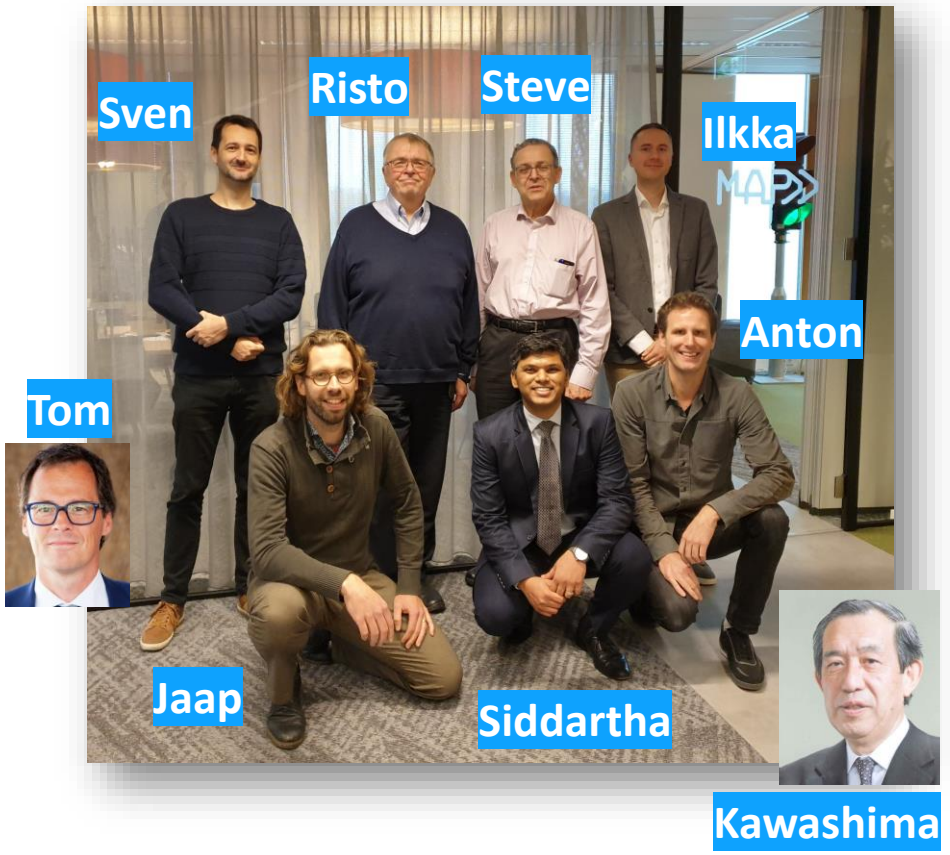
Traffic Management for Connected and Automated Driving (TM4CAD)

Workshop: ODD-ISAD architecture and NRA governance structure to ensure ODD compatibility

14th February 2022, 14:00 – 17:00 CET, Online MS Teams

Welcome

- 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)



Workshop objectives

1. Understand basic concepts and define common terminology associated with ODD definition
2. Present Distributed ODD Awareness (DOA) concept and relationship to ISAD
3. Discuss and validate results from the first work-package of the TM4CAD project

Target audience: (national) road authorities who are active in the field of vehicle automation, connectivity, traffic management and infrastructure readiness. Feel free to forward the invitation.

House rules:

- During presentations…well you know the drill by now
- Use the chat to post questions and comments
- Use the ‘raise hand’ feature if you want to speak
- During interactive part: camera on!

