OpenODD WP-4

Representing Uncertainty

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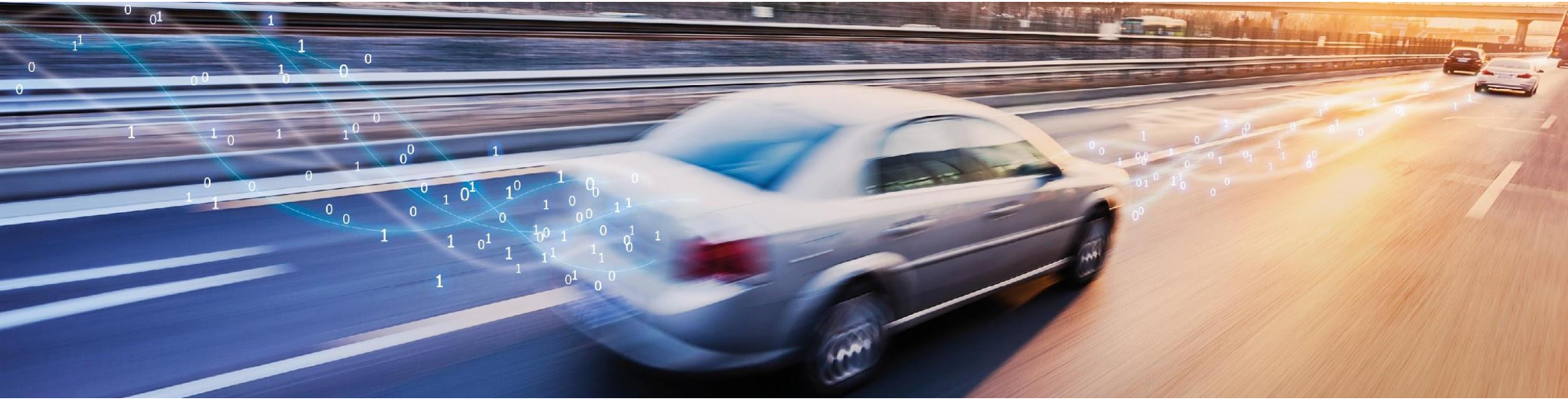

ASAM Association for Standardization of Automation and Measuring Systems

Motivating Challenge

"[a] description of the specific operating domain(s) in which an automated function or system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/nighttime, etc.), and other domain constraints."

--- **Federal Automated Vehicles Policy: Accelerating the Next Revolution In Roadway Safety**, page 85.

[t]he specific [environmental] conditions under which a given driving automation system or feature thereof is designed to function, including, but not limited to, driving modes. This can incorporate a variety of limitations, such as those from geography, traffic, speed, and roadways.

--- **Preparing for the Future of Transportation: Automated Vehicles 3.0**, page 46.

- The ODD must map every situation to an in or out of ODD binary classification
  - Example: Determine in/out of ODD for each video frame in a segment of naturalistic driving video.
  - Example: Determine in/out of ODD for each of the sequence of states in an OpenSCENARIO simulation.
- The Challenge is representing uncertain "environmental conditions" or "specific conditions"
  - Example: **Uncertainties** related to weather, pedestrians, sensor limitations, etc

There is a Need to

Introduce clarity into “fuzzy” situations

- Convert an otherwise **“fuzzy”** or **“uncertain”** situation into a **black-and-white true/false** determination.
- **Qualifiers are** the specification of the **conversion rules**.
- **Data** supporting evaluation of qualifiers **originates from environment sensors** (outside vehicle).
- **Qualifiers are optional** at the discretion of the ODD author.
- Adding Qualifiers **Increases Level of Detail (LOD).**

Uncertainty Qualifiers Approach

Acceptable Risk for Discrete Occurrence

Two options for representing requirements related to Presence of Pedestrians:

- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN Pedestrian

  In ODD when: **Pedestrian=false**

- Qualified True/False: Increasing LOD using qualifiers, similar to refined road types, e.g.

  SUITABLE Freeway EXCEPT WHEN Pedestrian**@P8**

  In ODD when: **Pedestrian=false <u>OR P8=true</u>**

  where P8=true if rate of occurrence < 10^{-8} Hr^{-1}; otherwise it is false.

