Driving Automated Vehicles in Complex Conditions

Bart van Arem

Keynote Presentation 7th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS) &
10th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS), 28-30 April 2021

TU Delft

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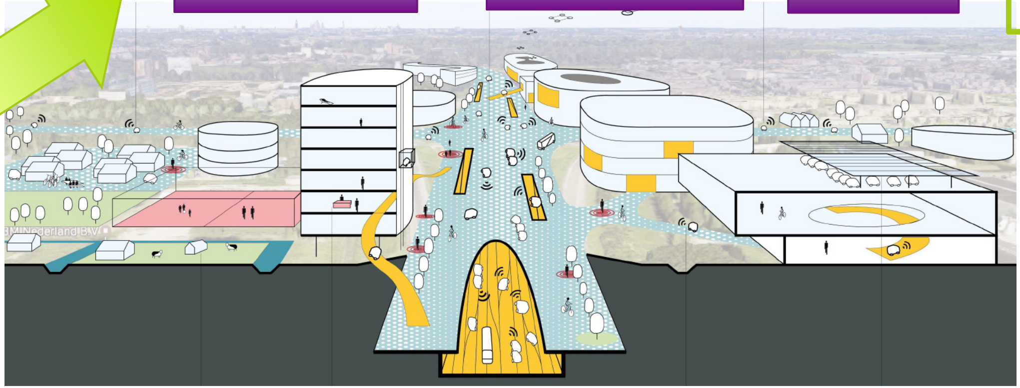
EiC IEEE Open Journal of Intelligent Transportation Systems

connected | electric | fair | safe

automated | sustainable | shared



empirics ↔ modeling

individual ↔ collective

2009

Full professor (0,4) Driver Assistance Systems University of Twente

2003

TNO, Researcher and program manager Intelligent Transport Systems

1991

PhD Queueing Models for communication systems University of Twente

1986

BSc+MSc Applied Mathematics University of Twente

1982

Spatial and Transport Impacts of Automated Driving

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Staying safe and sound!

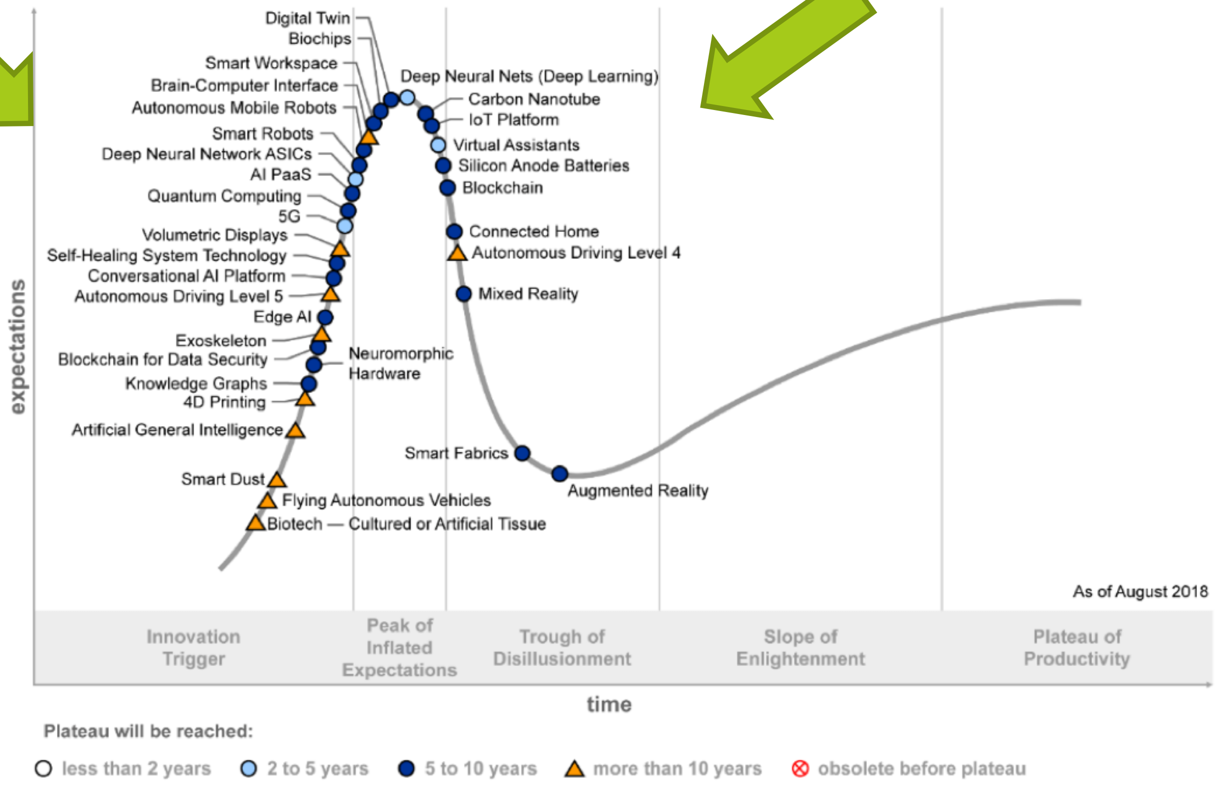
Hello world from Delft!

POLL 1

We've harvested the low hanging fruit in the field of automated driving. For further progress we need to:

1. Make humans smarter about when to use automated driving and when not.
2. Intensify R&D into automated driving using AI and ubiqutous connectivity
3. Invest in road infrastructure readiness for automated driving, physically and digitally

If ever there was a hype….