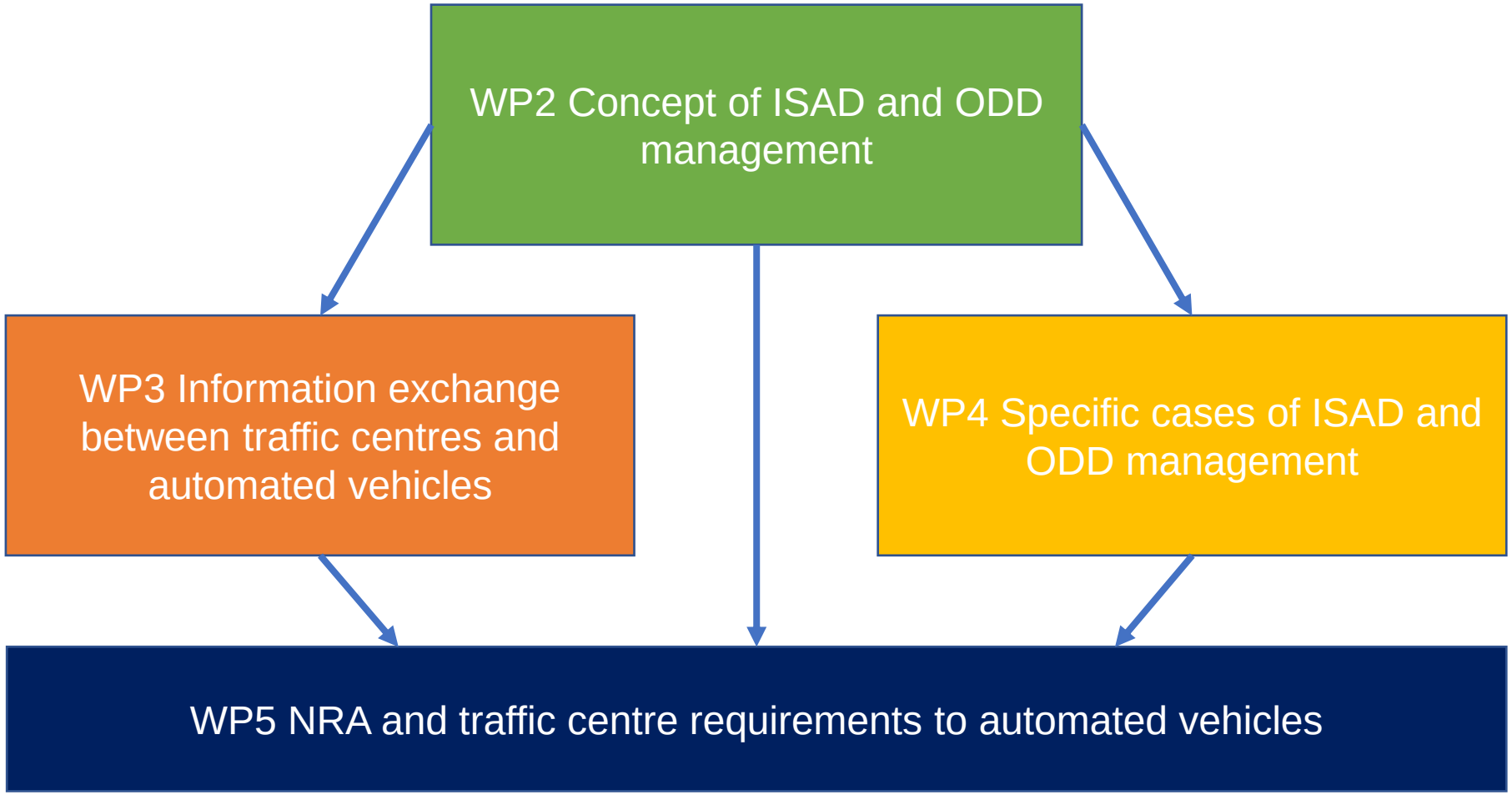
Agenda

14:00	Welcome, introduction to TM4CAD and research questions	Jaap Vreeswijk (MAPtm)
14:15	Basic concepts and terminology	Steve Shladover (independent)
14:35	Interactive part 1: what did you learn from the presentation, what thoughts and expectations do you have on the subject matter and what else would you like to learn at this workshop?	Ilkka Kotilainen (Traficon)
15:05	Distributed ODD Awareness (DOA) framework	Siddartha Khastgir (Warwick University)
15:25	10-min break	
15:35	Interactive part 2: how do NRAs understand the DOA framework?	Tom Alkim (MAPtm)
16:05	Translating DOA framework to ISAD and NRA roles & responsibilities	Risto Kulmala (Traficon) Jaap Vreeswijk (MAPtm)
16:25	Interactive part 3: are your expectations met and / or what is still unclear?	Sven Maerivoet (TML)
16:55	Conclusions	Jaap Vreeswijk (MAPtm)
17:00	End	

About TM4CAD – Expected results

- The project is funded by CEDR Call 2020 Impact of CAD on Safe Smart Roads
- Start: 13 September 2021 | End: 12 March 2023 (18 months)
- 7 workshops and 4 deliverables

- Identify the full range of **ODD attributes** for consideration, based on experience from working on ODD issues in standardization activities and in other related research projects;
- Integrate the very different perspectives of the CAD vehicle system developers and the road authorities and operators to **focus on the areas of intersection** between them;
- Introduce the concept of **ODD attribute awareness** and the role of infrastructure in it;
- Develop recommendations based on understanding the technical constraints on the ODD-relevant **information that can be perceived and exchanged in real time** by the NRAs and the sensing systems on the CAD-equipped vehicles;
- Provide insights on how to support CAD operation and ODD management, and **how ISAD should be refined** for traffic management use, and
- Detail how traffic management systems and CAD vehicles can **best interact** to improve traffic operations.


WP2 Concept of ISAD and ODD management
WP3 Information exchange between traffic centres and automated vehicles
WP4 Specific cases of ISAD and ODD management
WP5 NRA and traffic centre requirements to automated vehicles

TM4CAD Objectives – CEDR Research Questions

- **RQ1**: Should NRAs set requirements on the **desired behaviour of (partly) automated vehicles** on where and how they should drive?
- **RQ2**: Do brokers between traffic management centres and vehicles/OEM back ends add value in this interaction?
- **RQ3**: **How does CCAM support** the work of traffic management centres and **how can traffic management centres support** and facilitate the deployment of CCAM?
- **RQ4**: What kind of **information is to be transmitted** in the interaction (in both directions) between a traffic management centre and vehicle?
- **RQ5**: Which information is to be provided **by the NRA/roadside** and which information can be obtained by the sensors of the moving vehicle itself?
- **RQ6**: When and how should such information be available?
- **RQ7**: How to define and measure the **quality/correctness** of such information?

Traffic Management for Connected and Automated Driving (TM4CAD)

Basic Concepts and Terminology

Steve Shladover

Basic Concepts and Terminology

- Levels of automation
- Classes of cooperation in CAD systems
- Operational Design Domain (ODD)
- Importance of ODD and real-time ODD awareness
- Examples of needed ODD attributes

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)

Traffic Management for Connected and Automated Driving (TM4CAD)

Interactive Part 1

Ilkka Kotilainen

Interactive part 1

Questions about objective 1:

- What did you learn from the presentation?
- What thoughts and expectations do you have on defining common ODD definition language?

Question about all objectives:

- What expectations, and what else would you like to learn, at this workshop?