Uncertainty Qualifiers Approach

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  In ODD when: **Pedestrian=false** **OR P8=true** → **Acceptable Risk**

  where P8=true if rate of occurrence < 10^{-8} Hr^{-1}; otherwise it is false.

Uncertainty Qualifiers Approach

Acceptable Risk for Continuous Occurrence

Two options for representing requirements related to Presence of Pedestrians:

- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN IcyRoad

  In ODD when: **IcyRoad=false**

- Qualified True/False: Increasing LOD using qualifiers, similar to refined road types, e.g.

  SUITABLE Freeway EXCEPT WHEN IcyRoad**@Q2**

  In ODD when: **IcyRoad=false <u>OR Q2=true</u>**

  where **Q3=true** if rate of occurrence < 10^{-4} Hr^{-1}; otherwise it is false.

Uncertainty Qualifiers Approach

Acceptable Risk for Continuous Occurrence

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- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN IcyRoad

  In ODD when: **IcyRoad=false**

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  In ODD when: **IcyRoad=false <u>OR Q2=true</u>**

  where **Q3=true** if rate of occurrence < 10^{-4} Hr^{-1}; otherwise it is false.

  Convert to max-duration per hour: 10^{-4} *3600 = 0.36 secs.
  Convert to max-distance per hour, assuming 10 meter/sec: 0.36 * 10 = 3.6 meters; is 3.6 meters on ice <u>acceptable risk</u>?

Uncertainty Qualifiers Approach

Acceptable Risk for Continuous Occurrence

Two options for representing requirements related to Presence of Ice:

- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN IcyRoad

  In ODD when: **IcyRoad=false**

- Qualified True/False: Increasing LOD using qualifiers, similar to refined road types, e.g.

  SUITABLE Freeway EXCEPT WHEN IcyRoad**@Q4**

  In ODD when: **IcyRoad=false** **OR Q4=true** → **Acceptable Risk**

  where **Q3=true** if rate of occurrence < 10^{-4} Hr^{-1}; otherwise it is false.

  Convert to max-duration per hour: 10^{-4} *3600 = 0.36 secs.
  Convert to max-distance per hour, assuming 10 meter/sec: 0.36 * 10 = 3.6 meters; is **3.6 meters on ice** acceptable risk?

Uncertainty Qualifiers Approach

Acceptable Risk for Complex Situations

Acceptable risk for complex situations:

- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN Pedestrian OR IcyRoad

  In ODD when: **Pedestrian=false AND IcyRoad=false**

- Qualified True/False: Increasing LOD using qualifiers, similar to refined road types, e.g.

  SUITABLE Freeway EXCEPT WHEN Pedestrian**@P8** OR IcyRoad**@Q4**

  In ODD when: (**Pedestrian=false OR P8=true**) AND (**IcyRoad=false OR Q4=true**)

Uncertainty Qualifiers Approach

Acceptable Risk for Multiple Qualifiers

For representing uncertainty, there are two major options:

- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN Pedestrian

- Qualified True/False: Increasing LOD using qualifiers, similar to refined road types, e.g.

  SUITABLE Freeway EXCEPT WHEN Pedestrian**@P8,E2**

  Pedestrian=false OR P8=true OR E2=true

  where E2=true if **detection error** is less than 1%; otherwise it is false.

Uncertainty Qualifiers Approach

Acceptable Risk for Multiple Qualifiers

For representing uncertainty, there are two major options:

- Pure True/False Approach: Definitions should not contain any uncertainty qualifiers, e.g.:

  SUITABLE Freeway EXCEPT WHEN Pedestrian

- Qualified True/False: Increasing LOD using qualifiers, similar to refined road types, e.g.

  SUITABLE Freeway EXCEPT WHEN Pedestrian**@P8,E2**

  Pedestrian=false OR P8=true OR E2=true

  Acceptable Risk

  where E2=true if **detection error** is less than 1%; otherwise it is false.

