

Mapping scenarios in Operational Design Domain for AD/ADAS virtual testing

Dr Siddhartha Khastgir CEng MIMechE
Head of Verification & Validation,
WMG, University of Warwick, UK



Driving Simulation Conference (DSC) 2022 EUROPE
16 September 2022



DSC 2022 EUROPE VR

Talk of Appeals

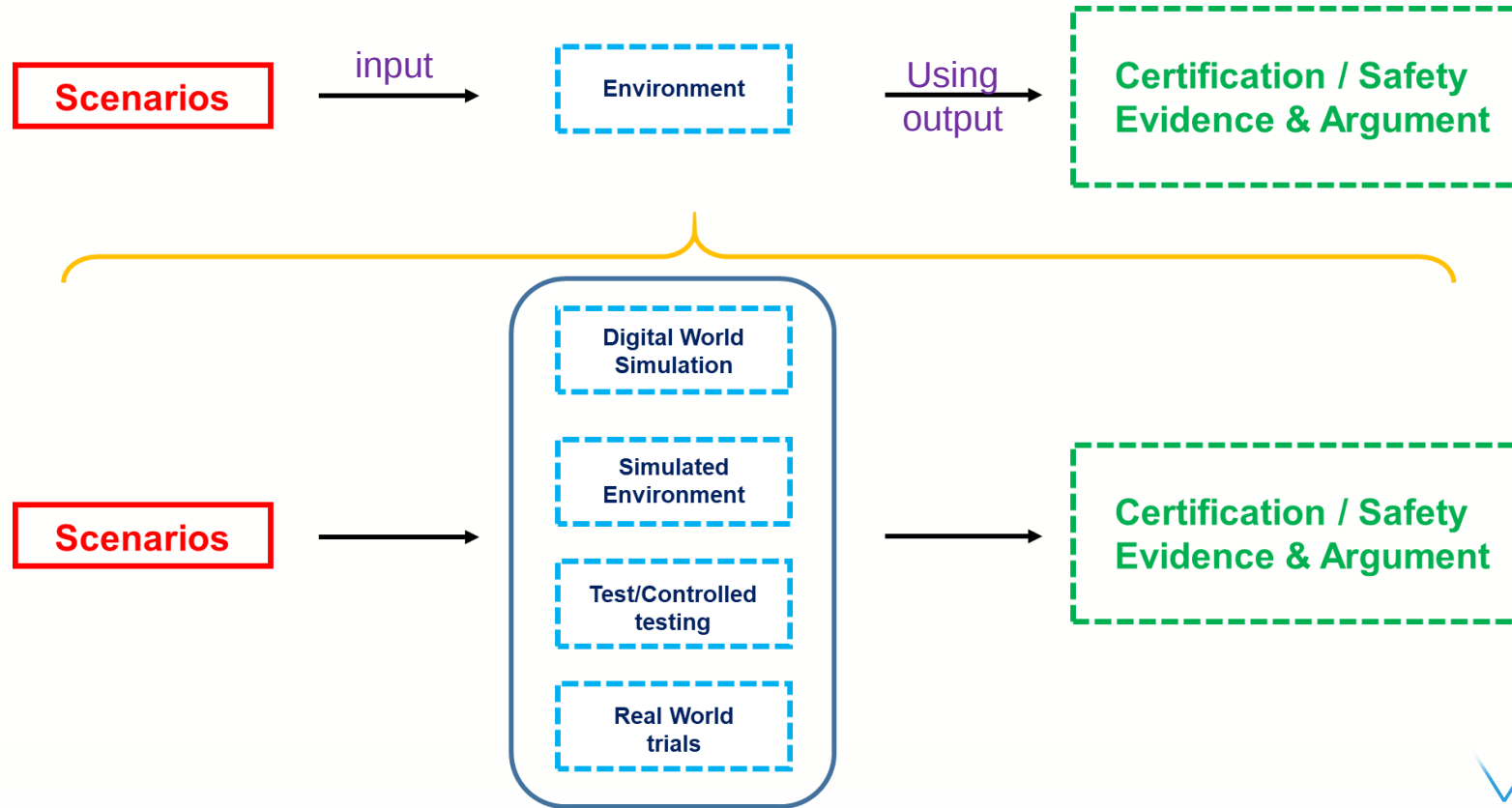
Talk of Appeals

serious, urgent, and heartfelt requests.