Workshop objectives

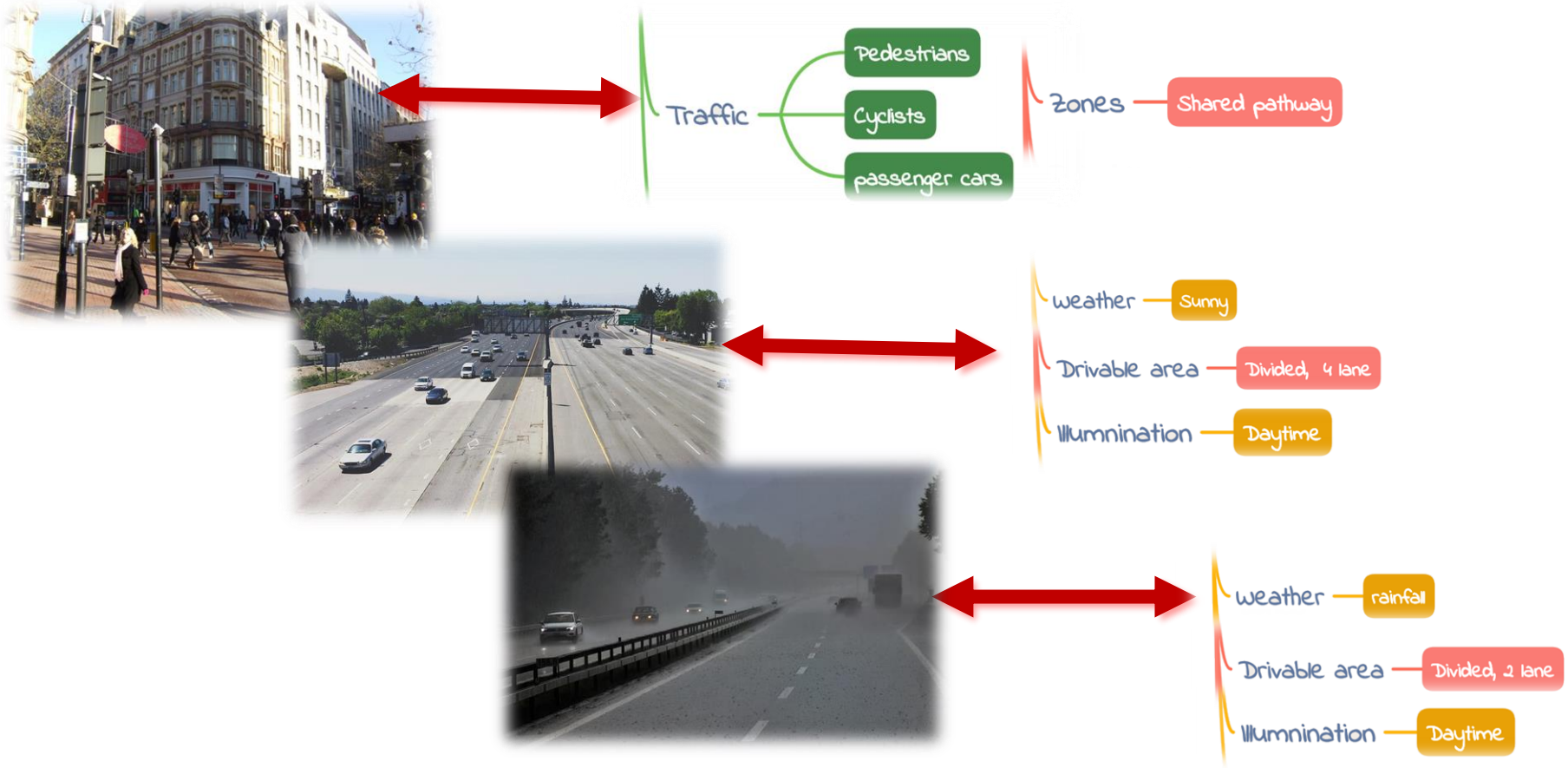
1. Understand basic concepts and define common terminology associated with ODD definition
2. Present Distributed ODD Awareness (DOA) concept and relationship to ISAD
3. Discuss and validate results from the first work-package of the TM4CAD project

Traffic Management for Connected and Automated Driving (TM4CAD)