Spatial and Transport Impacts of Automated Driving

Level	Name	Dynamic Driving Task (DDT)		DDT Fallback	Operational Design Domain (ODD)
		Sustained lateral and longitudinal vehicle motion control	*Object and Event Detection and Response (OEDR)*		
Driver performs part or all of the DDT					
0	No Driving Automation				N/A
1	Driver Assistance				Limited
2	Partial Driving Automation				Limited
Automated Driving System (ADS "System") performs the entire DDT (while engaged)					
3	Conditional Driving Automation				Limited
4	High Driving Automation				Limited
5	Full Driving Automation				Unlimited

https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic

Spatial and Transport Impacts of Automated Driving

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http://www.volvocars.com/intl/about/our-innovation-brands/intellisafe/intellisafe-autopilot/drive-me/real-life

Transportation Research Part C 96 (2018) 380–397

Contents lists available at ScienceDirect

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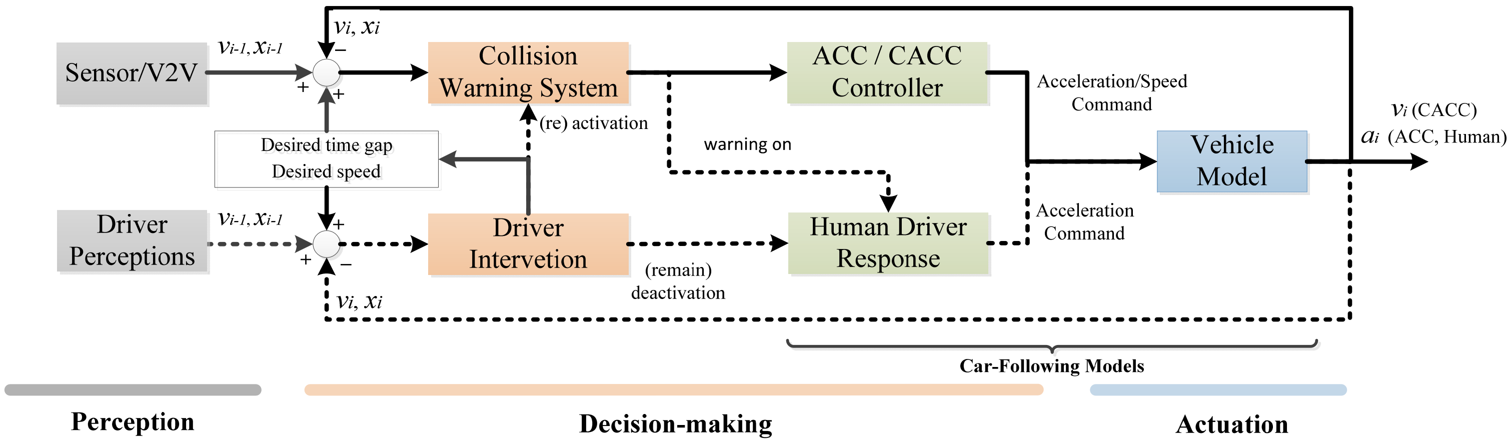
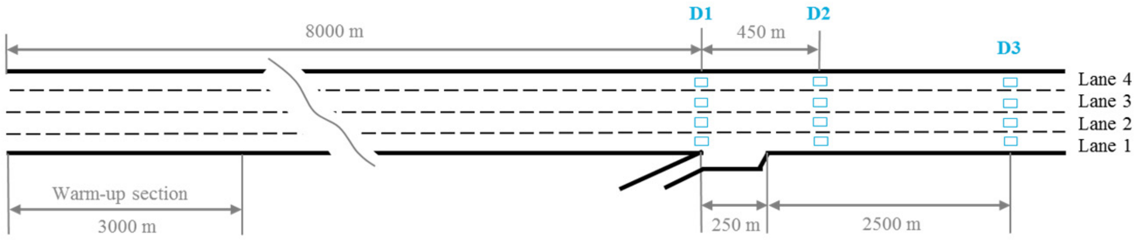
journal homepage: www.elsevier.com/locate/trc

Unravelling effects of cooperative adaptive cruise control deactivation on traffic flow characteristics at merging bottlenecks

Lin Xiao, Meng Wang*, Wouter Schakel, Bart van Arem

Department of Transport and Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, the Netherlands