Testing Continuum



Testing Continuum



Testing Continuum

Scenarios

Environment

**Certification / Safety
Evidence & Argument**

Create



Format



Store



Plan



Execute



Analyse



Decide

Testing Continuum

Scenarios

Environment

Certification / Safety
Evidence & Argument

Create

Format

Store

Plan

Execute

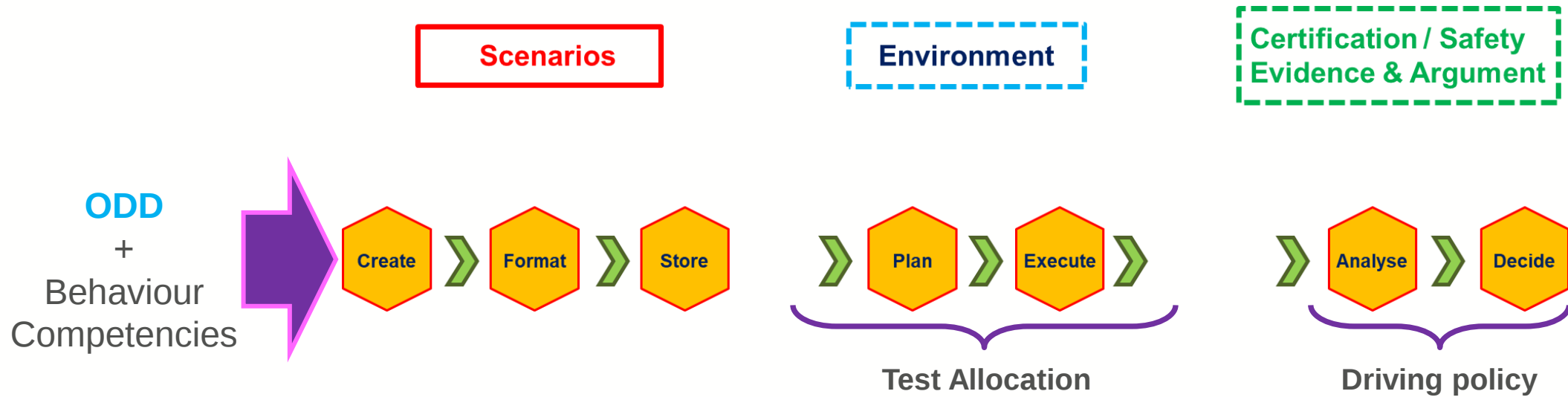
Analyse

Decide

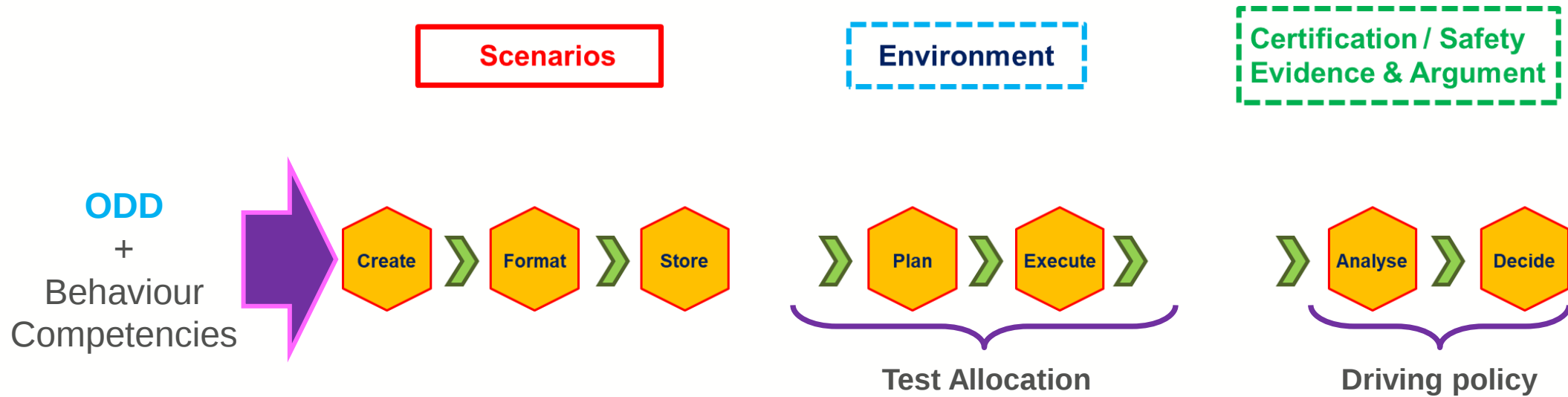
Test Allocation

Driving policy

ODD based Scalable Testing Framework



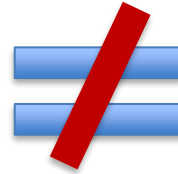
ODD based Scalable Testing Framework



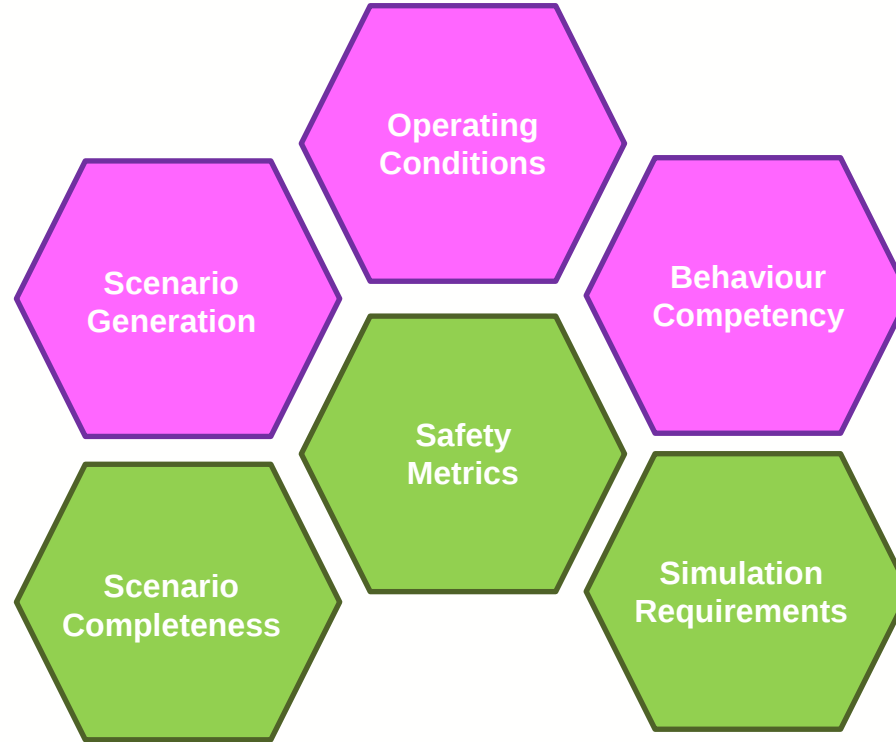
Standards and Tools!

Why is ODD important?

- Types of scenarios experienced?



Why is ODD important?



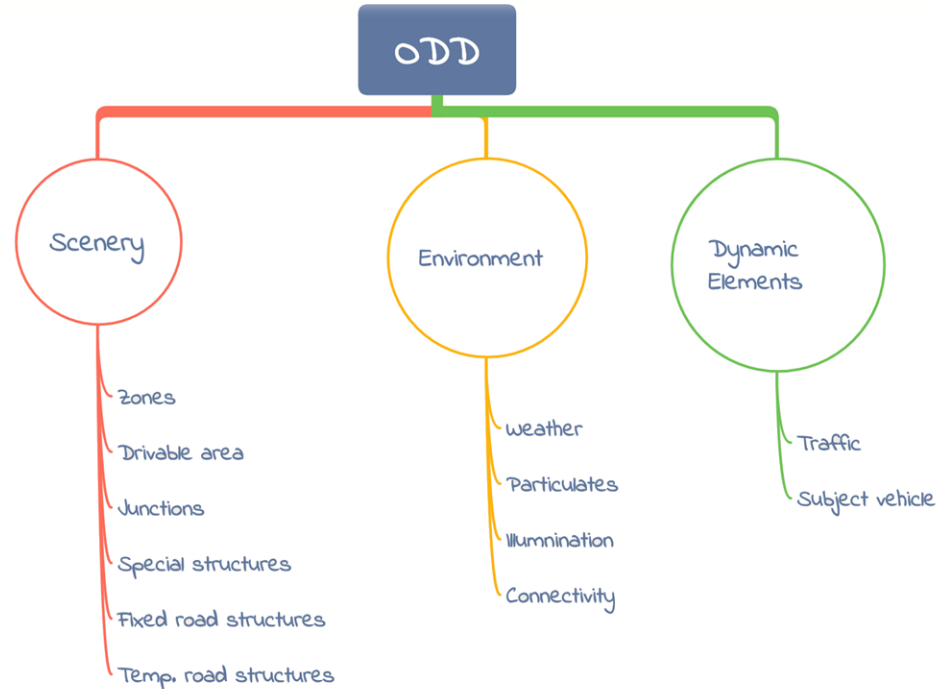
Operational Design Domain (ODD)

*“**Operating conditions** under which a given driving automation system or feature thereof is **specifically designed to function**, including, but not limited to, **environmental, geographical, and time-of-day restrictions**, and/or the requisite **presence or absence of certain traffic or roadway characteristics**.”*

- SAE J3016 (2021)

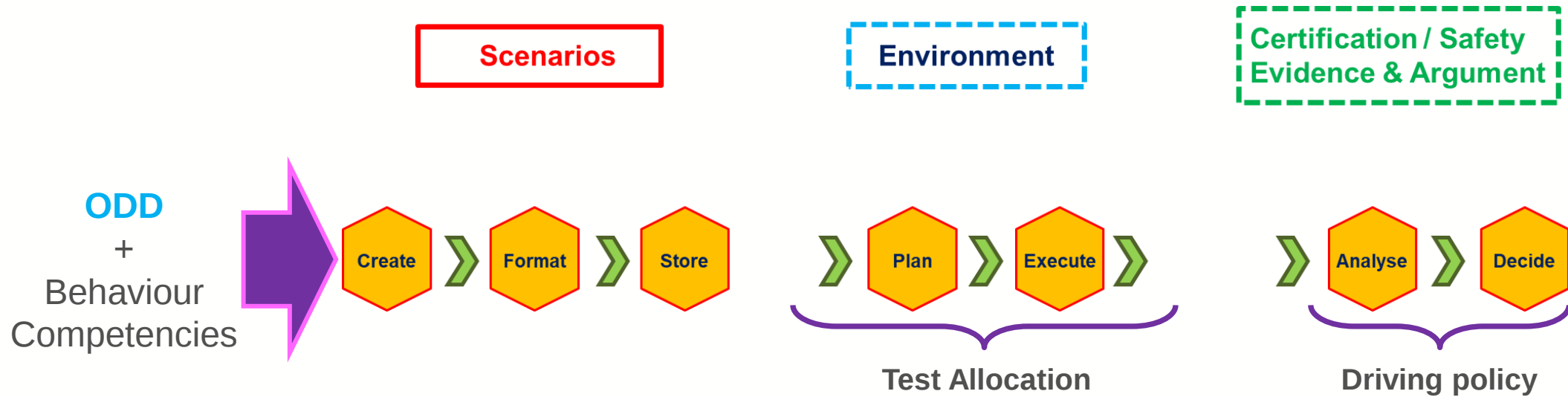
What is an ODD?