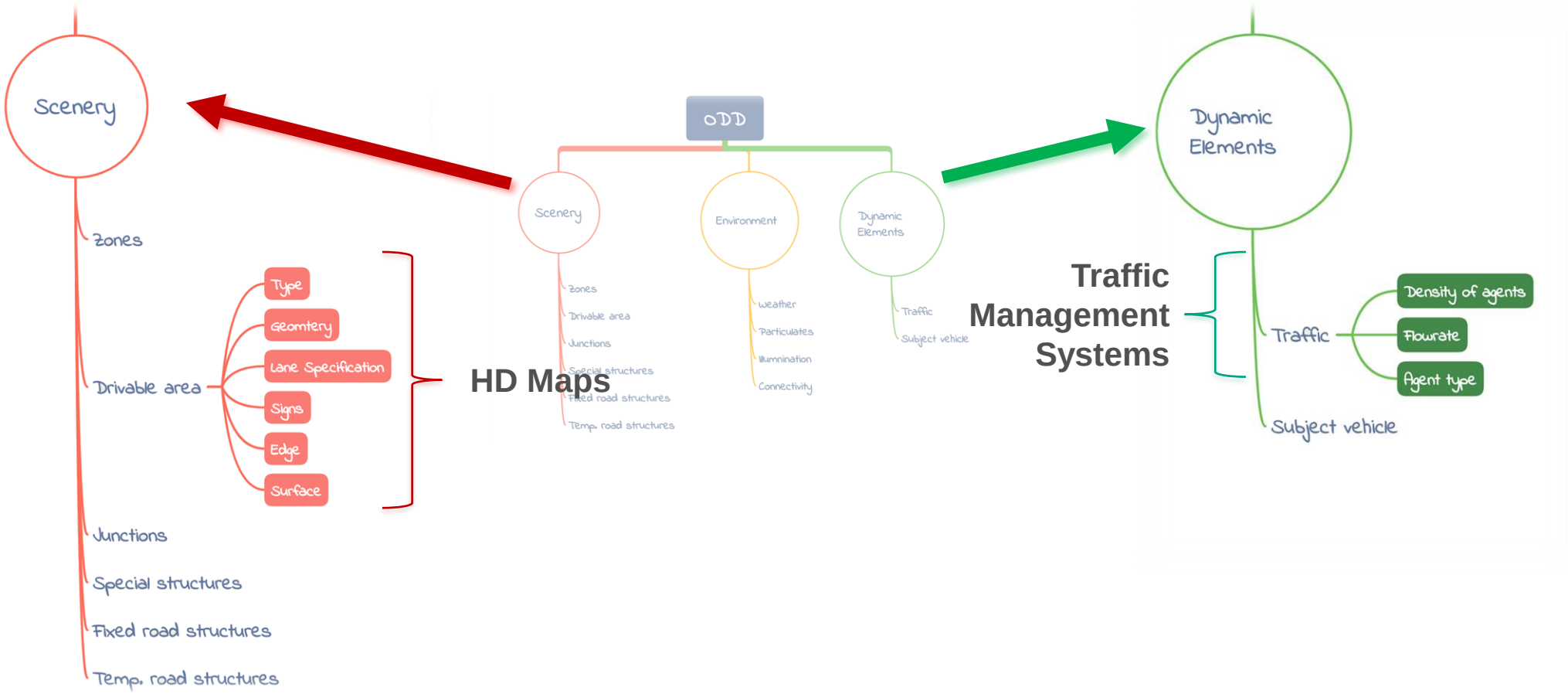
Distributed ODD Awareness (DOA) framework

Siddartha Khastgir

Distributed ODD Awareness



Distributed ODD Awareness

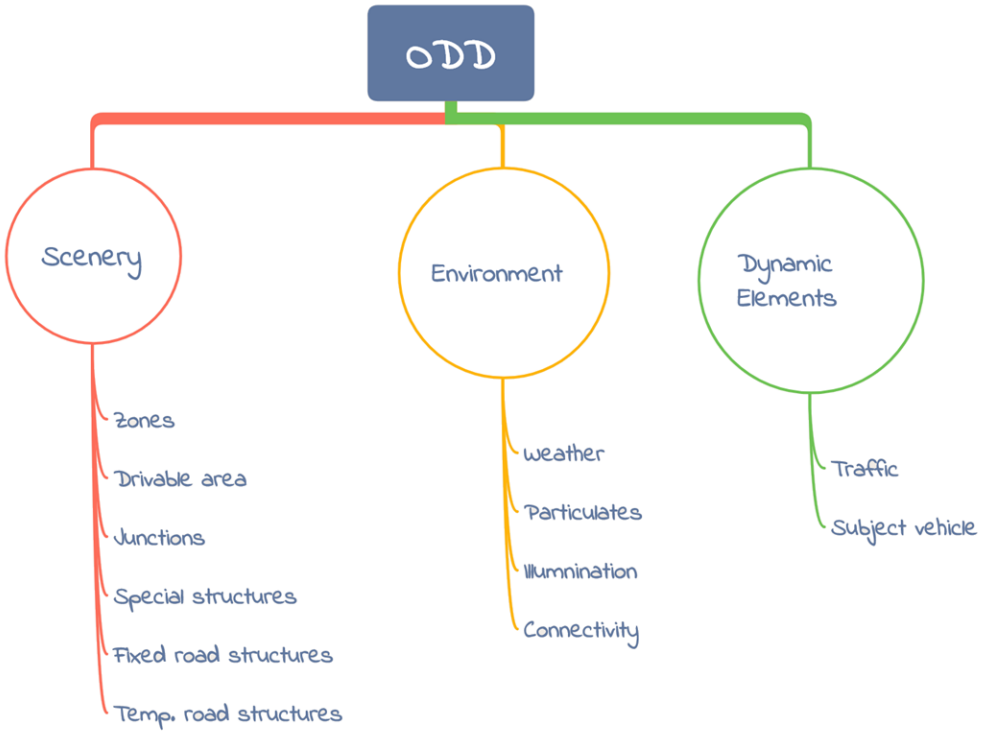


Distributed ODD Awareness - Rainfall

- What does rainfall rate mean?
- How do we measure rainfall rate?
- How do we address local variability issues?
- Can the CAD system measure it **via on-board sensing only?**