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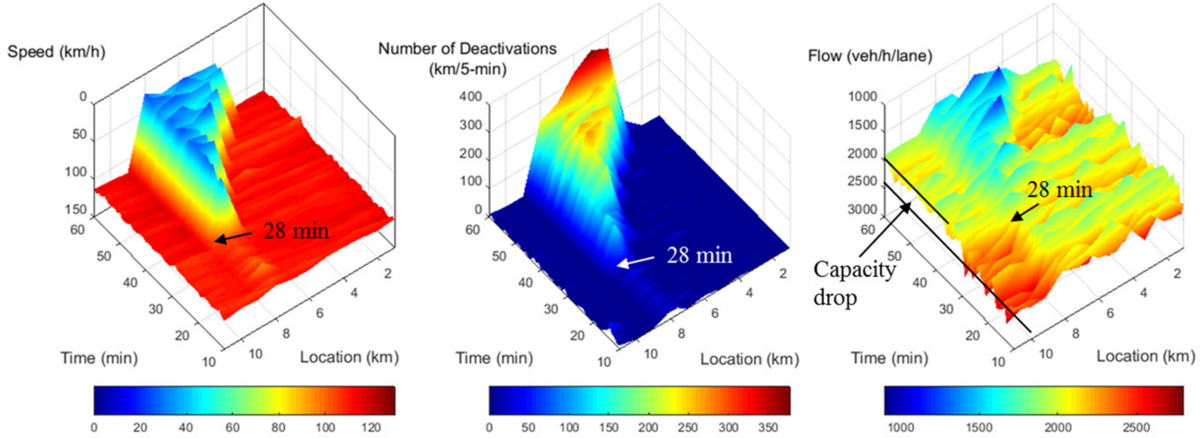
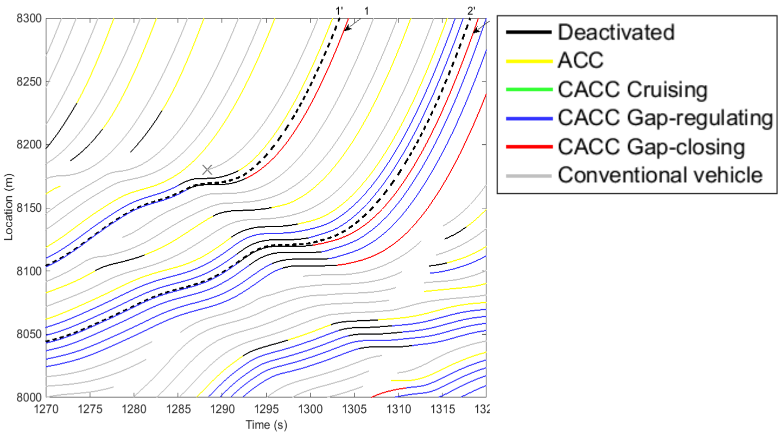




CACC benefits negligible at low MPR

CACC increases heterogeneity in fundamental diagram

Capacity drop prevails with CACC

Control transitons play significant role

Automated driving is (still) complex and challenging

Driver assistance/ Partial automation

Driver needs to be able to intervene at all times

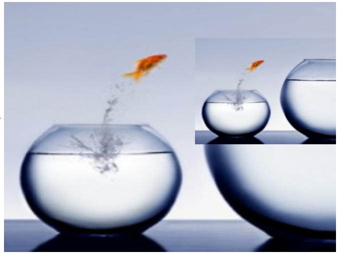
Automated parking, autocruise

Conditional/ High automation

Vehicle in control in special conditions

Taxibots, platooning, automated highways

Comfort, efficiency, safety, costs



Mode choice, location choice, urban and transport planning

A walk ascending the SAE levels?

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AVs moving into deployment

Appelscha
How to maintain public transport in shrinking rural areas? Easymile EZ10 on the bicycle lane.

Rivium ParkShuttle
Without a steward inside the vehicle, in Rotterdam and Capelle a/d IJssel! Served over 6,000,000 paxs since 1999

Container Exchange Route
AV s connecting Maasvlakte 1 and Maasvlakte 2 in Port of Rotterdam

AV in Japan
A case study conducted in regards to a demonstrator in Oku-Eigenji.

Over 100 shuttle experiments in the EU
Safety steward on board
Operational services very limited

How to operate safely in shared space?

Boersma et al, 2020, From Pilot to Implementation: What are Potential Deployments with Automated Vehicles in Public Transport Based on Knowledge Gained from Practice? TRB 100th Annual Meeting, paper TRBAM-21-00729

Spatial and Transport Impacts of Automated Driving

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POLL 2

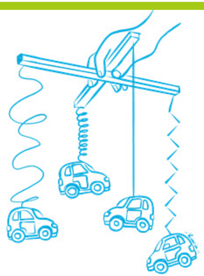
Humans either as driver, controller or supervisor remain the weak link in driving automated road vehicles.

1. We need to redefine automated driving as explainable and responsible.
2. We need less ‘drivers’ in the future, but those who are need to be highly skilled and certified.
3. Automated driving builds on an aging concept called ‘car driving’, we need radical new mobility solutions.

This keynote…

How can Automated Vehicles share the road with Vulnerable Road Users?

How can Automated Vehicles be controlled in a meaningful way?



How can Automated Vehicles enable (re-) design of smart and sustainable cities?