ODD Taxonomy as per BSI PAS 1883



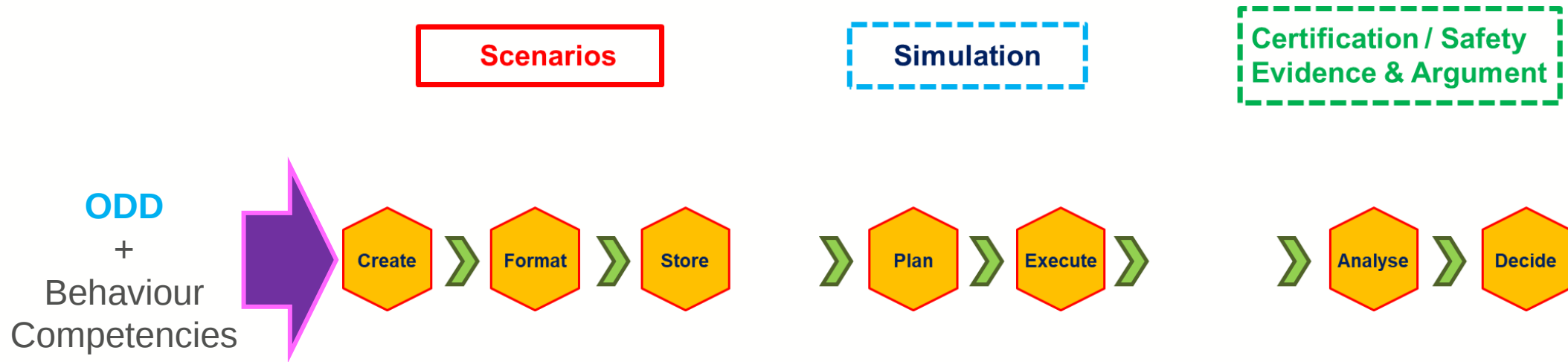
For more on Curious case of ODD: <https://bit.ly/CuriousCaseODD>

ODD based Scalable Testing Framework

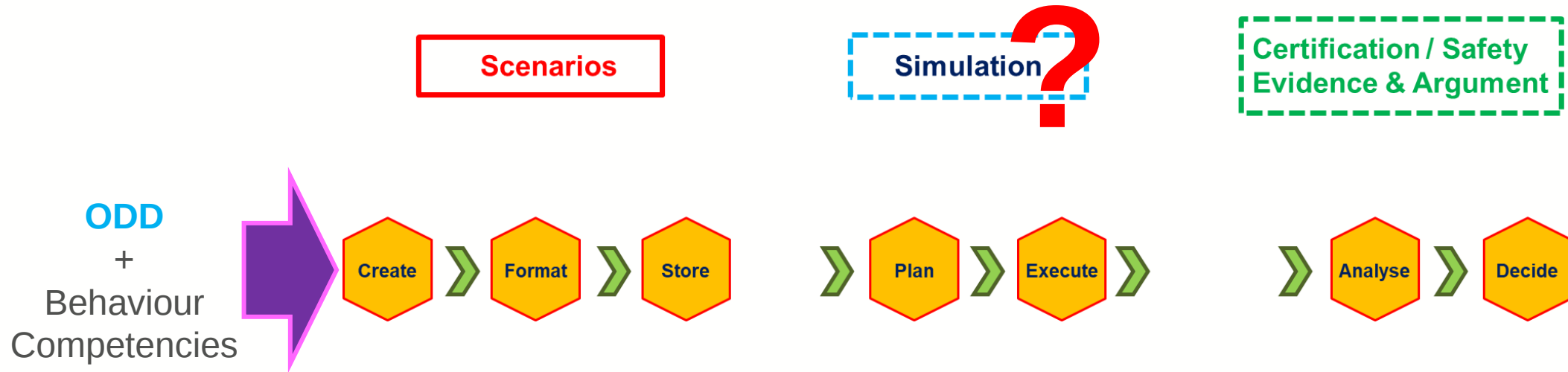


Standards and Tools!

ODD based Scalable Testing Framework



ODD based Scalable Testing Framework



Qualifying Simulation Environment (VTE)