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

Distributed ODD Awareness: Freedom of Choice

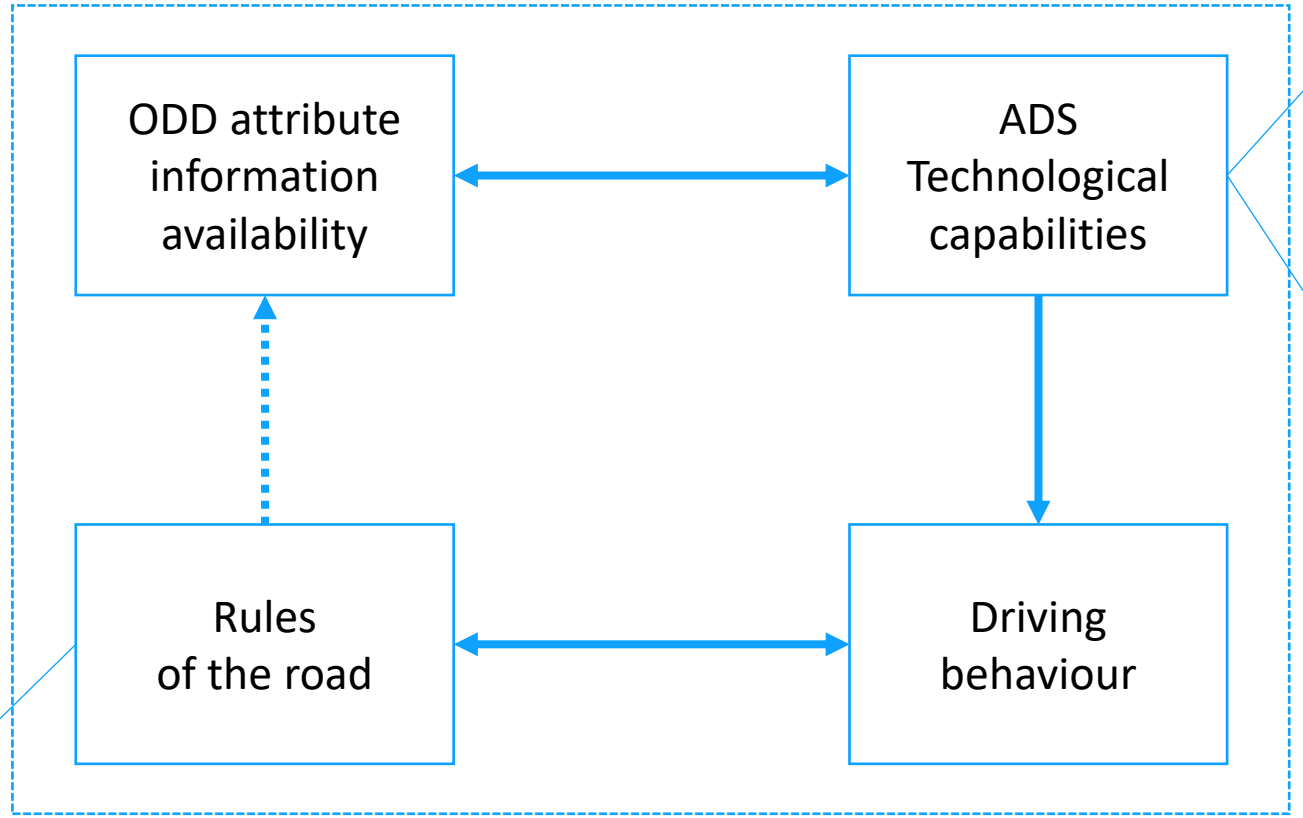
- DOA Framework can be implemented in multiple ways
- NRAs need to decide based on stakeholder needs and required investment
- Trade-off between the best setup and the most beneficial setup
- Potentially, use case driven

Distributed ODD Awareness: CAD Safety Assurance

Sources of information:

- *Maps*
- *Vehicle sensors*
- *Roadside equipment*
- *Traffic centres*
- *Digital twin*
- *…*

Redundant | Exclusive



"Wide diversity"

"Behaviour competencies"

"Codified"

ADS can or cannot operate

Traffic Management for Connected and Automated Driving (TM4CAD)

Interactive Part 2

Tom Alkim

Interactive part 2

Questions about objective 2:

- What did you learn from the presentation?
- What thoughts and expectations do you have on Distributed ODD Awareness (DOA)?
- Road Operators do not make automated vehicles, but they can make it happen. How and at what cost?

Workshop objectives

1. Define common ODD definition language
2. Present Distributed ODD Awareness (DOA) concept and relationship to ISAD
3. Discuss and validate results from the first work-package of the TM4CAD project

Traffic Management for Connected and Automated Driving (TM4CAD)

Translating DOA framework to ISAD and NRA roles & responsibilities

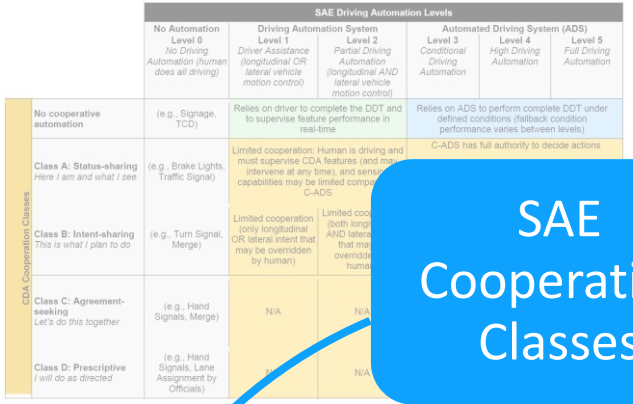
Risto Kulmala and Jaap Vreeswijk

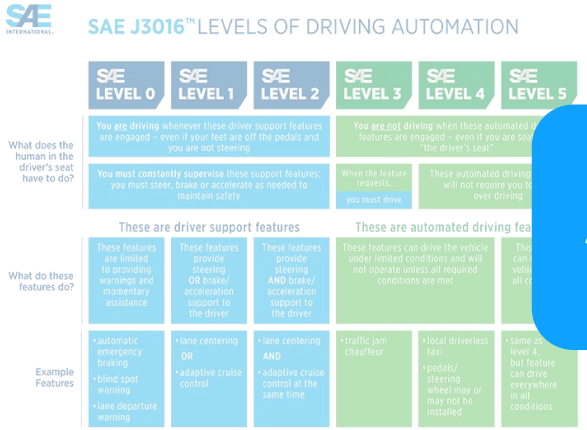
Cooperative Driving Automation (CDA)