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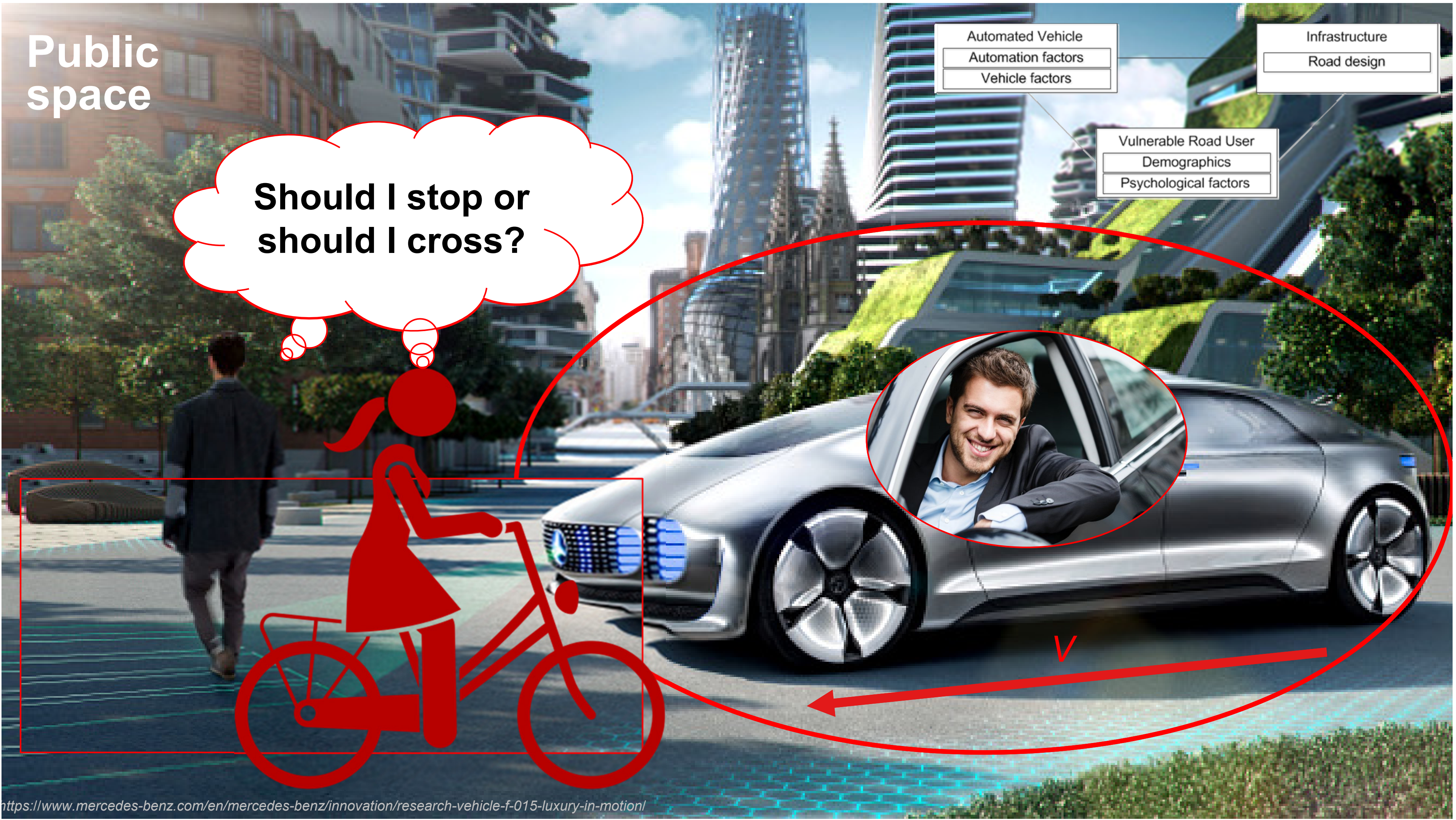
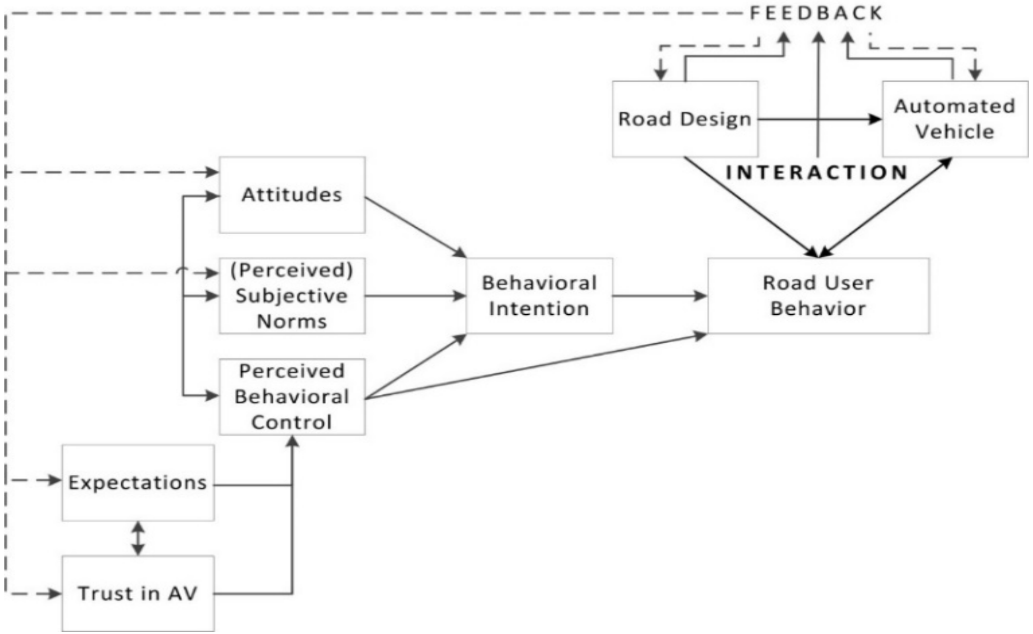
Spatial and Transport Impacts of Automated Driving



Public space
Should I stop or should I cross?
Automated Vehicle
Automation factors
Vehicle factors
Infrastructure
Road design
Vulnerable Road User
Demographics
Psychological factors
V
https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/

Ajzen Theory of Planned Behaviour for VRU AV interaction



Núñez Velasco, J. P., et al (2016). Interactions between Vulnerable Road Users and Automated Vehicles: A Synthesis of Literature and Framework for Future Research. Proceedings of Road Safety and Simulations Conference 2016.