Qualifying Simulation Environment (VTE): Performance

Qualifying Simulation Environment (VTE): Performance

Scenarios

Simulation

**Certification / Safety
Evidence & Argument**

Create



Format



Store



Execute

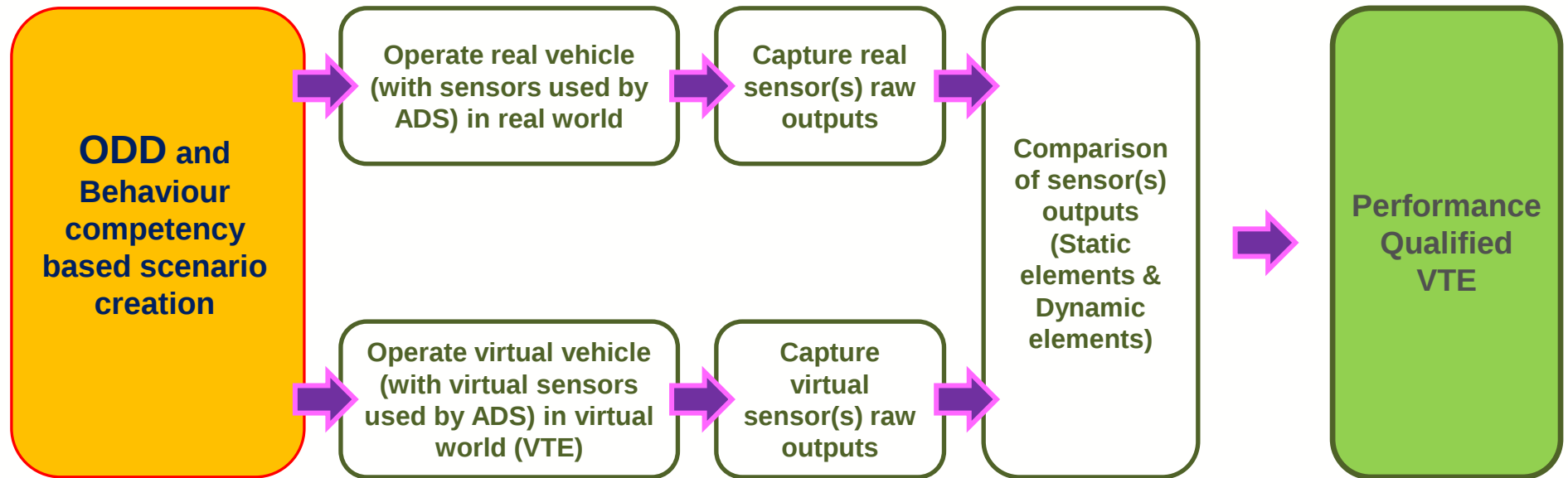


Analyse



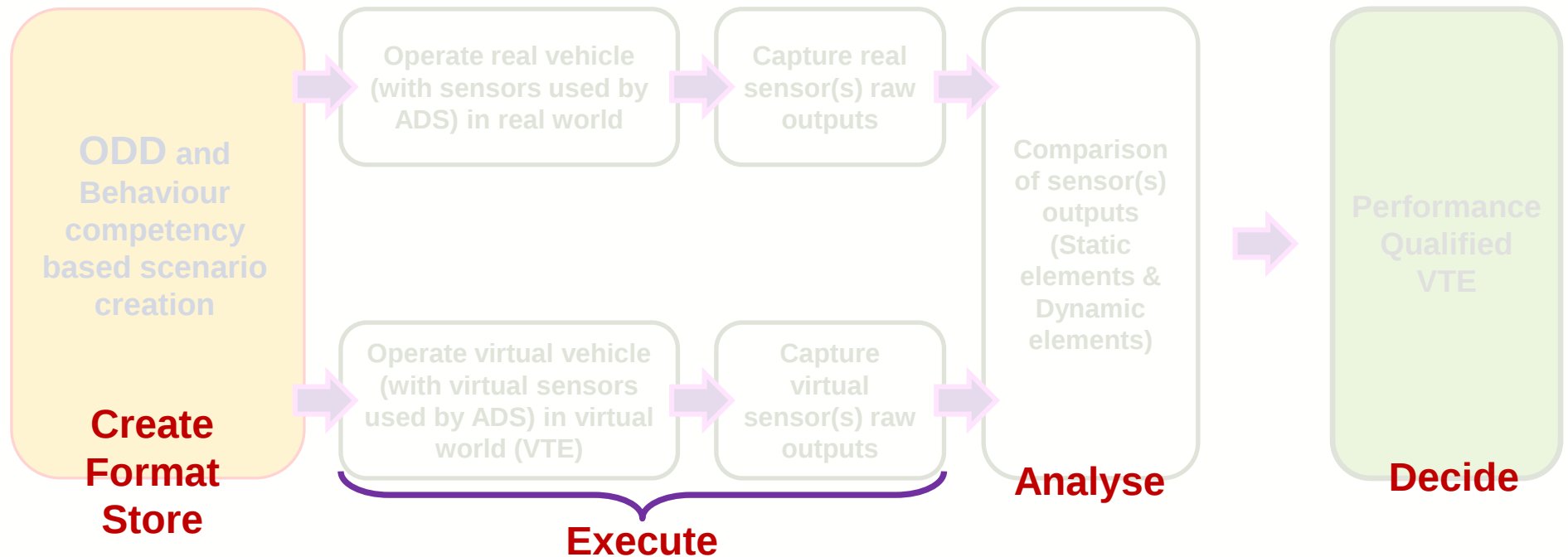
Decide

Qualifying Simulation Environment (VTE): Performance



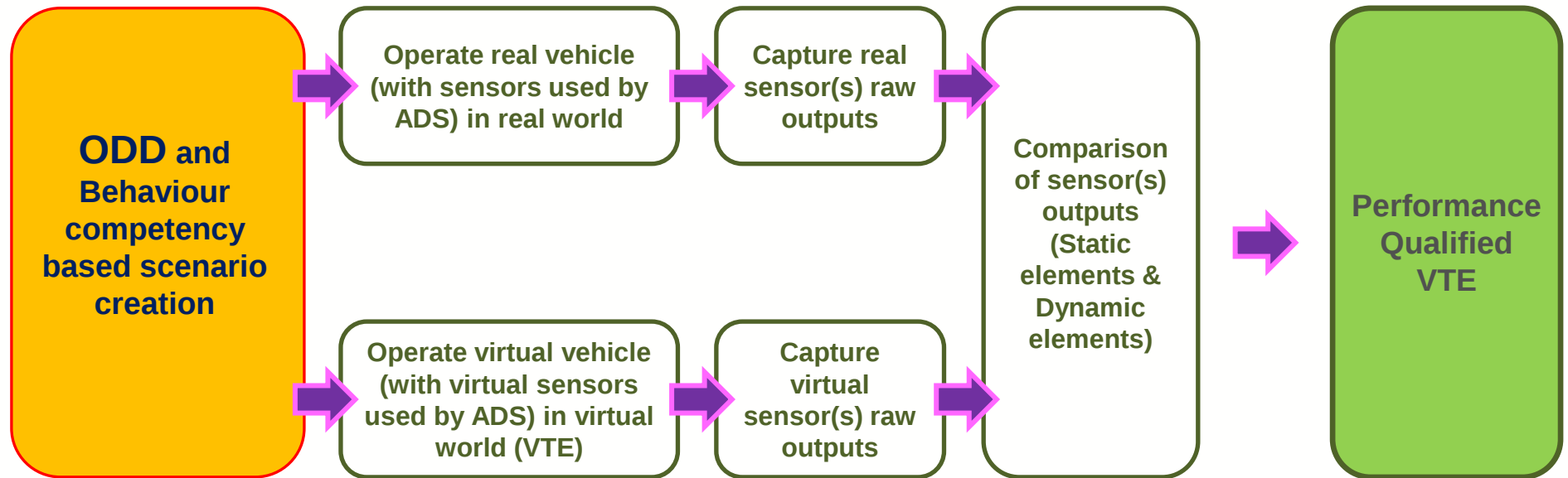
Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Qualifying Simulation Environment (VTE): Performance



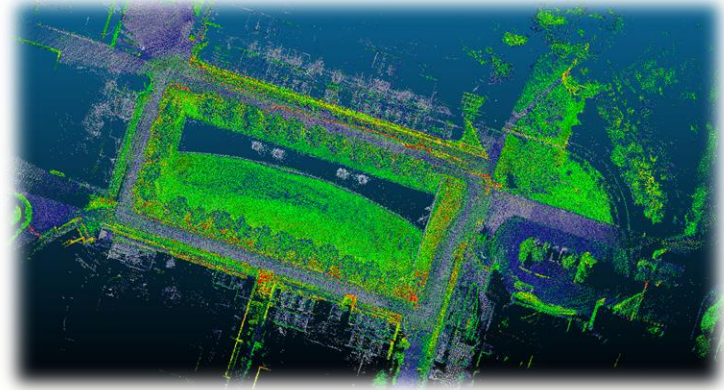
Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Qualifying Simulation Environment (VTE): Performance



Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Qualifying Simulation Environment (VTE): Performance



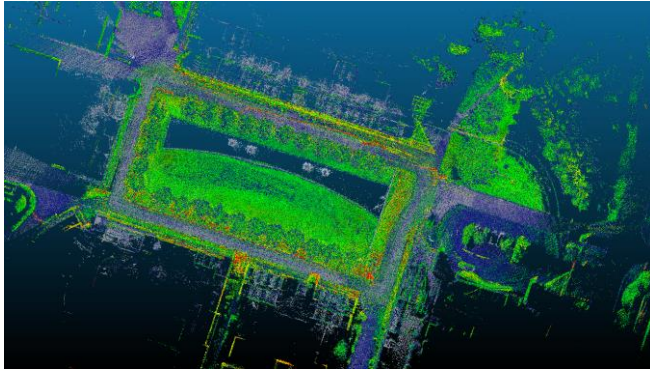
Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Qualifying Simulation Environment (VTE): Performance

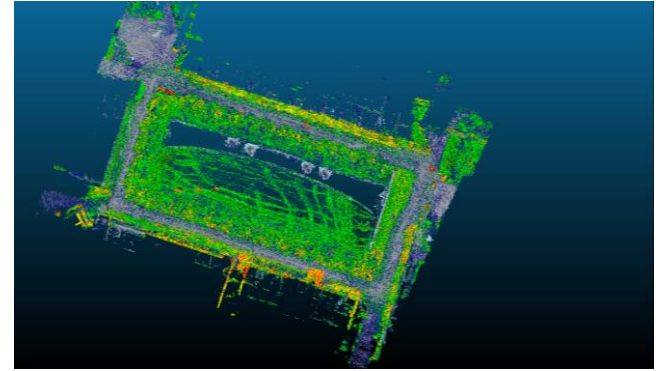


Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Qualifying Simulation Environment (VTE): Performance



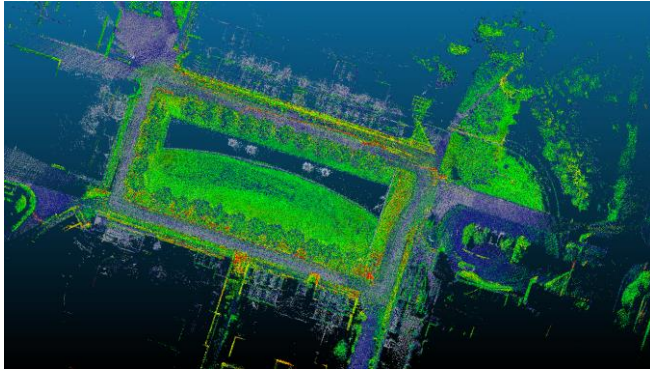
Real LiDAR Sensor Point Cloud



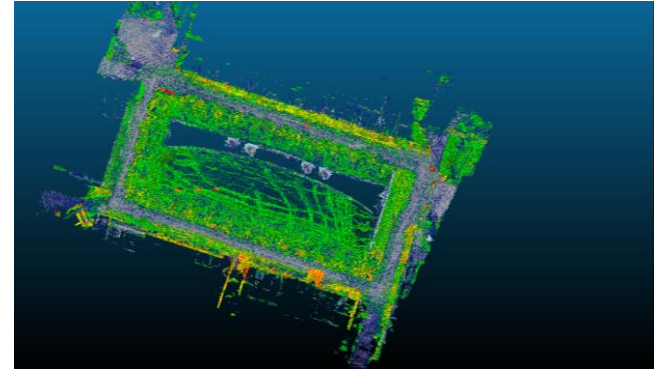
Virtual LiDAR Sensor Point Cloud

Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Qualifying Simulation Environment (VTE): Performance



Real LiDAR Sensor Point Cloud



Virtual LiDAR Sensor Point Cloud

Citation: Wallace, A., Khastgir, S., Zhang, X., Brewerton, S., Anctil, B., Burns, P., Charlebois, D. and Jennings, P., 2022, June. Validating Simulation Environments for Automated Driving Systems Using 3D Object Comparison Metric. In *2022 IEEE Intelligent Vehicles Symposium (IV)* (pp. 860-866). IEEE.

