Distributed ODD Awareness Framework

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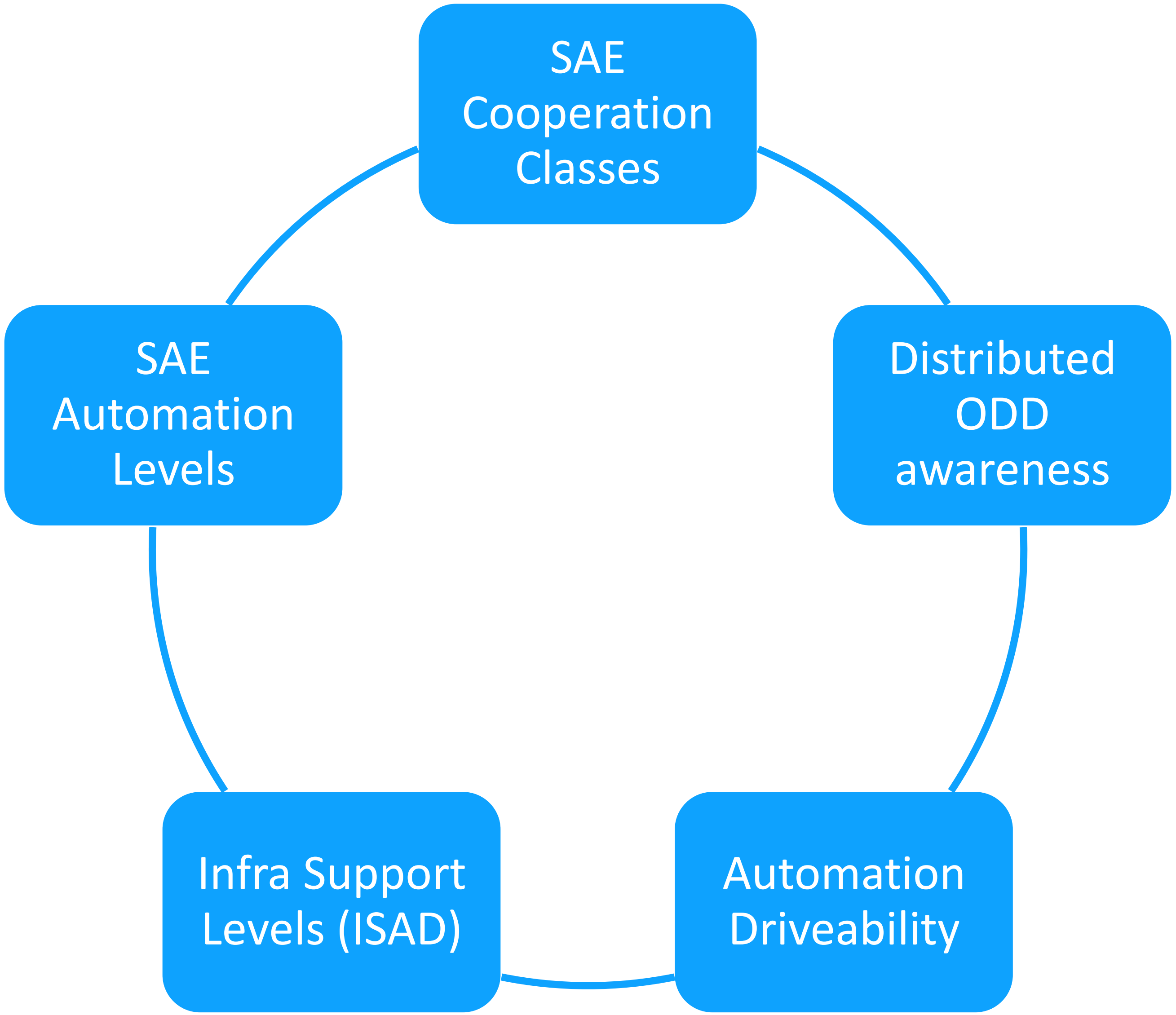
TM4CAD

- MAP traffic management (the Netherlands)
- Traficon (Finland)
- Transport & Mobility Leuven (Belgium)
- WMG, University of Warwick (UK)
- Steve Shladover (US – independent)
- Hiranao Kawashima (Japan – Keio University)

Tom

Kawashima


SAE Cooperation Classes
Distributed ODD awareness
Automation Driveability
Infra Support Levels (ISAD)
SAE Automation Levels