Multiple Qualifiers

Custom Qualifier Specification

- Qualified EXCEPT Statements:

  SUITABLE Freeway EXCEPT WHEN Pedestrian**@P1,Q2,R3**

- Qualifier Definition Statements:

  QUALIFIER **P** BASE **10** UNITS **Hr**$^{-1}$ // Probability of Occurrence <10^{-i}

  QUALIFIER **Q** BASE **2** UNITS **Min**$^{-1}$ // Probability of Occurrence <2^{-i}

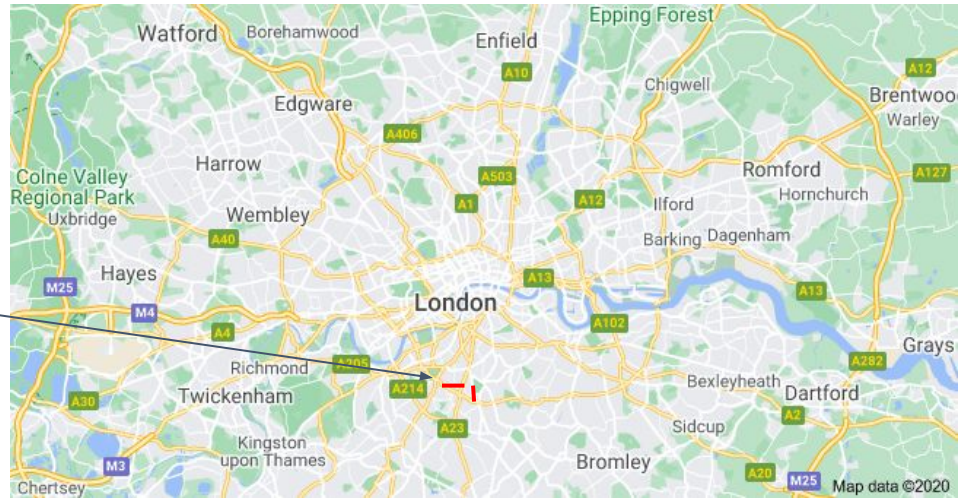
  QUALIFIER **R** BASE **2.718** UNITS **Sec**$^{-1}$ // Probability of Occurrence <e^{-i}

Visualizing Qualifiers

Color Coding on Maps

P-value data provided by
X2V infrastructure

Unsuitable roads
due to low P-value



Color-Coding **map of London**
according to Pi values

ODD as a Query Language

An approach to define semantics

Decompose the multi-file ODD specifications into a collection of statements.

For each situation:

- Convert every statement into a collection of propositions.
- Provide rules for evaluating each proposition as true/false.

”SUITABLE Freeway EXCEPT WHEN [rain-heavy]”

returns True/False values for every situation.

ODD as a Query Language

An approach to define semantics

Example: Pythonic DSL Statements:

- **IncludeTaxonomy** [BSI PAS 1883]
- **AddCond** [rain-light] **to** [rainfall/weather/ODD]
- **Determine** [rain-light] **when**
  [(rain rate <2mm/hr) **AND** (droplet size <1mm)]
- **AddCond** [rain-heavy] **to** [rainfall/weather/ODD]
- **Determine** [rain-heavy] **when**
  [(rain rate >5mm/hr) **AND** (droplet size >1mm)]

ODD as a Query Language

An approach to define semantics

Example: Pythonic DSL Statements:

- **IncludeTaxonomy** [BSI PAS 1883]
- **AddCond** [rain-light] **to** [rainfall/weather/ODD]
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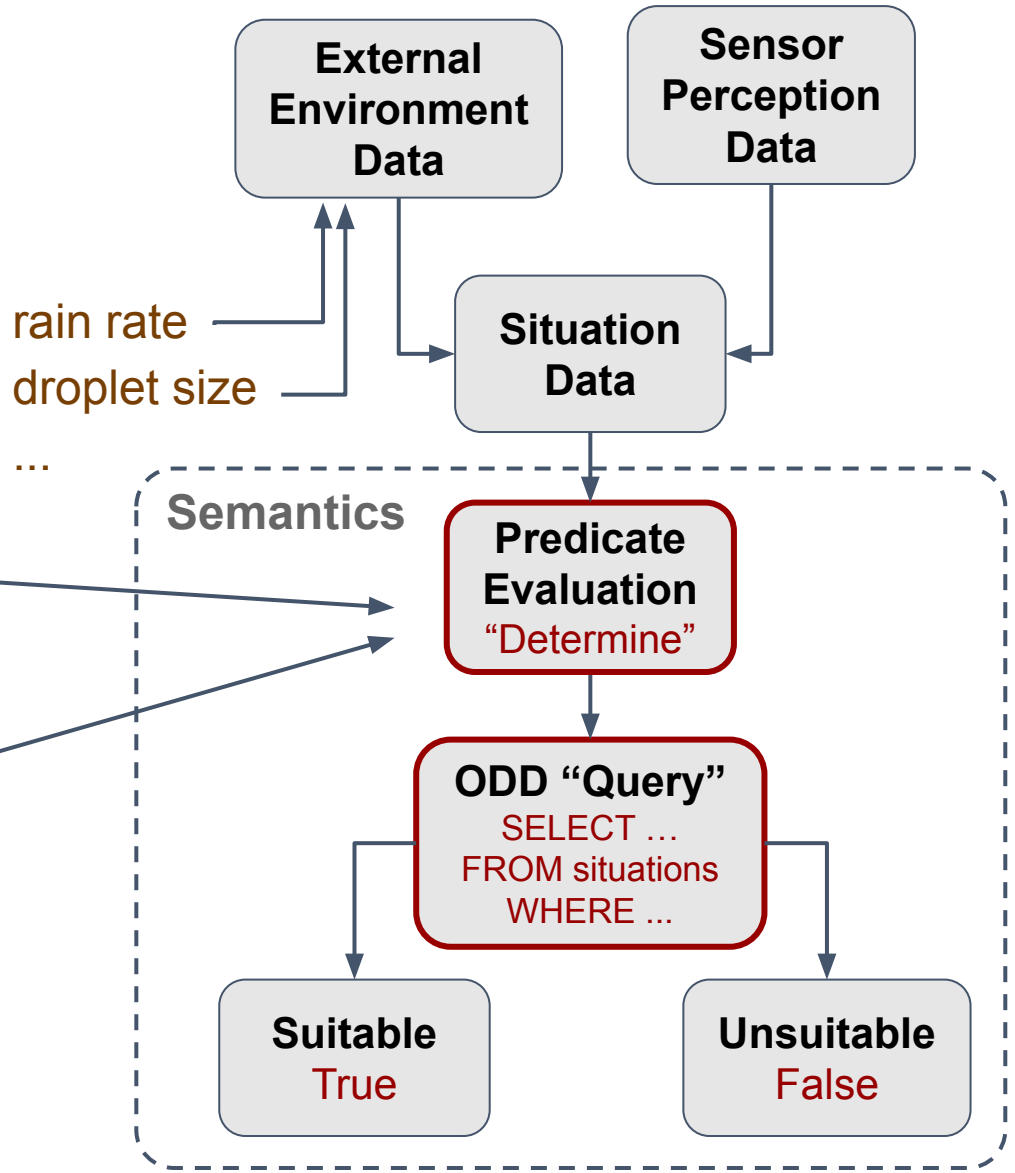