Appeal # 1

**Validated Sensor Model (only)
is a MYTH!**

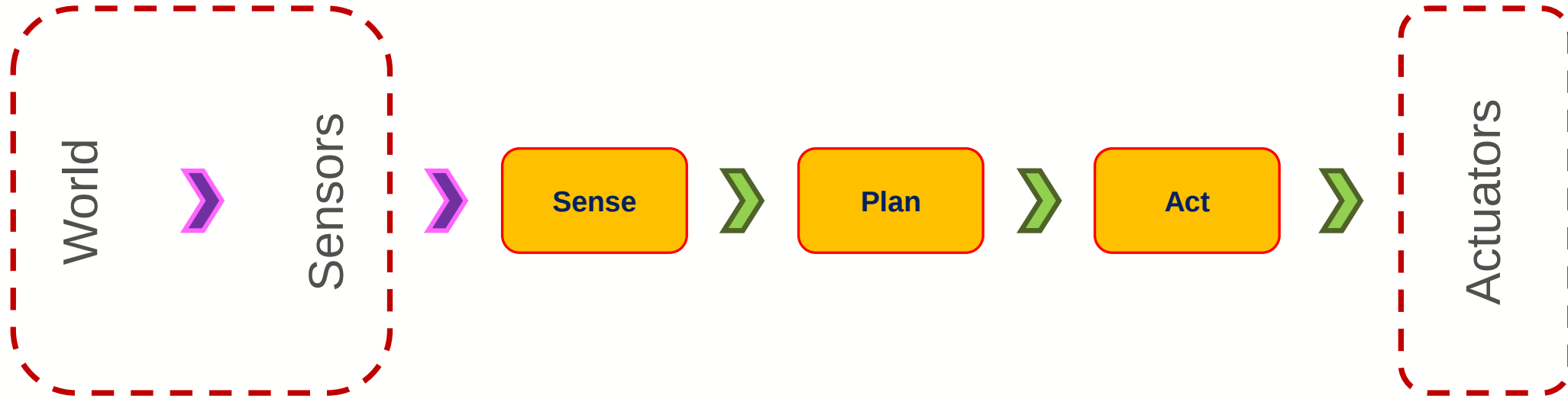
Understanding Automated Vehicle Functions



Understanding Automated Vehicle Functions



Understanding Automated Vehicle Functions



Appeal # 1

**Validated Sensor Model (only)
is a MYTH!**

Qualifying Simulation Environment (VTE): Process

- Data management
- Code verification
- Calculation verification
- Release Management



Reference: Regulation (EU) 2019/2144: EU Implementing Regulation for automated vehicles (Adopted 5 Aug 2022)

Qualifying Simulation Environment (VTE): Usage

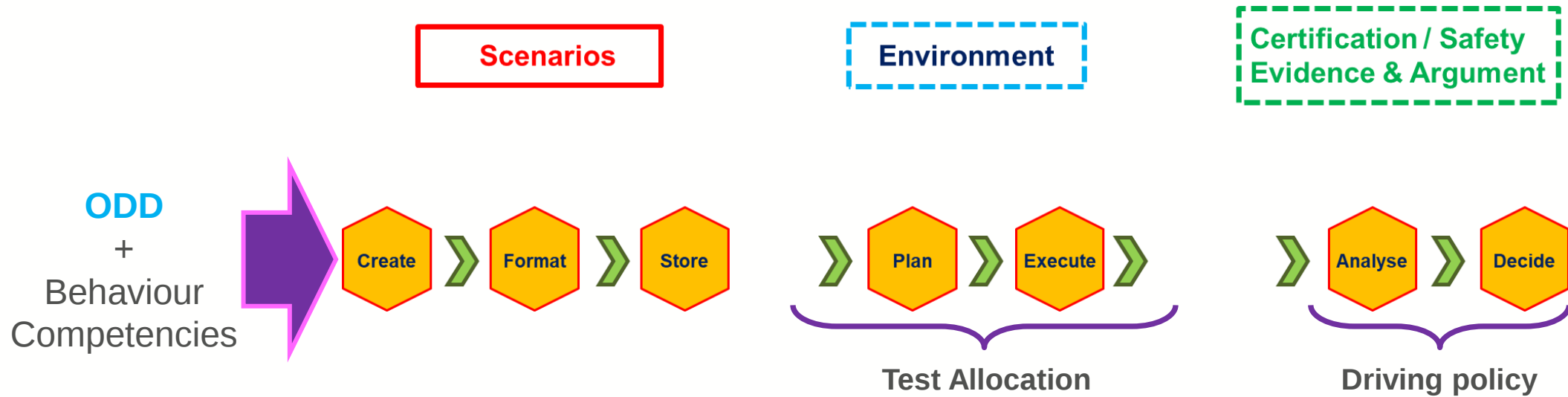


Reference: Regulation (EU) 2019/2144: EU Implementing Regulation for automated vehicles (Adopted 5 Aug 2022)

Appeal # 2

**Don't just sell / create a tool.
Enable correct usage.**

ODD based Scalable Testing Framework



Standards and Tools!