SAE J3216

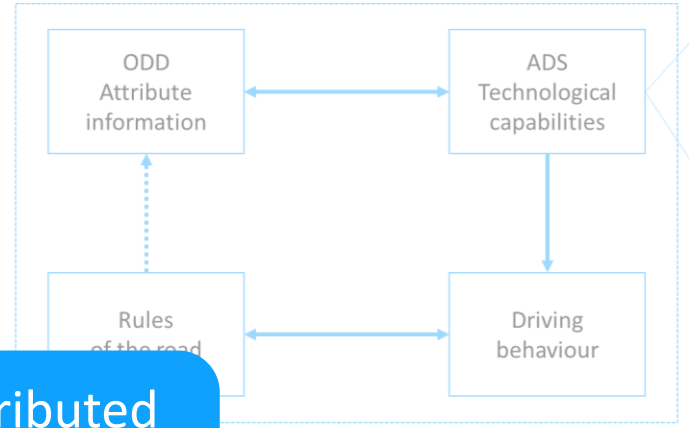
CDA Cooperation Class	CDA Feature Level of Functionality Enhancement	
	Supporting	**Enabling**
Class A: Status-sharing *Here I am and what I see*	Enhanced functionality: Localization, world modeling, perception	New function: Anticipate lane drop, see occluded object, expand ODD
Class B: Intent-sharing *This is what I plan to do*	Enhanced functionality: e.g., higher fidelity mapping of future states	New function: Predictive intersection arrival and departure, lane change
Class C: Agreement-seeking *Let's do this together*	N/A	New function: Coordinated intersection arrival and departure, coordinated merge, join platoon
Class D: Prescriptive *I will do as directed*	N/A	New function: Traffic authorities can direct operations and management to improve safety and operations
		New function: Vehicle directed remotely by fleet operations center to resolve operation issue or achieve safe state in the event of incident occurrence

Level	ISAD Level Interpretation from NRA perspective (FTIA 2021)			
	Physical infrastructure	Digital infrastructure	Environmental conditions	Dynamic elements
D	Infrastructure easily perceived and identified by AVs	Digital map data (incl. static road signs) complemented by physical reference points; Traffic lights, short-term roadworks and VMSs have to be recognised by AVs on their own	Historic information on environmental conditions available in machine readable format	Traffic management measures and plans provided in a way correctly perceived by AVs, self-diagnostic TMC hardware
C	Enhanced physical infrastructure for AVs with regard to improved infrastructure maintenance	All static and dynamic information can be provided to the AVs in digital form; AVs receive infrastructure support data	Infrastructure-based weather information available	Dynamic traffic and incident management including connectivity, self-healing TMC hardware
B	Improved physical infrastructure for AVs with regard to MRMs	Infrastructure is capable of perceiving microscopic traffic situations; AVs receive infrastructure support data in real time	Detailed cooperative weather information (V2I): obtained via processing and sharing perception sensor findings by vehicles present on the particular road segment and infrastructure-based information	Enhanced dynamic traffic and incident management, self-learning TMC hardware
A	Improved physical infra-structure for AVs related to positioning support and vehicle supervision	Infrastructure is capable of perceiving vehicle trajectories and coordinate single AVs and AV groups; Infrastructure helps to coordinate vehicle manoeuvres to optimise traffic flow	Individual trajectory recommendation available taking into account the prevailing environmental conditions	Local traffic management arrangement provision for AVs, self-management TMC systems



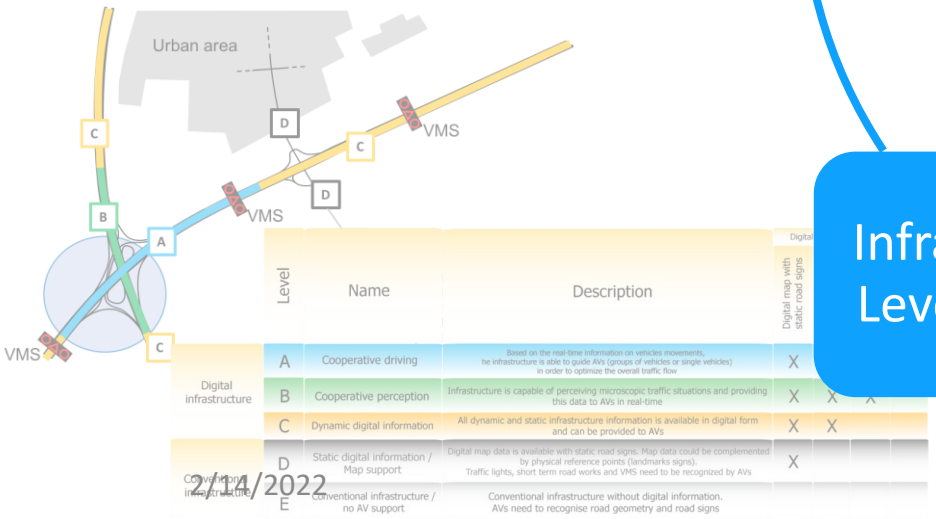


SAE Cooperation Classes



SAE Automation Levels

Distributed ODD awareness



Infra Support Levels (ISAD)