Levels of Automation – SAE J3016/ISO PAS 22736

Distinguishing roles of human driver and driving automation technology

- **Level 0** – Human performs entire dynamic driving task (DDT)
- Driving assistance systems:
  - **Level 1** – System performs either lateral or longitudinal vehicle motion control (ACC or lane tracking)
  - **Level 2** – System performs both lateral and longitudinal vehicle motion control under continuous driver supervision (many current products)
- Automated Driving Systems (ADS):
  - **Level 3** – System performs entire DDT under specified ODD conditions, but driver must be available to intervene when requested by system
  - **Level 4** – System performs entire DDT under specified ODD conditions, and can achieve minimal risk condition without human intervention
  - **Level 5** – System can drive under all conditions that human can (dream)

Classes of CAD Cooperation (SAE J3216)

- Cooperation may be infrastructure-vehicle (I2V/V2I), vehicle-vehicle (V2V) and may also involve vulnerable road users
- May enhance performance of a specific functionality or enable a new functionality
- **Class A**: Status sharing ("here I am and here is what I see")
  - Vehicle location, speed, acceleration; current traffic signal phase
- **Class B**: Intent- sharing ("this is what I plan to do")
  - Time to next signal phase change; desire to change lane
- **Class C**: Agreement-seeking ("let's do this together")
  - Cooperative lane change or merge maneuver
- **Class D**: Prescriptive ("Do this…" and "I will do as directed")
  - Yield to emergency vehicle; variable speed limit

Operational Design Domain (ODD)

- The combination of operating conditions under which a specific driving automation system or feature is designed to function
- Much more than just geographical location, but also including:
  - Categories of roads and their physical attributes
  - Traffic conditions (speed, density, presence of VRUs,…)
  - Weather conditions
  - Visibility constraints (lighting, obscurants such as dust, smoke, fog…)
  - Electromagnetic environment
  - Availability of localization services and digital maps of varying levels
  - Availability of other digital support services (traffic and incident information, traffic signal and VMS status, …)
  - Any other external factor that affects the ability of the system to function properly….

Importance of ODD

- At least as important as level of automation
- Defined by each CAD system developer based on their design constraints, not by any other entity
- Different for every CAD system, based on limitations of its technology
- To ensure safe operations, each CAD system must remain within its ODD constraints:
  - If ODD constraints are violated, cease automated driving
  - (Level 3) – request driver to intervene
  - (Level 4) - automatically transition to minimal risk condition (safe stop)

Need for real-time ODD awareness

- CAD system continuously monitors ODD attributes where it is operating to determine whether it can continue to operate
  - Safety cases and regulations should prohibit operations when ODD constraints are violated
- Anticipate impending ODD constraint violations to allow time for graceful transition to driver control (Level 3) or to minimal risk condition (Level 4)
- Infrastructure cooperation needed for information about attributes that CAD vehicle sensors cannot detect directly, such as:
  - Traffic incidents obstructing lanes beyond line of sight
  - Fog obstructing visibility beyond line of sight
  - Planned road works
  - Freezing pavement causing black ice