Testing Continuum

Scenarios

Environment

Certification / Safety
Evidence & Argument

Create

Format

Store

Plan

Execute

Analyse

Decide

Test Allocation

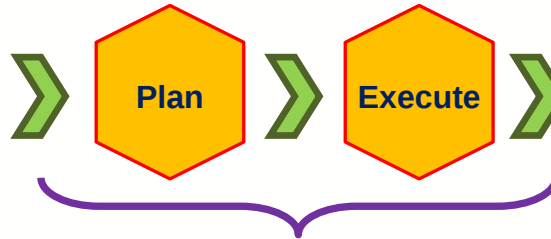
Driving policy

Testing Continuum

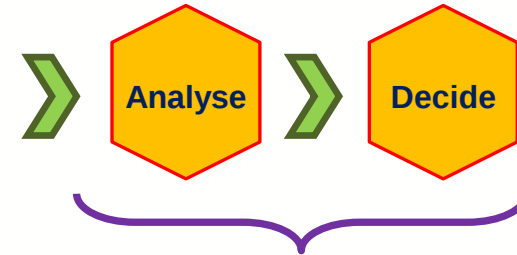
Scenarios

Environment

Certification / Safety
Evidence & Argument

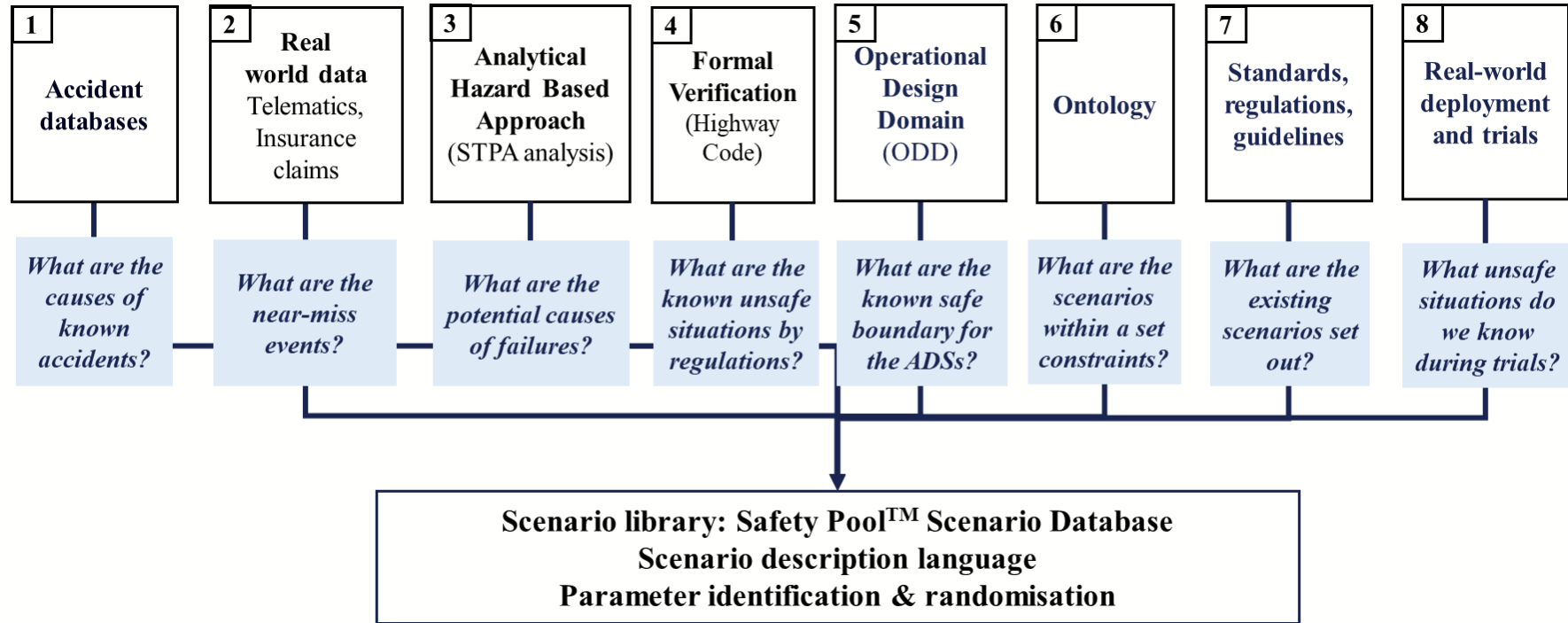


Test Allocation

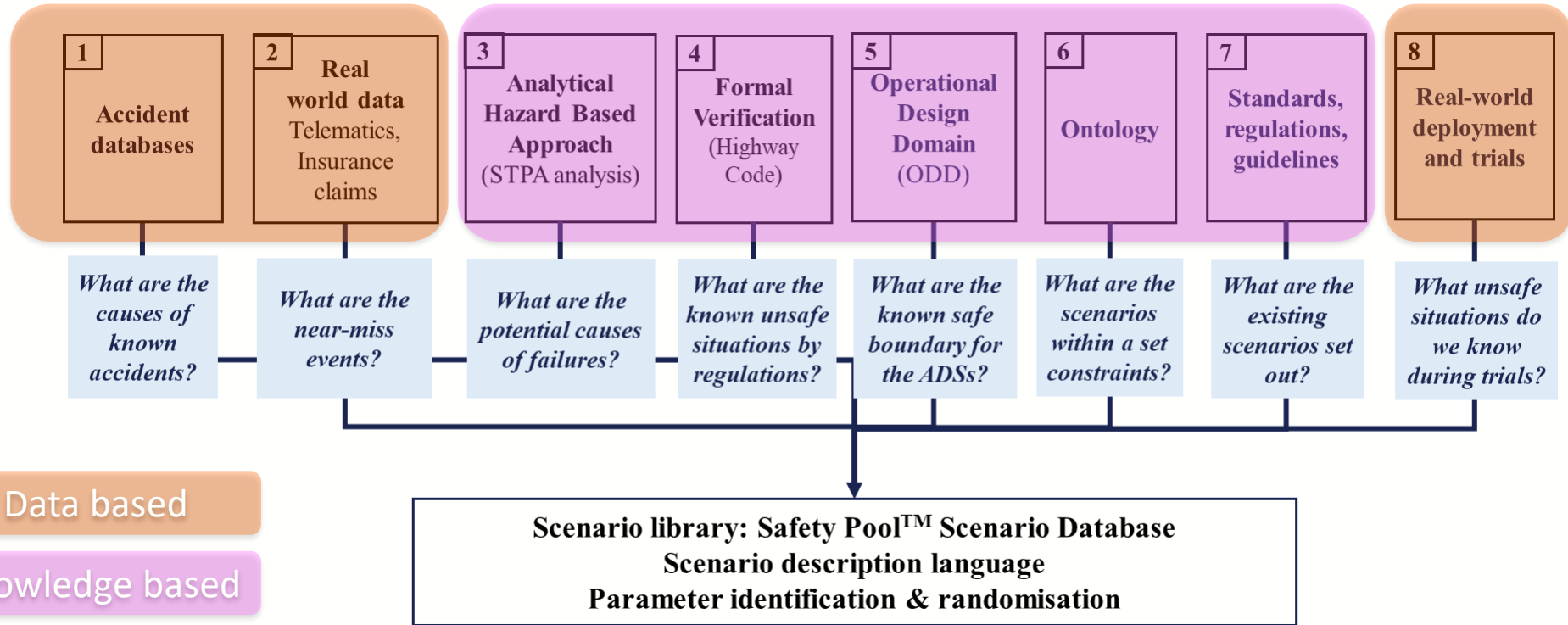


Driving policy

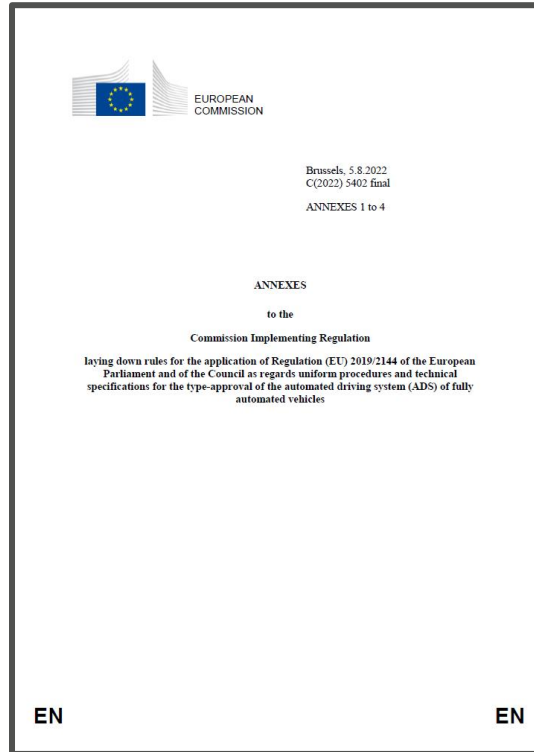
Scenarios



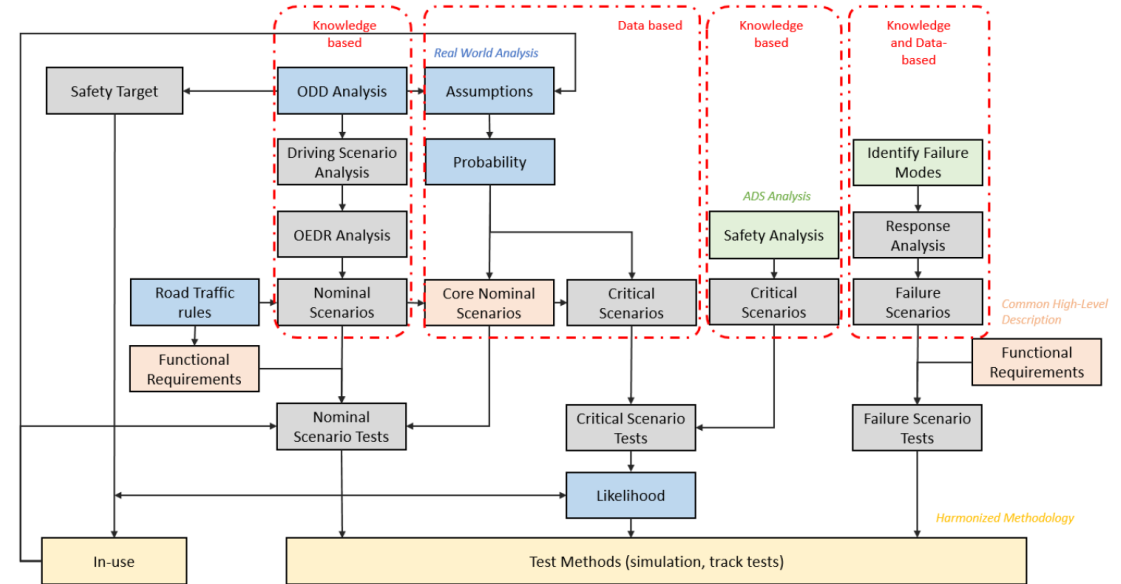
Scenarios



Scenarios



Overall Summary



EU Implementing Regulation for automated vehicles (Adopted 5 Aug 2022)

Appeal # 3

Define a detailed ODD.

Minimum ODD definition

ODD Definition 1

Motorways



ODD Definition 2

4 lane motorway,
Lane width min. 3m,
Daytime only,
Sunny days only.

Appeal # 3

Define a detailed ODD.