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Spatial and Transport Impacts of Automated Driving


Public space
Nuñez Velasco (2019)

https://www.youtube.com/watch?v=jCCIAFpxrKY

UNIVERSITY OF LEEDS
Institute for Transport Studies (ITS)

nsport Impacts of Automated Driving

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Findings

- Motion cues of vehicles are the most important factors (speed, distance)
- Little difference between response to automated and regular vehicles
- Trust and high perceived behavioral control lead to more and faster crossing
- Intention cues (eHMIs) potentially useful
- Long term adaptation to exposure to automated vehicles uncertain

Nuñez Velasco, J.P., et al (2019) Studying pedestrians' crossing behavior when interacting with automated vehicles using virtual reality, Transportation Research Part F: Traffic Psychology and Behaviour, 66, pp. 1-14. DOI: 10.1016/j.trf.2019.08.015

Nuñez Velasco, J.P., et al. (2021) Cyclists' crossing intentions when interacting with automated vehicles: A virtual reality study (2021) Information (Switzerland), 12 (1), art. no. 7, pp. 1-15. DOI: 10.3390/info12010007

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Spatial and Transport Impacts of Automated Driving

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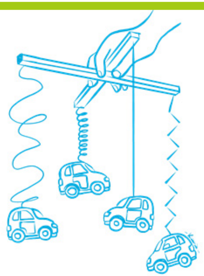

How can Automated Vehicles enable (re-) design of smart and sustainable cities?

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Spatial and Transport Impacts of Automated Driving

Meaningful human control of automated driving systems

… so much more than robot-dilemmas

NWO

Responsible Innovation

Meaningful Human Control
over automated driving systems

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Responsibility gaps of AI and networked systems

Human controllers

… can lose track of their role in the control chain,
… ending up not being able to effectively steer the system in the desired direction
…though remaining, technically speaking, "in-the -loop", and possibly legally liable for it.

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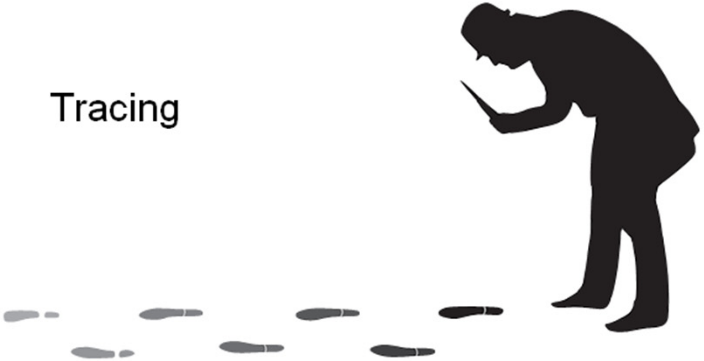
Toward Meaningful Human Control

Tracking

The system (human operators, operated devices, infrastructures…) should be able to co-vary its behavior with the relevant reasons of the relevant human agent(s) for carrying out X or omitting X

Tracing



There is at least one human agent in the system design history or use context who can appreciate the capabilities of the system and her own role as target of potential moral consequences for the system's behaviour

Santoni de Sio F and van den Hoven J (2018) Meaningful Human Control over Autonomous Systems: A Philosophical Account. Front. Robot. AI 5:15. doi: 10.3389/frobt.2018.00015

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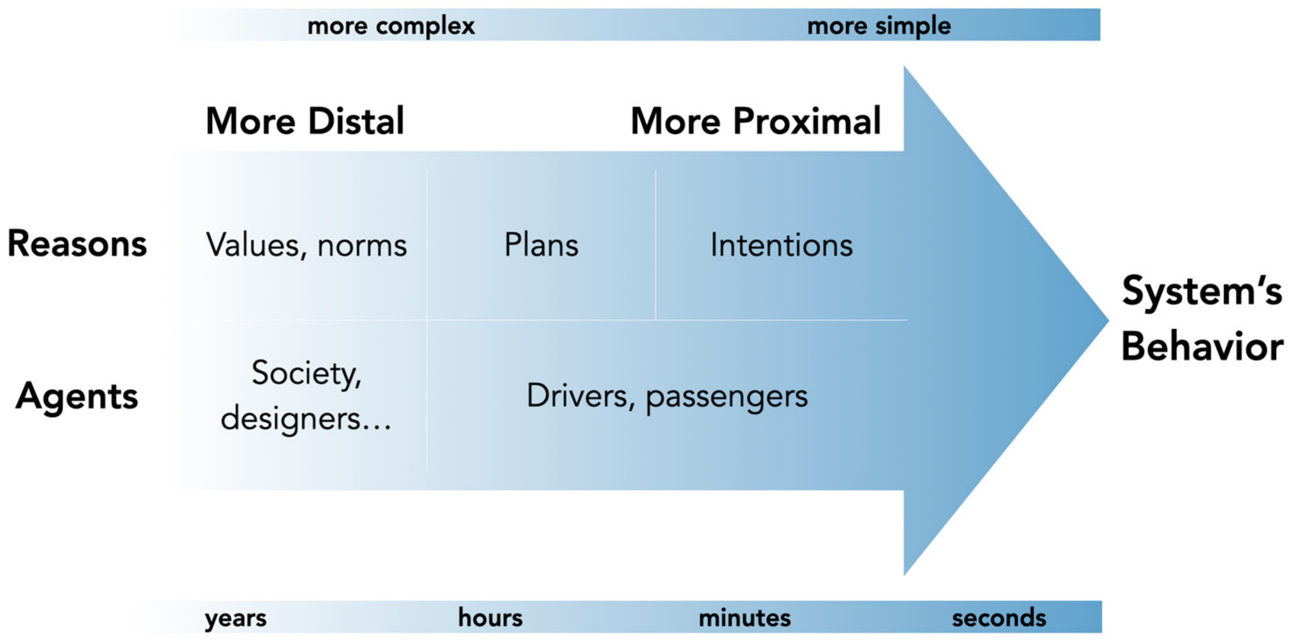
Tracking by proximal scale of reasoning