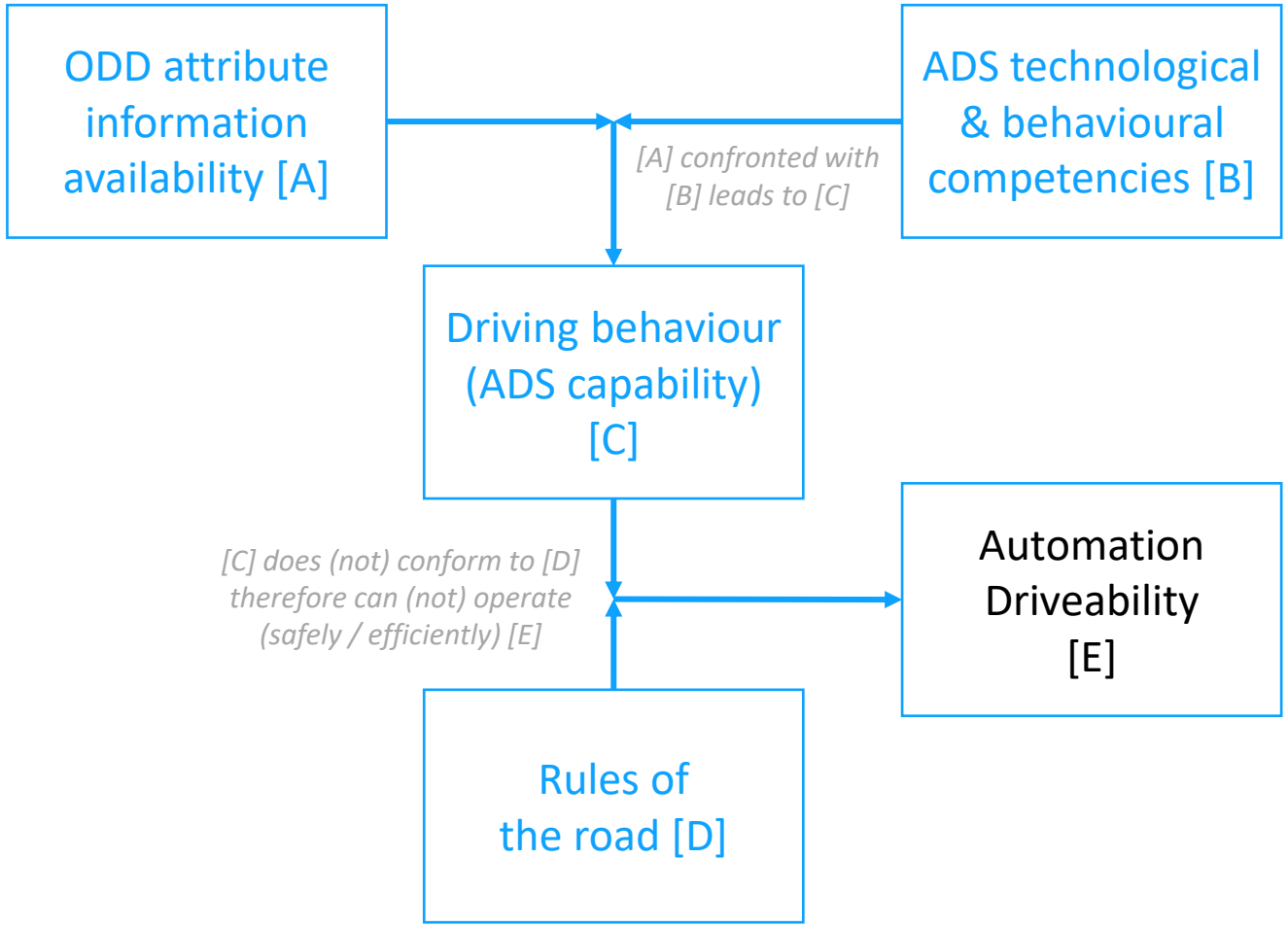
Automation Driveability

How do these frameworks fit together?

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

A recap:

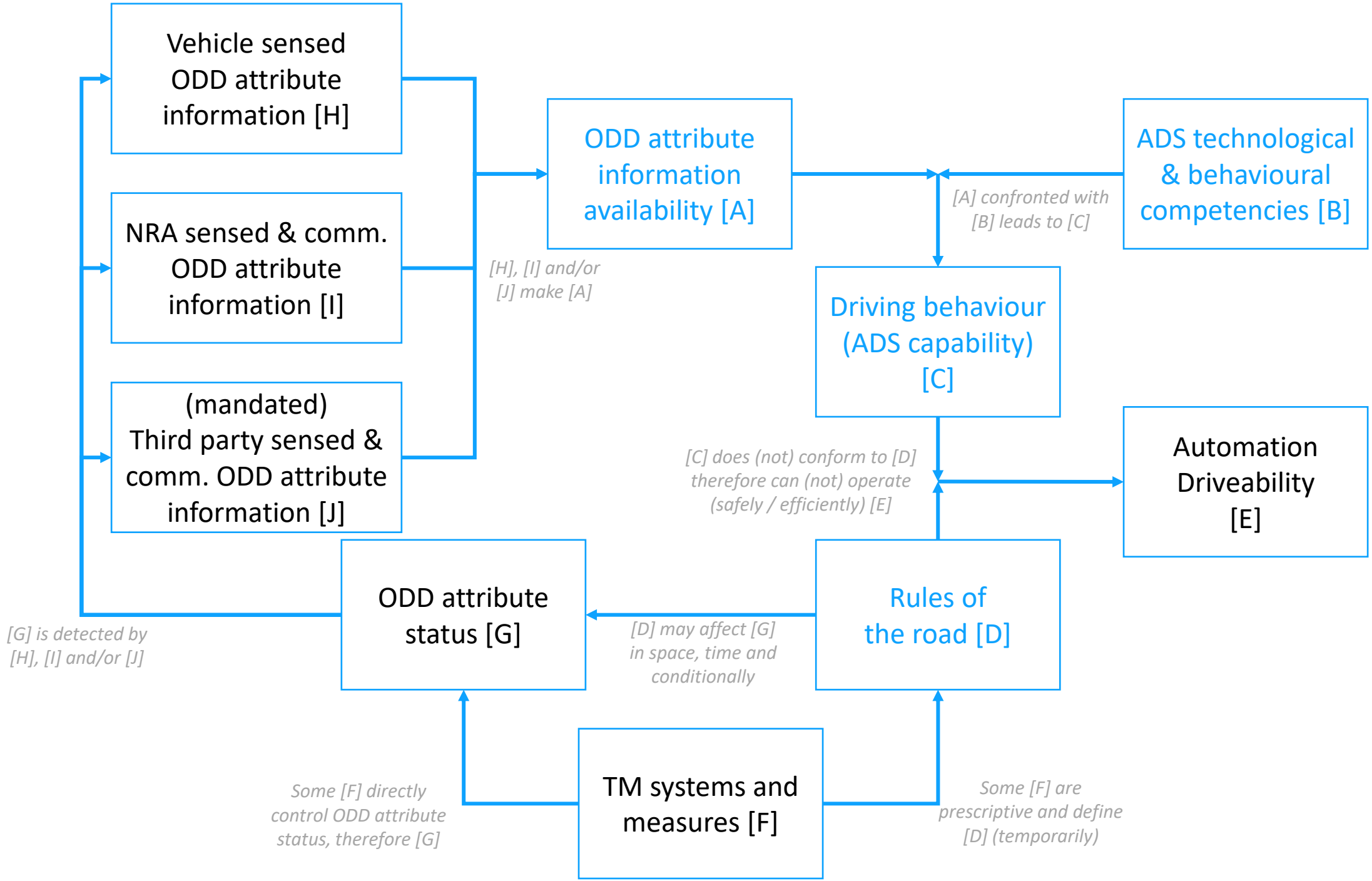
- An ADS with a certain ODD when active monitors the condition/status of ODD attributes
- Distributed ODD awareness implies different sources have information of ODD attribute(s) condition/status
- Some ODD attributes and ODD attribute information are (exclusively) within the sphere of influence of NRAs
- 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


ODD attribute information availability [A]
ADS technological & behavioural competencies [B]
[A] confronted with [B] leads to [C]
Driving behaviour (ADS capability) [C]
[C] does (not) conform to [D] therefore can (not) operate (safely / efficiently) [E]
Automation Driveability [E]
Rules of the road [D]

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

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 of various stakeholders, CEDR members:
  - 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)

Interactive Part 3

Sven Maerivoet

Background: research questions

- **RQ1**: Should NRAs set requirements on the **desired behaviour of (partly) automated vehicles** on where and how they should drive?
- **RQ4**: What kind of **information is to be transmitted** in the interaction (in both directions) between a traffic management centre and vehicle?
- **RQ5**: Which information is to be provided **by the NRA/roadside** and which information can be obtained by the sensors of the moving vehicle itself?

- ***RQ3**: **How does CCAM support** the work of traffic management centres and **how can traffic management centres support** and facilitate the deployment of CCAM?*

- ***RQ2**: Do brokers between traffic management centres and vehicles/OEM back ends add value in this interaction?*

Your thoughts were among the following…

- **Levels of automated driving:**
  - **L3 allowance** → define requirements on safety of implementation
  - **ToC for L4** → driver takeover is an option, not a requirement
  - Dealing with **different levels of vehicle technology** → which sections of the road network will be feasible for a vehicle's abilities?
  - **Different NRAs' requirements** → cross-border compatibility

- **'Taken care of':**
  - **Safety** → regulated by having all ODD conditions satisfied
  - **V2V**, e.g. platooning → not ODD-related but rather about compatibility with other (nearby) vehicles

Your thoughts were among the following…

- **Flow of information:**
  - NRA needs info '**on the double**' (accidents, queues, etc.) → NRA has freedom of choice
  - **MRM initiation** → interesting information to have by the NRAs for TM purposes, BUT standards are not well-enough developed/adopted yet

- **Time/information criticality:**
  - **Alignment with OEMs** (cf. NRA supporting ALKS) → NRA needs to know which information categerories required to support a certain ADAS?
  - ⇔ **NRA perspective**: start from different digital layers → put time criticality on top of these (focus mainly on NRAs, less on OEMs)

All that information…

- Could you fully understand and follow our explanations/questions?
  - Yes, absolutely, I got it!
  - (Part of) it was new to me.
  - I thought I did, but I have to rethink now.
  - Well, actually, I have a different point of view.

- Do you think we missed an important step or piece of information?

Please, be **concise** in your answers.

Your general impressions after all this?

- ODD / ISAD / Distributed ODD awareness (DOA) / ODD attributes
- NRA roles and responsibilities, differentiated between:
  - road authority / operator
  - ⇔ traffic manager
  - ⇔ traffic information service provider
  - ⇔ road works or maintenance operator
  - ⇔ communication infrastructure provider
  - ⇔ transport authority
- What about the OEMs? How to interact with them (operational, legal)?

Traffic Management for Connected and Automated Driving

TM4CAD

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