Testing Continuum

Scenarios

Environment

Certification / Safety
Evidence & Argument

Create

Format

Store

Plan

Execute

Analyse

Decide

Test Allocation

Driving policy

[Home](#)
[Scenarios](#)
[Libraries](#)
[Test Suites](#)
[Testbeds](#)
[Users](#)
[Roles](#)
[Settings](#)
[Audit Log](#)

Welcome

The Safety Pool Database is an extensive collection of curated test scenarios which can be used for testing connected and autonomous driving technologies.

[Learn more](#)

Safety Pool™ Scenario Database

World's Largest Public Scenario Database



File Storage

Quota used



In use: 31.9MB

Quota: 9.3GB

Quota used: 0%

License

Maximum Active Users

20

File Storage Quota

9.3GB

Agreement

[Safety Pool™ License Agreement](#)

[Home](#)
[Scenarios](#)
[Libraries](#)
[Test Suites](#)
[Testbeds](#)
[Users](#)
[Roles](#)
[Settings](#)
[Audit Log](#)

Welcome

The Safety Pool Database is an extensive collection of curated test scenarios which can be used for testing connected and autonomous driving technologies.

[Learn more](#)


Safety Pool™ Scenario Database

World's Largest Public Scenario Database

File Storage

Quota used



In use: 31.9MB

Quota: 9.3GB

Quota used: 0%

License

Maximum Active Users

20

File Storage Quota

9.3GB

Agreement

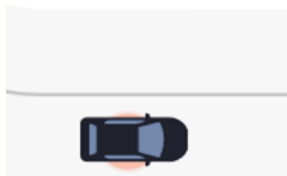
[Safety Pool™ License Agreement](#)

Over 250,000 edge case scenarios

Tokenized Scenario Exchange

An incentive-based mechanism to encourage scenario contributions, reward scenario diversity and relevance, and enable stakeholders to enlarge and enrich their test suites

Submit Scenarios to the Public section



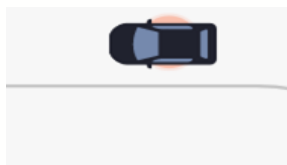
Scenarios are vetted for quality and validated



- Similarity metric
- Criticality metric
- Volume

Scenarios get scored

Spend tokens to get access to more curated scenarios



Safety Pool Tokens are poured into your account



Appeal # 4

AV Safety is pre-competitive.

Testing Continuum

Scenarios

Environment

Certification / Safety
Evidence & Argument

Create

Format

Store

Plan

Execute

Analyse

Decide

Test Allocation

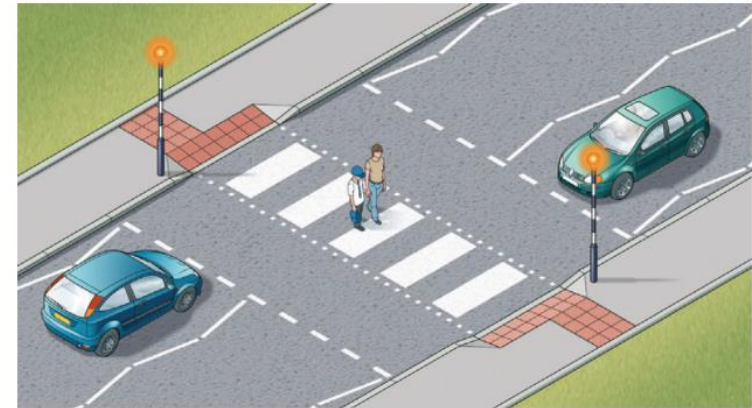
Driving policy

Rules of the Road (for human drivers)

- UK Highway code (for human drivers) rule defines:
 - Doing some behaviour somewhere
 - NOT doing some behaviour somewhere
- Doing/not doing: Behaviour competency library
- Somewhere: ODD instantiation

UK Highway Code: Rule 195

“As you approach a zebra crossing: look out for pedestrians waiting to cross and be ready to slow down or stop to let them cross; you MUST give way when a pedestrian has moved onto a crossing”



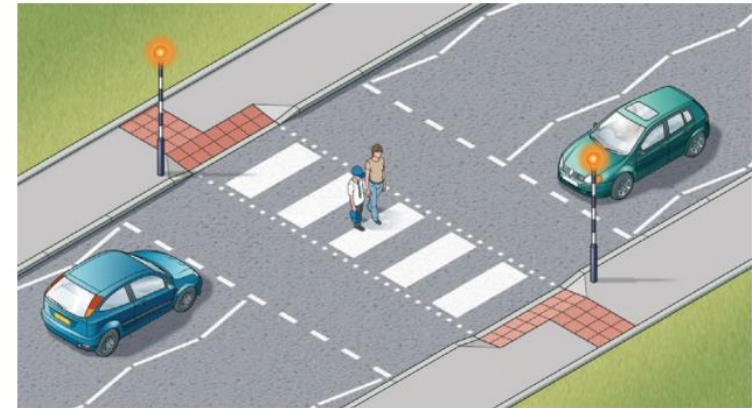
Rule 19: Zebra crossings have flashing beacons

Behaviour

ODD

UK Highway Code: Rule 195

“As you approach a zebra crossing: look out for pedestrians waiting to cross and be ready to slow down or stop to let them cross; you MUST give way when a pedestrian has moved onto a crossing”



Rule 19: Zebra crossings have flashing beacons

How long to wait?

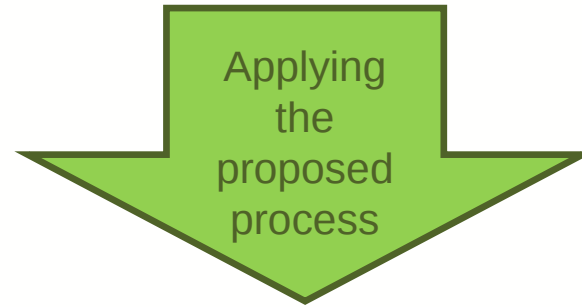
Behaviour

ODD

Assumptions

ODD based Codified Rules of the Road

*Current Rules of Road
(for human drivers)* = $f(\text{Operating condition, Behaviour competency, Assumptions})$



*Codified
Rule of the Road* = $f(\text{Operating condition, behaviour competency, driving characteristics})$

Codification of Vienna Convention Rules of Road

Chapter II

RULES OF THE ROAD

PART I

CONVENTION ON ROAD TRAFFIC

DONE AT VIENNA ON 8 NOVEMBER 1968

(Consolidated version)*

* Including the amendment to the Convention which entered into force on 3 September 1993 (marked in the margin with a single line) and the amendment which entered into force on 28 March 2006 (marked in the margin with a double line)

Codification of Vienna Convention Rules of Road

Chapter II - Rules of the Road – Article 11 (Overtaking)

ARTICLE 11

Overtaking and movement of traffic in lines

1. (a) Drivers overtaking shall do so on the side opposite to that appropriate to the direction of traffic.

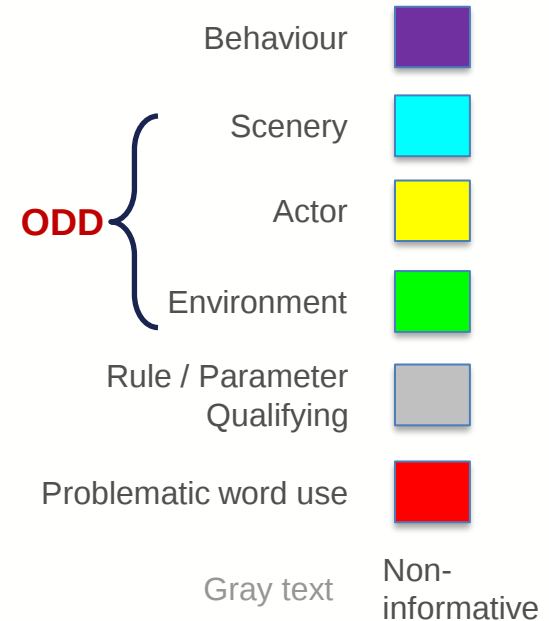
4. When overtaking, a driver shall give the road-user or road-users overtaken a sufficiently wide berth.