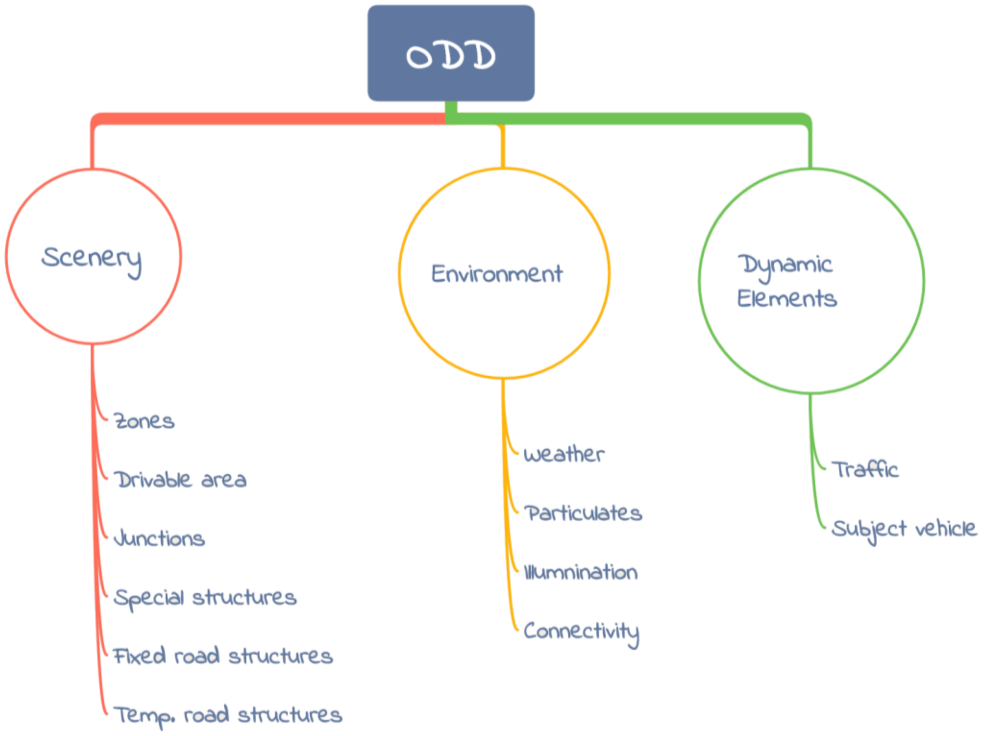
ODD Attribute Categories

- Physical attributes of the roadway and its environs
  - Quasi-static physical infrastructure
  - Road surface conditions that vary with weather conditions
- Operational attributes of the roadway (traffic management services available, traffic conditions)
- Digital information support for CAD operations
- Ambient environment attributes (weather, visibility, electromagnetic)

(These will need updates on different time scales)

Distributed ODD Awareness

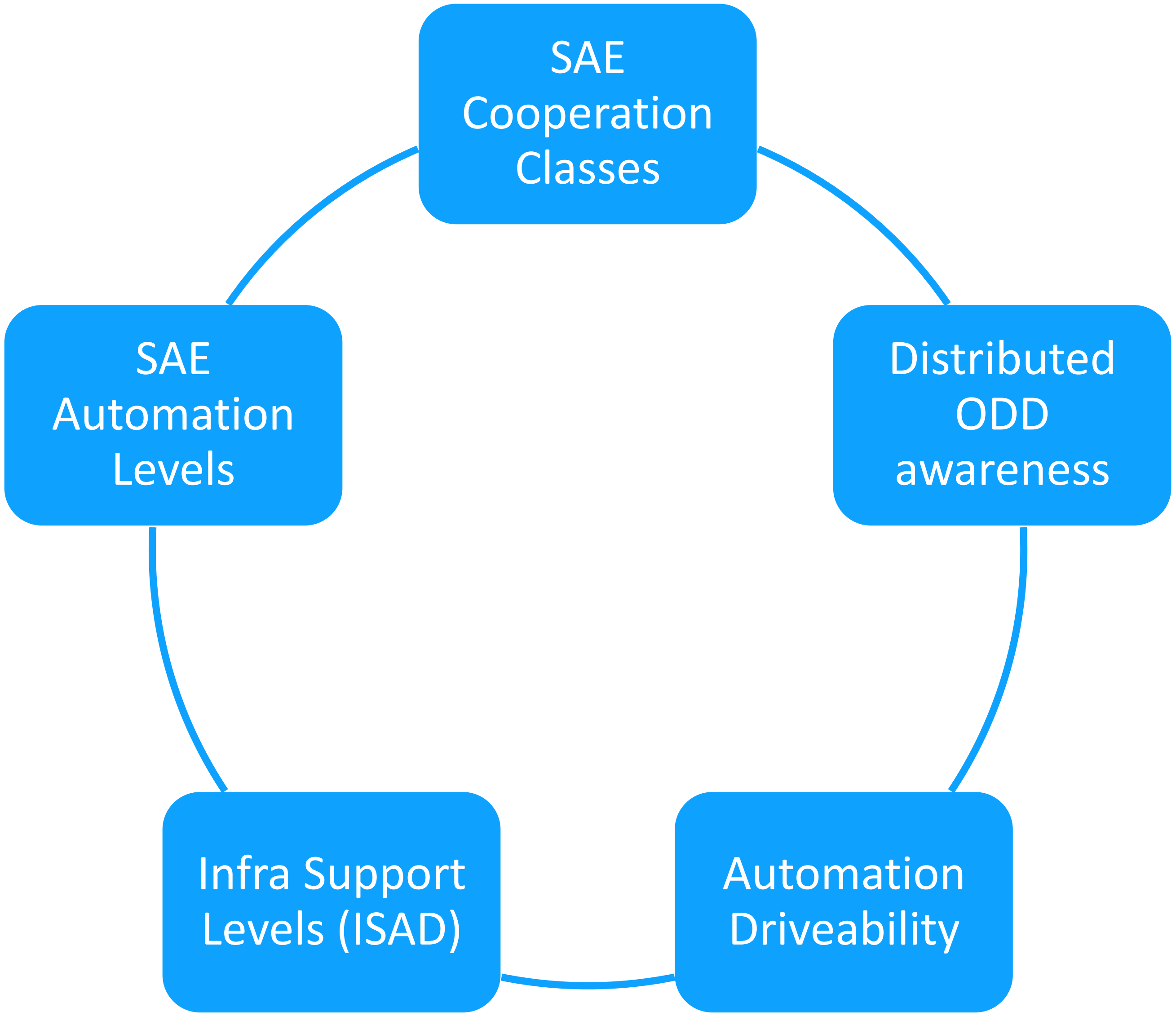
- Any ODD attribute can be measured via off-board sensing
- Every ODD attribute doesn't need to be measured via off-board sensing
- Off-board measurements will require infrastructure investment
- Connectivity implicitly becomes a requirement