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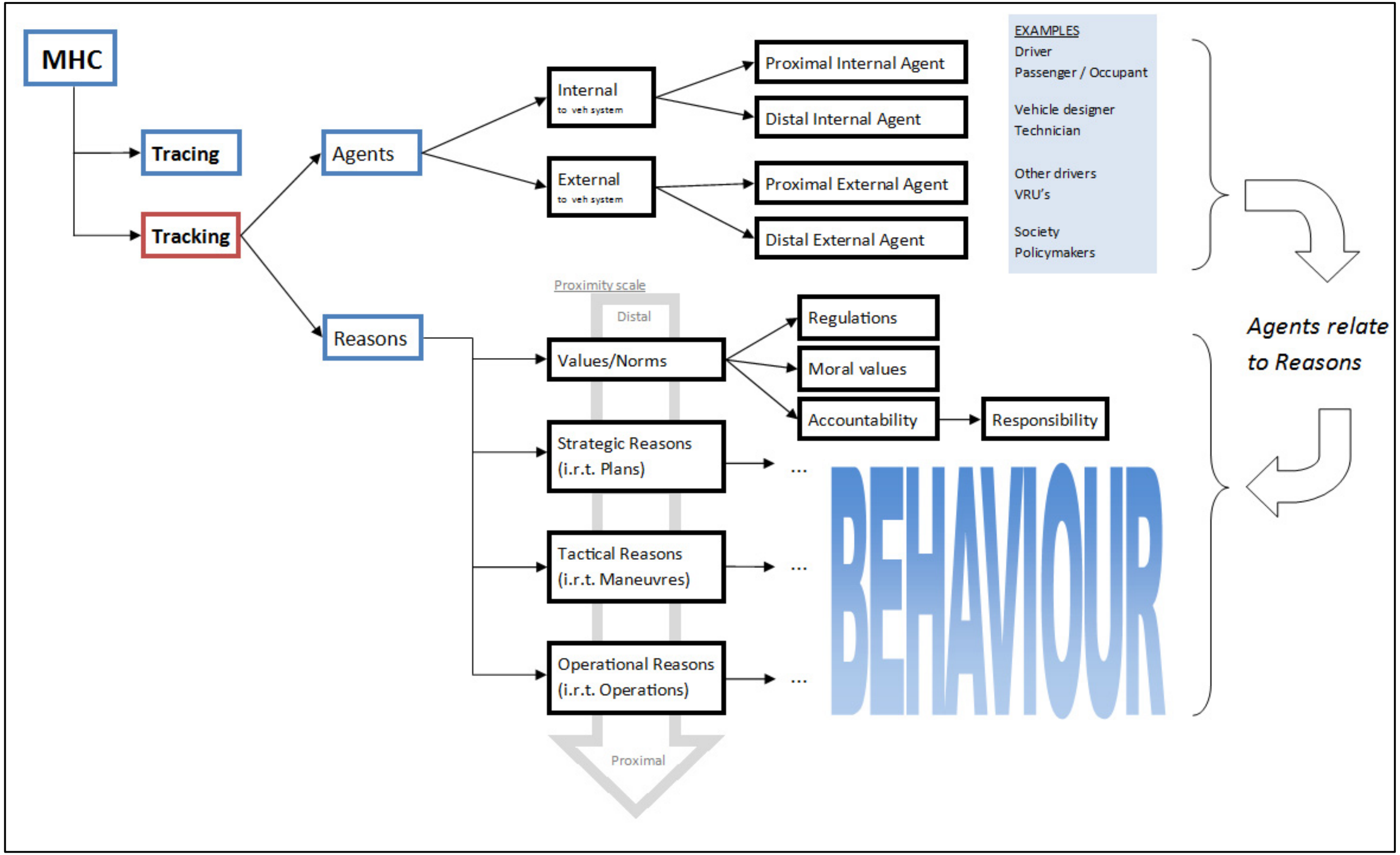
Tracking taxonomy



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Calvert, S. C., & Mecacci, G. (2020). A conceptual control system description of Cooperative and Automated Driving in mixed urban traffic with Meaningful Human Control for design and evaluation. IEEE Open Journal of Intelligent Transportation Systems, 1, 147-158.

