepers, horse-drawn vehicles

- Seasonal effects
  - EXAMPLES: Foliage changes (e.g., leaves (dis) appearing), sun angle changes, seasonal behavioral patterns (e.g., summer beach traffic), seasonally-linked events (Oktoberfest, regatta crowds, fireworks gatherings, air shows)
SPI Metrics

Safety Performance Indicator (SPI)
- A KPI (Key Performance Indicator) specific to safety
- Provides metrics on safety case validity

SPI measures:
- Behavior metrics for safety-related behaviors
  - E.g.: Acceptable violation rate of standoff to pedestrians
- Assumption validity within safety case
  - E.g.: Tolerates gaps of up to X meters in lane markings
  - E.g.: Correlated camera and lidar false negative rate
- Any other metrics that validate safety case
SPIs and Lifecycle Feedback

- SPI: direct measurement of claim failure
  - Independent of reasoning ("claim is X ... yet here is ~X")
  - Partial measurement(s) OK; multiple SPIs for a claim OK

- A falsified safety case claim:
  - Not (necessarily) imminent loss event
  - Safety case has some defect

- Root cause analysis might reveal:
  - Product or process defect
  - Invalid safety argument
  - Issue with supporting evidence
  - Assumption error, ...
Feedback Loops

- Don’t assume perfection – manage & improve imperfections
  - Feedback data incorporated in safety case
Elements out of Context (EooC)

- Reused or 3rd party system “component”
  - Similar in spirit to ISO 26262 SEooC
  - Hardware, software, sensor, map data, ...

- EooC has a safety case fragment
  - Vendor need not expose that safety case
  - Instead, provides an interface containing:
    - Properties & characteristics
    - Assumptions that system must honor
    - Fault model used for assessment
    - 4600 clause coverage (might be partial)
    - Assessment report

CLAIM

ARGUMENT 2

Sub-CLAIM 2A

Sub-ARGUMENT 2A

EooC Interface

EooC Interface

EVIDENCE 2A

EVIDENCE 2B

EVIDENCE 2B

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Complementing Other Standards

- ISO 26262, MIL-STD 882, etc.: potential starting points
  - Still useful where applicable

- ISO 21448 etc. for scenarios
  - Design and validation process framework
  - SaFAD and emerging standards

- 4600 has #DidYouThinkofThat? lists
  - Initial safety case coverage
  - Learn from experience: yours; others
  - Objective assessment criteria for safety case

Other Key Points

- Version 3 explicitly addresses heavy trucks
- Self-certification is permitted
  - Internal assessor OK; no external “certificate” required
- Only necessary technical mitigations required
  - Can use non-technical mitigations (e.g., “not applicable”)
- Underwriters Laboratories is a non-profit SDO
  - Voting committee (STP) has diverse representation
  - Continuous Maintenance process provides timely updates
- Does 4600 conflict with ISO 26262 or ISO 21448?
  - No
- What if you can’t afford to buy a copy?
  - Issued standard is free to browse (“digital view”) on-line in its entirety: https://www.shopululstandards.com/ProductDetail.aspx?productid=UL4600
Review of Key Ideas

- System-level safety case provides direction
  - Highlights gaps in evidence and arguments

- Vehicle, infrastructure, and lifecycle processes all matter
  - If safety case depends upon it, that makes it safety related

- Metrics combine with feedback loops
  - Operational feedback will be essential for practical safety

- Third party component interface to protect proprietary info
  - EooC interface permits separate component assessment

- 4600 helps you know that you’ve done enough safety work
  - Robust prompts and pitfalls capture best practice/lessons learned
More Information

- Personal UL 4600 launch page:
  - Pointers to recorded talks
  - Pointers to viewable copies of standard

- UL 4600 Guidebook
  - Hard copy & e-book
  - International Amazon print-on-demand
    - Country-specific info via launch page above
  - (Personal project – not officially endorsed by ULSE)