Understanding information criticality

Criticality of information refresh rate will impact infrastructure investment & connectivity requirements:

- **Category 1**: Changes very seldom (e.g. road layout, intersections etc.)
- **Category 2**: Changes every (few) days (e.g. vegetation growth)
- **Category 3**: Changes every (few) hours (e.g. wet road surface)
- **Category 4**: Changes every (few) minutes (e.g. variable message signs)
- **Category 5**: Changes every (few) seconds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How do these frameworks fit together?

- First and foremost: NO infrastructure classification (scheme) is a guarantee for (SAE level) automation drivability

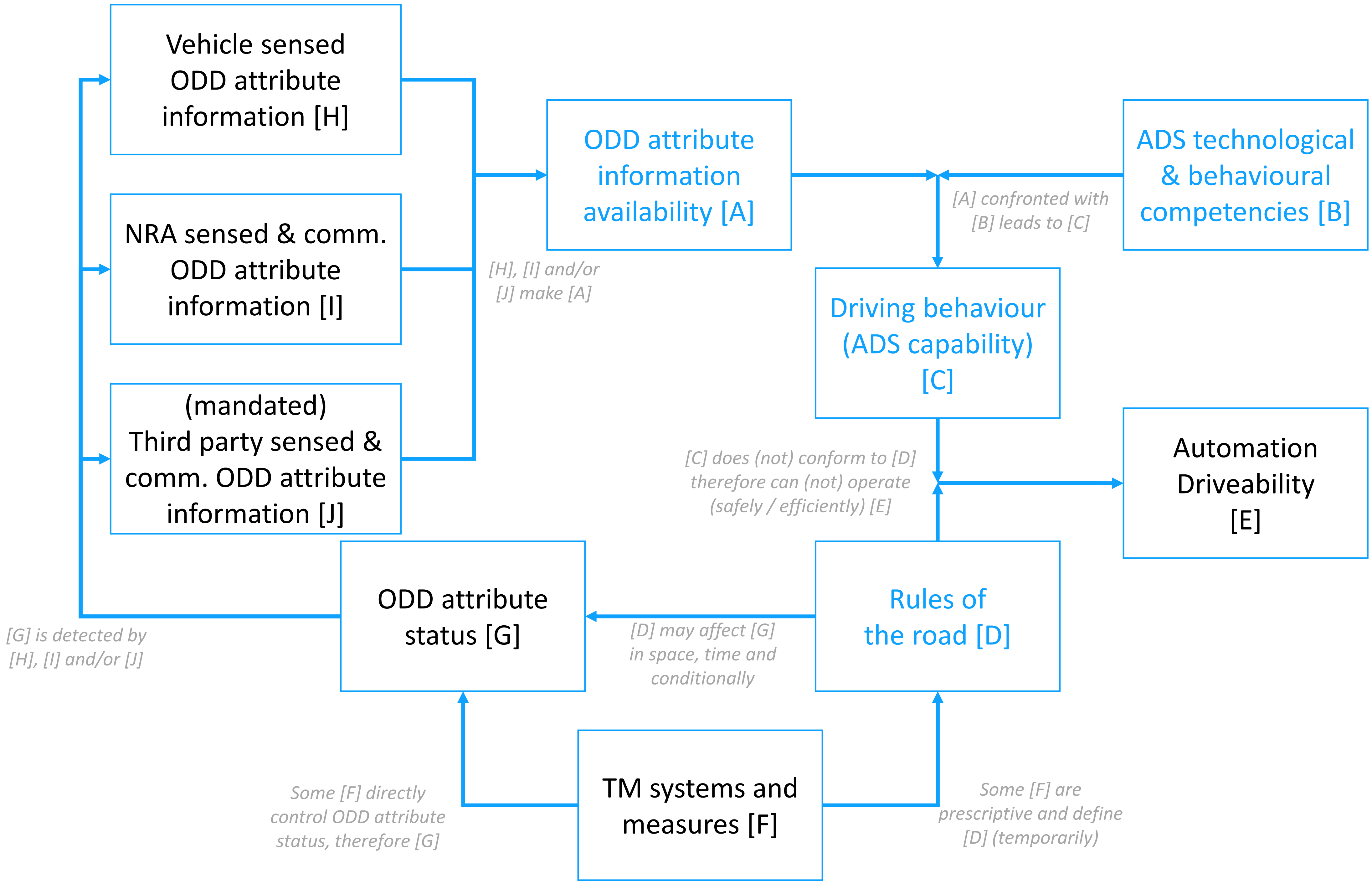
A recap:

- An ADS with a certain ODD when active monitors the condition/status of ODD attributes
- Distributed ODD awareness implies different sources have information of ODD attribute(s) condition/status
- Some ODD attributes and ODD attribute information are (exclusively) within the sphere of influence of NRAs
- Absence of (quality) ODD attribute information can be critical to an ADS, causing ODD exit leading to ToC/MRM
- ODD attribute awareness does not by itself lead to automation drivability, but the set of ODD conditions does
- Based on ODD attributes' condition/status an ADS determines if it is within its ODD and if it can/cannot operate

Think of infrastructure classification in terms of ODD attribute information availability

- Some TM measures affect ODD attributes and have regulatory implications on driving rules
- ISAD levels resemble the availability of (information provision of) different clusters of ODD attributes
- Most ODD attribute information is of CDA Cooperation Class A: Status-sharing (of ODD conditions)
- Some TM measures have planned short-term effects and/or deliver advisory non-binding information intended to suggest actions to road users, therefore are of CDA Cooperation Class B: Intent-sharing
- Some TM measures with regulatory implications are of CDA Cooperation Class D: Prescriptive

- ODD attribute information availability when projected on a road network offers a geographical road classification system which is based on ODD attributes present and their information quality
- Suggested use case focus: local conditions that occur regularly, with ODD attribute status that is infrastructure-sensed and changes frequently.



Vehicle sensed ODD attribute information [H]
NRA sensed & comm. ODD attribute information [I]
(mandated) Third party sensed & comm. ODD attribute information [J]
ODD attribute information availability [A]
[H], [I] and/or [J] make [A]
ADS technological & behavioural competencies [B]
[A] confronted with [B] leads to [C]
Driving behaviour (ADS capability) [C]
Automation Driveability [E]
[C] does (not) conform to [D] therefore can (not) operate (safely / efficiently) [E]
ODD attribute status [G]
[G] is detected by [H], [I] and/or [J]
Rules of the road [D]
[D] may affect [G] in space, time and conditionally
TM systems and measures [F]
Some [F] directly control ODD attribute status, therefore [G]
Some [F] are prescriptive and define [D] (temporarily)

Distributed ODD Awareness: Freedom of Choice

- DOA Framework can be implemented in multiple ways
- NRAs need to decide based on stakeholder needs and required investment
- Trade-off between the best setup and the most beneficial setup
- Potentially, use case driven

Implementation of the DOA framework

- Different phases of implementation and operation
  - Development – concept, planning, specifications
  - Deployment – setting it up in practice, investment
  - Operation
  - Maintenance
- Roles and responsibilities that can be related to NRAs:
  - Road operator
  - Traffic manager
  - Traffic information service provider
  - (Road works or maintenance operator)
  - (Communication infrastructure provider)
  - (Transport authority)