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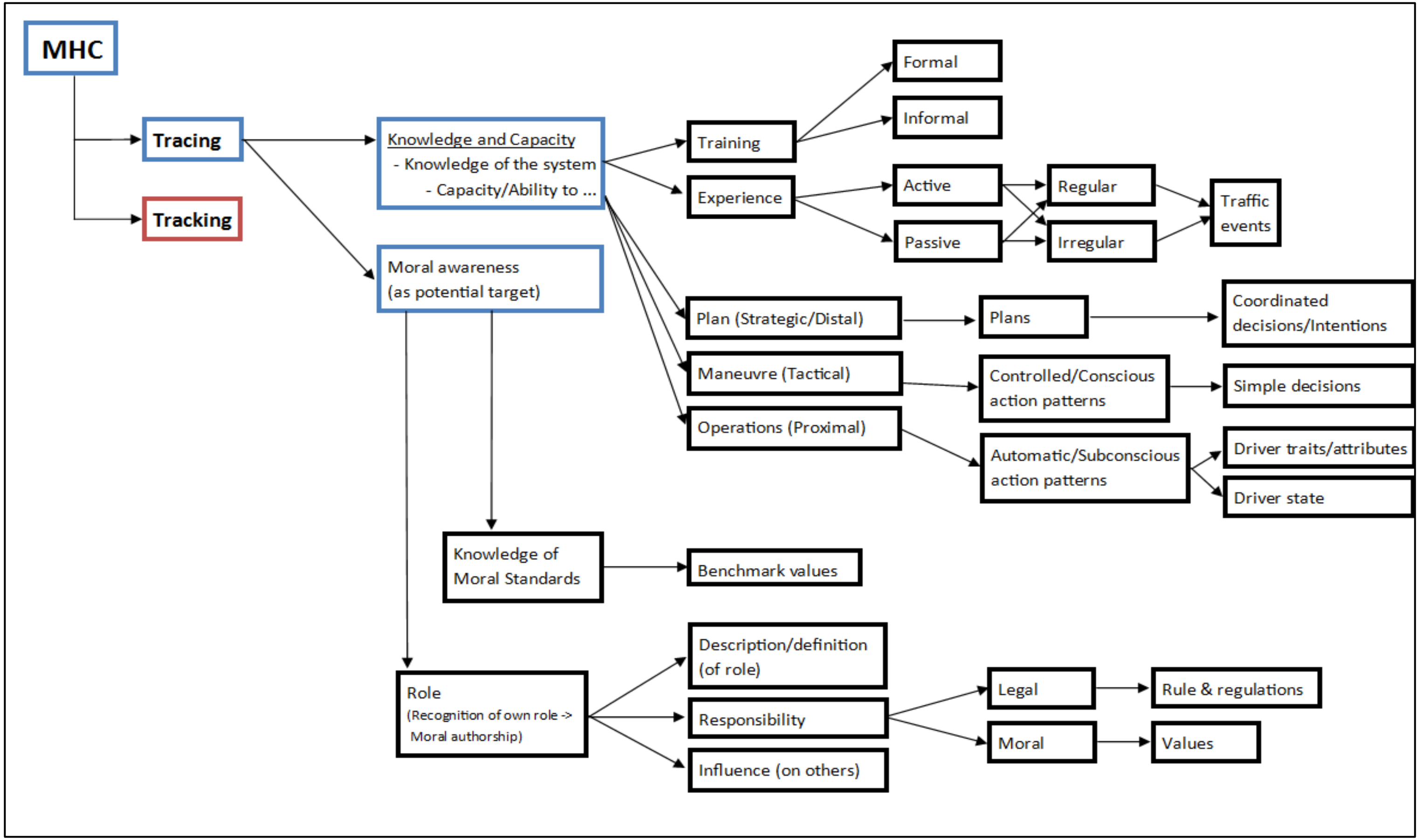
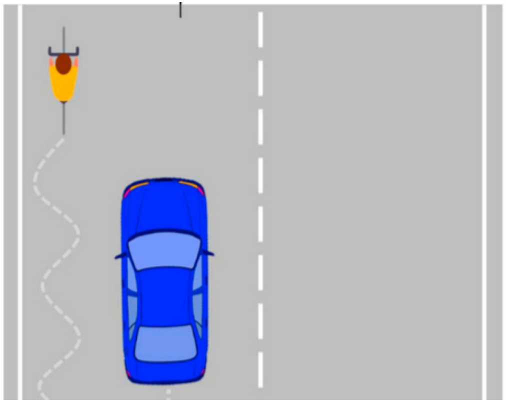
Tracing taxonomy



Cyclist lateral position sinus function with random error

L4 CAV



Operationalisation of Meaningful Human Control

Minimising risk and overtaking duration

Overtaking strategy
- Lateral distance from cyclist
- Overtaking speed

Experience and capability

A crash can occur because cyclist lateral position is not fully predictable

Repeated simulation with updated parameters of overtaking strategy

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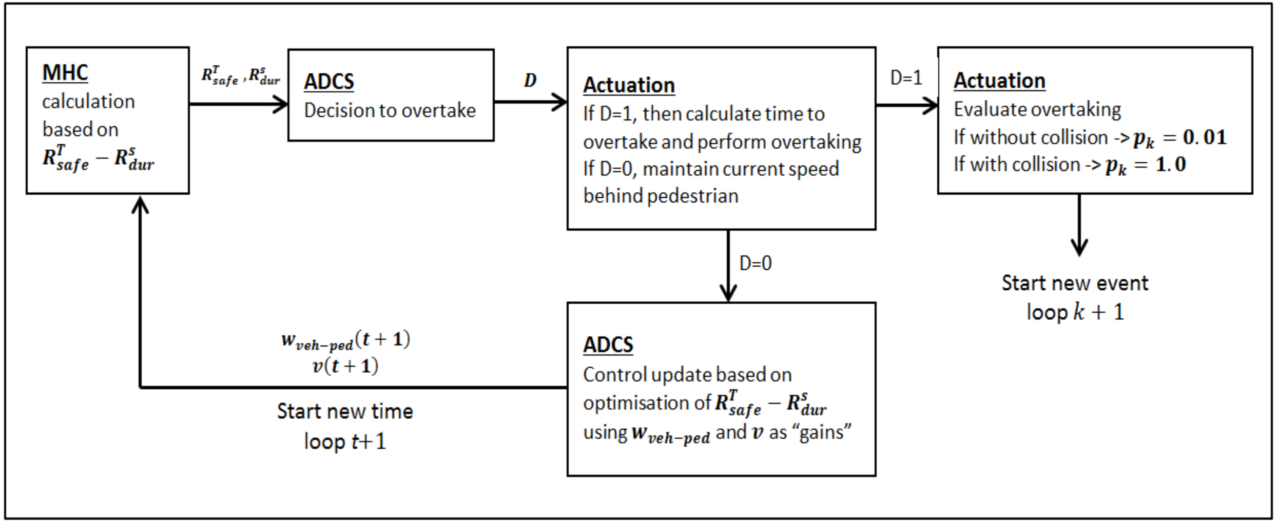
Calvert, S. C., & Mecacci, G. (2020). A conceptual control system description of Cooperative and Automated Driving in mixed urban traffic with Meaningful Human Control for design and evaluation. IEEE Open Journal of Intelligent Transportation Systems, 1, 147-158.