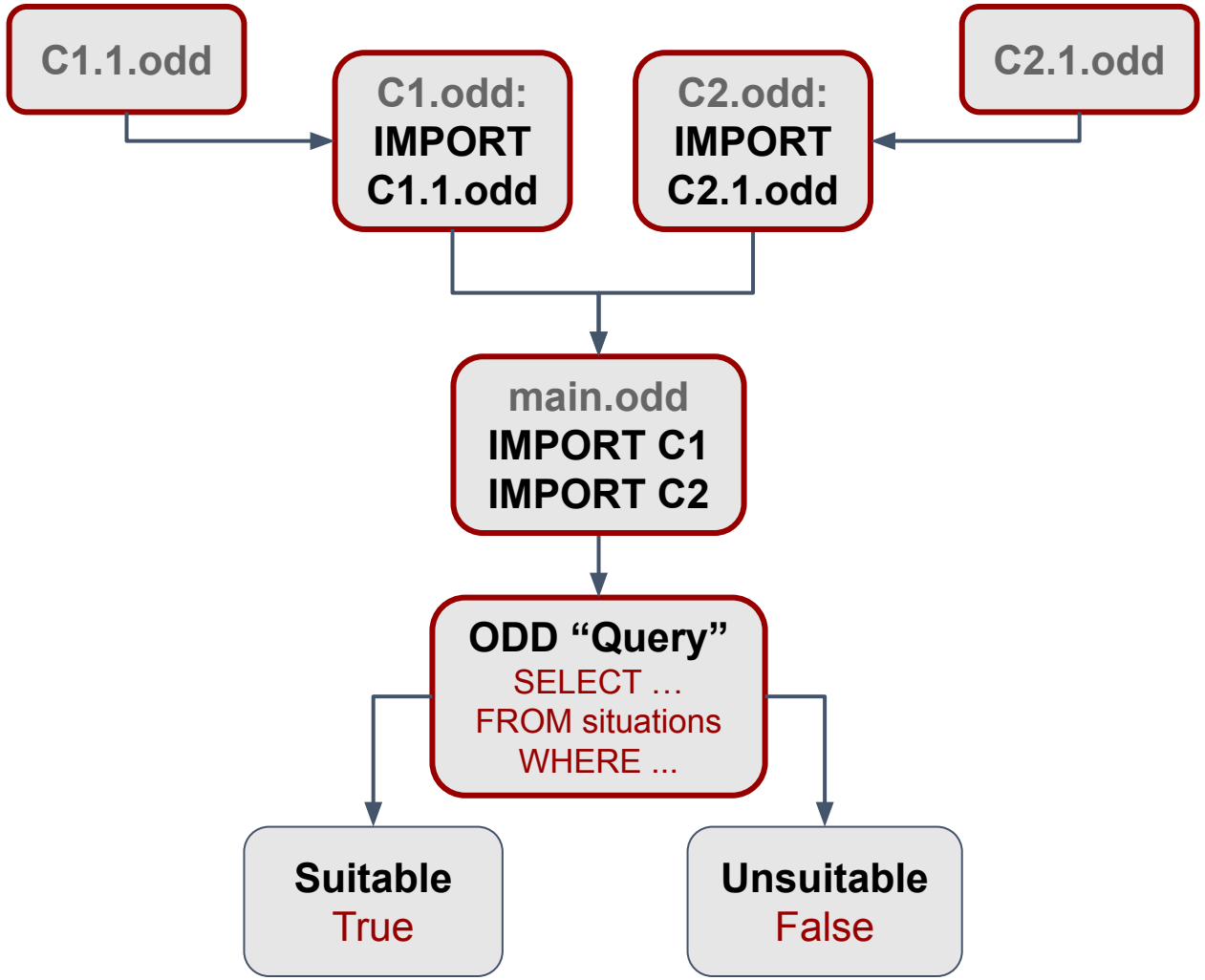
- **AddCond** [rain-heavy] **to** [rainfall/weather/ODD]
- **Determine** [rain-heavy] **when**
  [(rain rate >5mm/hr) **AND** (droplet size >1mm)]