Roles and responsibilities

	Responsibility in DOA framework implementation			
Role	Development	Deployment	Operation	Maintenance
Road authority/ operator	Input to development	Deployment in road infrastructure and related contracts with various service contractors	Monitor the use of DOA at the infrastructure side	Report problems in use; fix problems related to own infrastructure
Traffic manager	Input to development	Deployment at TMC and roadside systems and related contracts with various service contractors	Use of DOA in traffic management	Report problems in use; fix problems related to own services, systems and infrastructure
Traffic information service provider	Input to development	Deployment in service portfolio and service adaptation	Provision of services facilitating DOA	Report problems in use; fix problems related to own services
Road works or maintenance operator	-	Adaptation of processes	Provision of real-time data related to DOA	Report problems in use; fix problems related to own operations
Communication infra-structure provider	Input to development	Adaptation of communication network capacity if and where needed	Operate the communications networks	Fix problems in own services and infrastructure
Transport authority	Input to development	Regulate the deployment if necessary	Monitor the status of DOA operation	Monitor the status of DOA maintenance

Traffic Management for Connected and Automated Driving

TM4CAD

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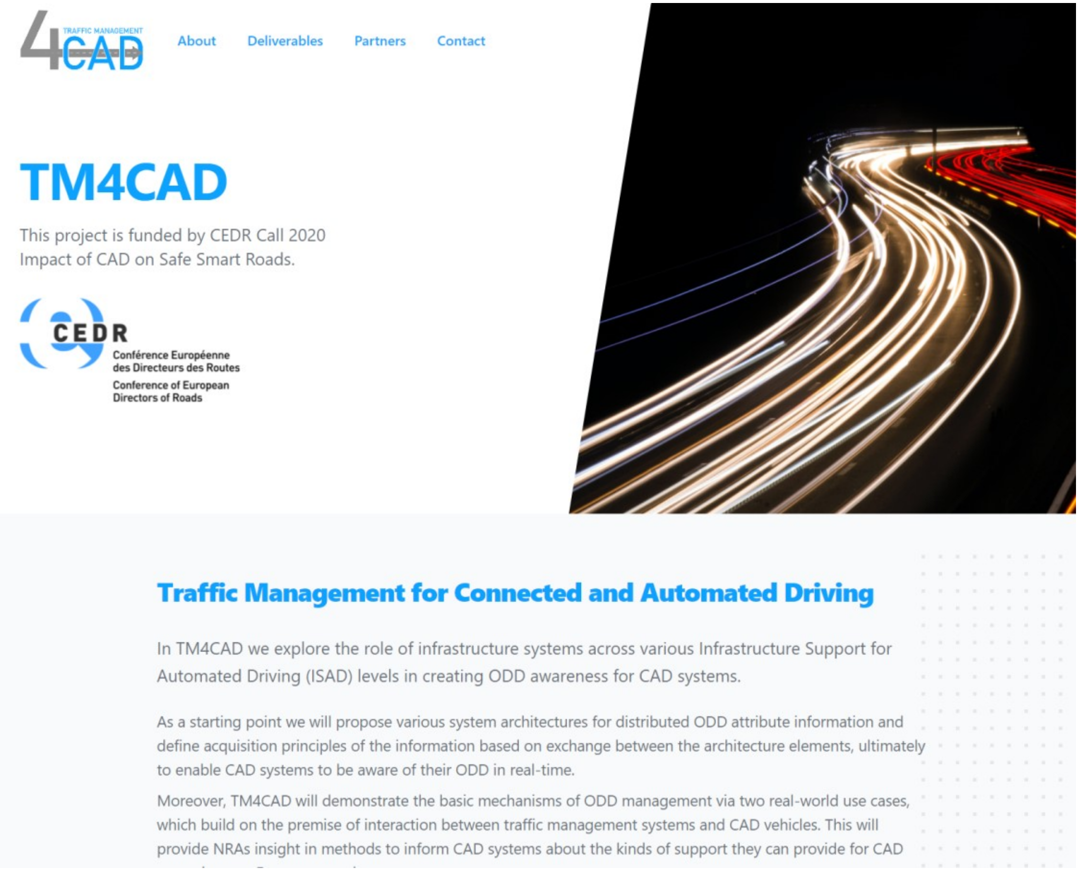

MAP TRAFFIC MANAGEMENT

TRAFICON

TRANSPORT & MOBILITY LEUVEN

WMG THE UNIVERSITY OF WARWICK