9. A vehicle shall not overtake another vehicle which is approaching a pedestrian crossing marked on the carriageway or signposted as such, or which is stopped immediately before the crossing, otherwise than at a speed low enough to enable it to stop immediately if a pedestrian is on the crossing. Nothing in this paragraph shall be construed as preventing Contracting Parties or subdivisions thereof from prohibiting overtaking within a prescribed distance from a pedestrian crossing, or from imposing stricter requirements on a driver of a vehicle proposing to overtake another vehicle stopped immediately before such a crossing.

Codification of Vienna Convention Rules of Road

Chapter II - Rules of the Road – Article 11 (Overtaking - 4)

When **overtaking**, a driver shall give the **road-user** or **road-users** **overtaken** a **sufficiently wide berth**.



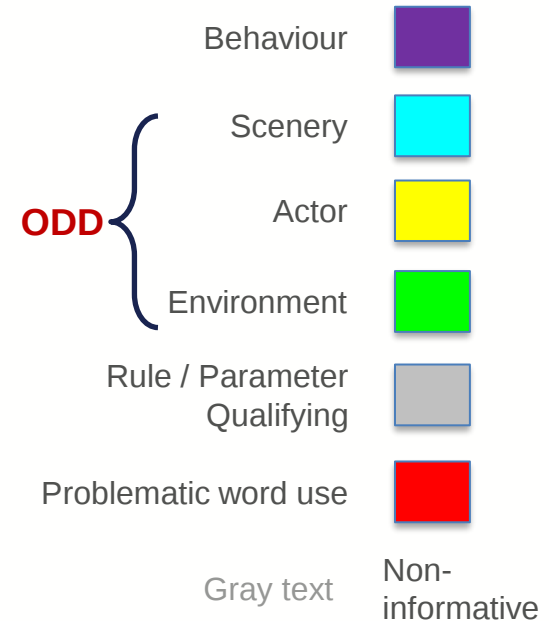
Codification of Vienna Convention Rules of Road

Chapter II - Rules of the Road – Article 11 (Overtaking - 4)

When **overtaking**, a driver shall give the **road-user** or **road-users** **overtaken** a **sufficiently wide berth**.

$\text{isVehicle}(x) \wedge \text{onRoad}(x,r) \wedge$
 $\text{roadUser}(y,r) \wedge$
 $\text{isOvertaking}(x,y) \wedge$
 $\text{lateralDistance}(x,y,z)$

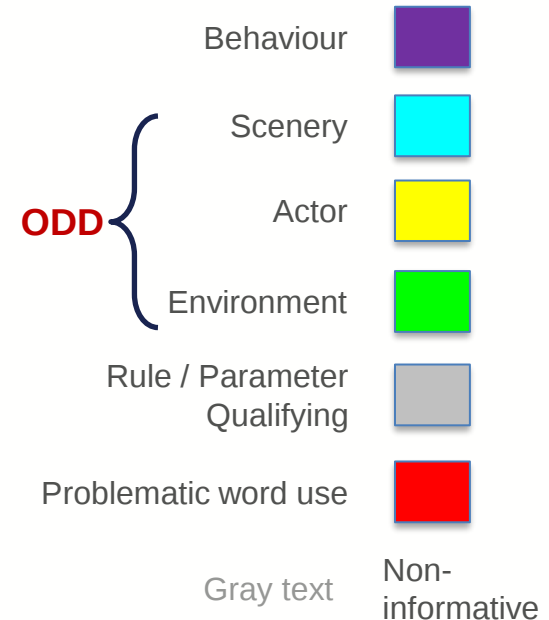
$\rightarrow \text{sufficientlyWideBerth}(z)$



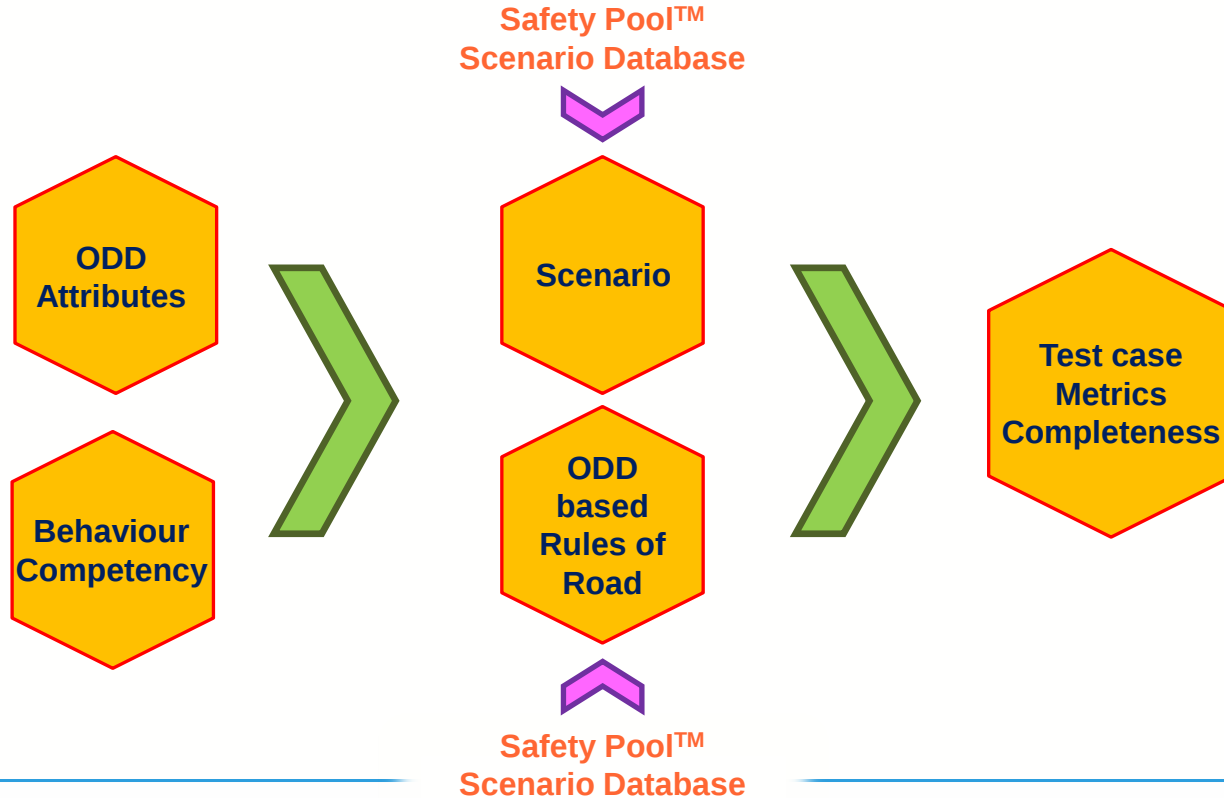
Codification of Vienna Convention Rules of Road

Chapter II - Rules of the Road – Article 11 (Overtaking - 11)

A vehicle shall not **overtake** **another vehicle** which is **approaching** a **pedestrian crossing** marked on the **carriageway** or **signposted** as such, or which is **stopped** immediately before the **crossing**, otherwise than at a **speed** low enough to enable it to **stop** immediately if a **pedestrian** is on the **crossing**.



ODD based **Scalable** Testing Framework



Testing Continuum

Scenarios

ISO 34502
UNECE VMAD SG1

ISO 34504
OpenLabel

Environment

OSI

Certification / Safety Evidence & Argument

ISO 21448, ISO TS 5083
ISO 21434, IEEE 2846

Create

Format

Store

Plan

Execute

Analyse

Decide

ISO 34503
OpenODD
BSI 1883
SAE ORAD

OpenDrive
OpenScenario 1.x, 2.0
BSI Flex 1889

Test Allocation

UNECE VMAD SG2

Driving policy

Appeal # 5

No competing standards.

Summary

Each aspect of testing framework of Automated Driving Systems (including simulation) needs to consider its relationship with ODD.

My serious, urgent, and heartfelt requests.

Appeal #1: Validated Sensor Model (only) is a MYTH!

Appeal #2: Don't just sell / create a tool. **Enable correct** usage.

Appeal #3: Define a detailed ODD.

Appeal #4: AV Safety is **pre-competitive**.

Appeal #5: No competing standards.

Success will be dependent upon suitable collaboration and data sharing, and **common understanding** nationally and internationally.



Thank you... Discussions...



@siddkhastgir

Dr Siddartha Khastgir CEng MIMechE

S.Khastgir.1@warwick.ac.uk