ODD as a Query Language

Acceptable Risk Libraries with Controlled Scope



Components ODD controls OEM scope

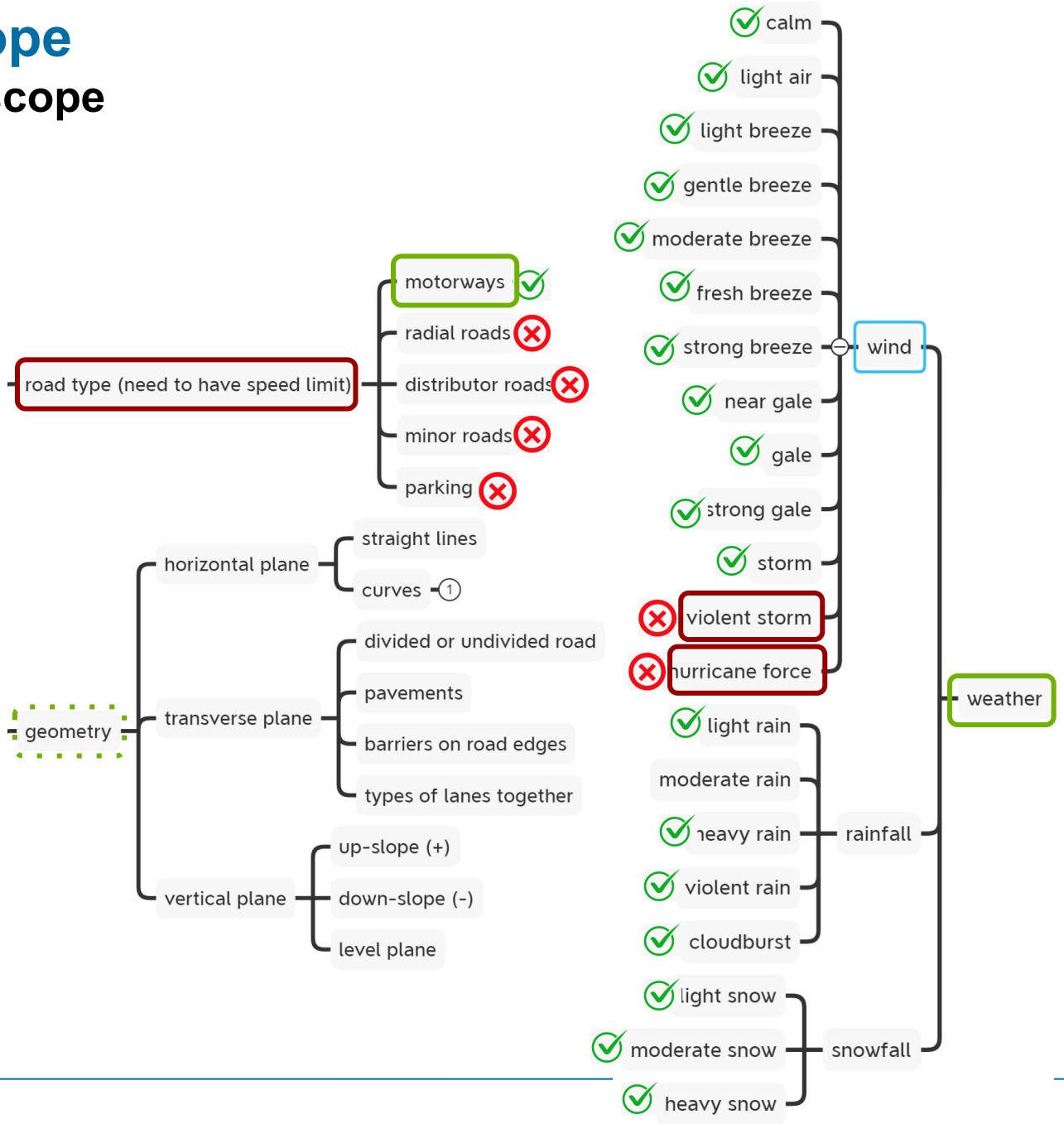
Reversing the constraint on parent controls scope

Unsuitable [road type]
except when [road type] is [motorway]

➢ **Addition are Unsuitable**

Suitable [weather] is [wind]
except when [wind] is [violent storm]
or when [wind] is [hurricane force]

➢ **Addition are Suitable**



OpenODD Capablities

Allow Representing Uncertainty and Acceptable Risk

- The ODD must map every situation to an in or out of ODD binary classification
  - Example: We can tell in/out of ODD for each video frame in a segment of naturalistic driving video.
  - Example: We can tell in/out of ODD for each of the sequence of states in an OpenSCENARIO simulation.
- Represent Acceptable Risk using qualifiers
  - Example: Pedestrians and IcyRoad are not in ODD unless risk of occurrence is acceptable
  - Example: Breaching lane marker near cliff edge has a different risk than exiting lane marker in parking lot.
- Allows specifying uncertain behavior of road users using qualifiers
  - Example: Suitable only when 90% of drivers stop at the red light.
- Allows extending to “newly discovered” uncertainties using “import”:
  - Example: Uncertainty due to environment impact of recent accidents, etc
- Allows controlling uncertainty and scope of extensions:
  - Example: Prevent main.odd from extending road types or whether specified in included components.

OpenODD Requirements

Allow Representing Uncertainty and Acceptable Risk

- Allows specification at multiple levels of details (LOD):
  - Level 0: No details, **no uncertainty** (baseline)
  - Level 1: Uncertainty of **weather** (need external data sources)
  - Level 2: Uncertainty of **occurrence** (need external data sources)
  - Level 3: ...
- Allows specifying both Discrete and Continuous Occurrences.
  - Example: The occurrence of a pedestrian is discrete.
  - Example: Icy road (section) is a continuous occurrence.
- Allows ODD to reference X2V data
  - Example: Temporary road closures or lane configuration changes, weather conditions, etc.
  - Example: Temporary increased uncertainty after accident or natural disaster.
- Avoids “flicker” of in/out ODD

Qualifiers Concept

Without Qualifiers

SUITABLE Freeway EXCEPT WHEN Pedestrian present
The above states that Freeways are within the ODD, unless Pedestrians are present on the road.

+ This concept makes modelling an ODD rather easy.
- With this it is hard to satisfy real world requirements

Clearly does not satisfy requirement of converting “fuzzy” to true/false.

With Qualifiers (Uncertainty LOD)

SUITABLE Freeway EXCEPT WHEN Pedestrian**@P8**
The above states that freeways are within the ODD, unless the likelihood to encounter pedestrians is greater than P8.

This includes already a risk assessment within the ODD. How the information about the current likelihood of pedestrians on a certain road is obtained is not relevant for the ODD definition.

Clearly Satisfies requirement of converting “fuzzy” to true/false.

Qualifier only states the threshold applied to externally provided data.

Simple in/out ODD rules supporting Uncertainty LOD.

Concept

Without Qualifiers

Data points necessary to determine if the situation/scene/scenario is within the ODD or not:

SUITABLE Freeway EXCEPT WHEN Pedestrian present

```
# source can be e.g.
road.type = “freeway”
# source can be AD-System
pedestrians.present = “false”

if odd.roadtype == road.type and
 odd.pedestrians == pedestrians.present:
      scene.odd.status = “OK”
else:
      scene.odd.status = “NOK”
```

With Qualifiers (ULOD)

Data points necessary to determine if the situation/scene/scenario is within the ODD or not:

SUITABLE Freeway EXCEPT WHEN Pedestrian present <P8

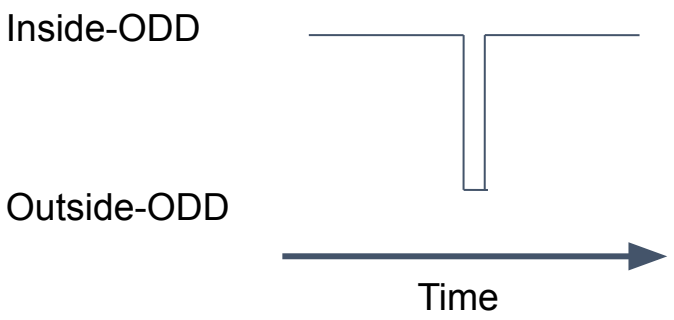
```
# source can be e.g.
road.type = “freeway”
# source can be C2X
pedestrians.present.threshold = “P9”

if odd.roadtype == road.type and
 odd.pedestrians.threshold <  pedestrians.present.threshold:
      scene.odd.status = “OK”
else:
      scene.odd.status = “NOK”
```

Concept

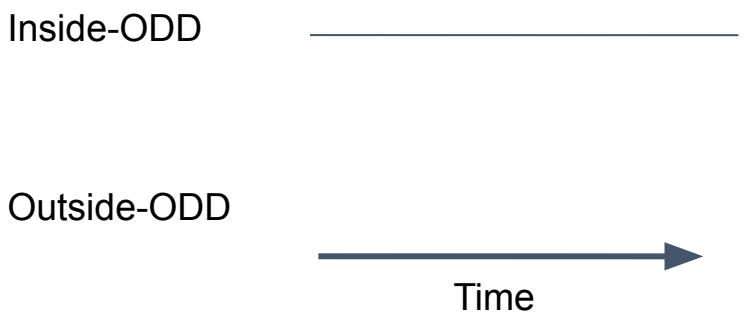
Without Qualifiers

Occurrences, such as pedestrians, can cause a “flicker” between in and out of ODD:



With Qualifiers (ULOD)

Occurrences do not change inside or outside ODD status over time when the P-values does not change.



Note: When the P-Value changes due to weather, it remains at the modified value for the entire road section.