Spatial and Transport Impacts of Automated Driving

Iteratively building capability and experience



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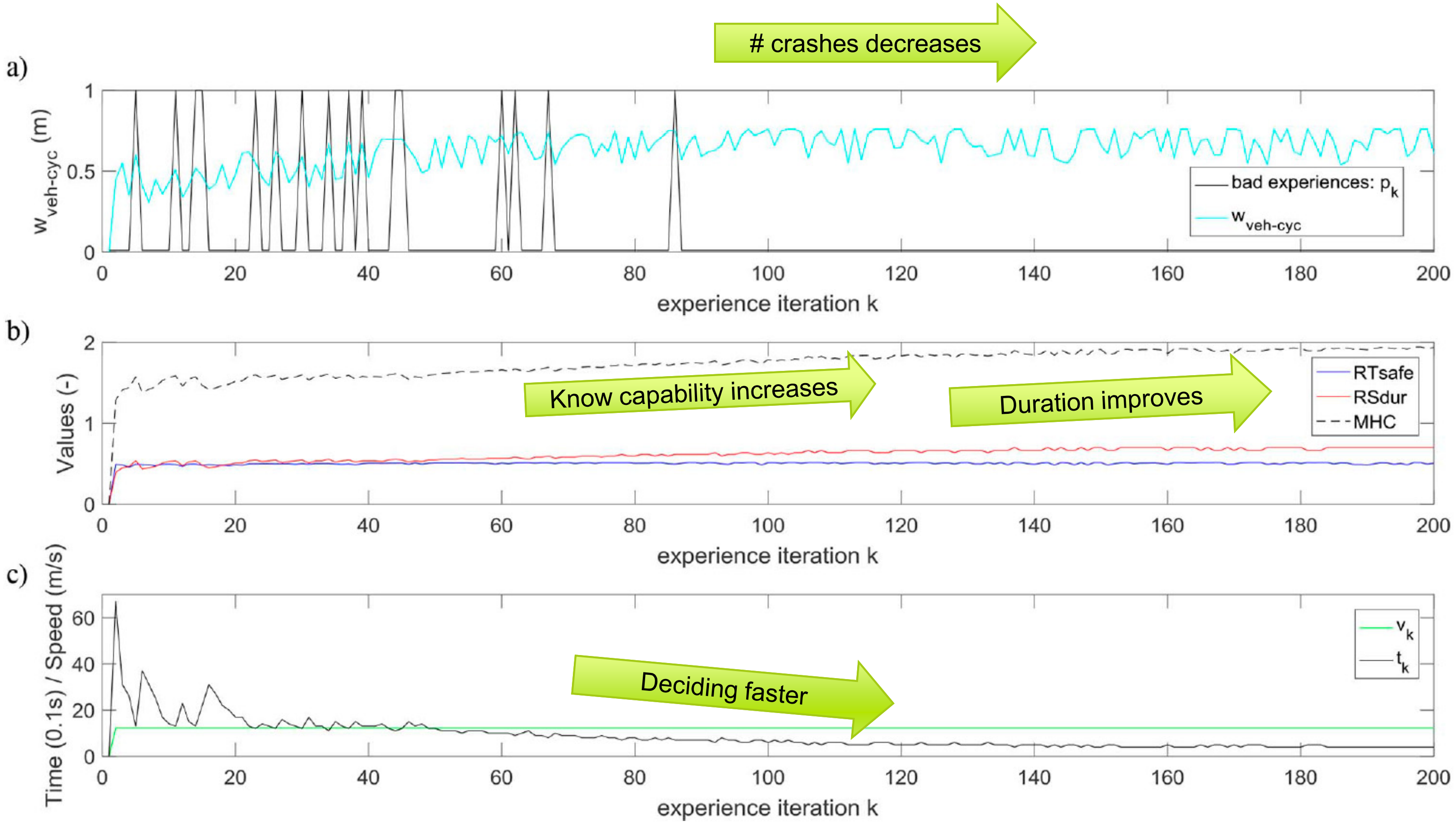

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Spatial and Transport Impacts of Automated Driving

Contributions

- Abstract concept made applicable in practice
- Demonstrates ways that MHC can be considered in vehicle and infrastructure design
- Demonstrates an approach to evaluate the extent of MHC
- Demonstrates potential policy influence on MHC

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Spatial and Transport Impacts of Automated Driving

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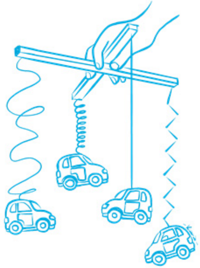

How can Automated Vehicles enable (re-)design of smart and sustainable cities?

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Spatial and Transport Impacts of Automated Driving

How can Automated Vehicles enable (re-) design of smart and sustainable cities?

Ionescu, A.I, V.M. Sanz, R. Dijkstra (2019) Robocar and Urban Space Evolution, Faculty of Architecture and the Built Environment, TU Delft.

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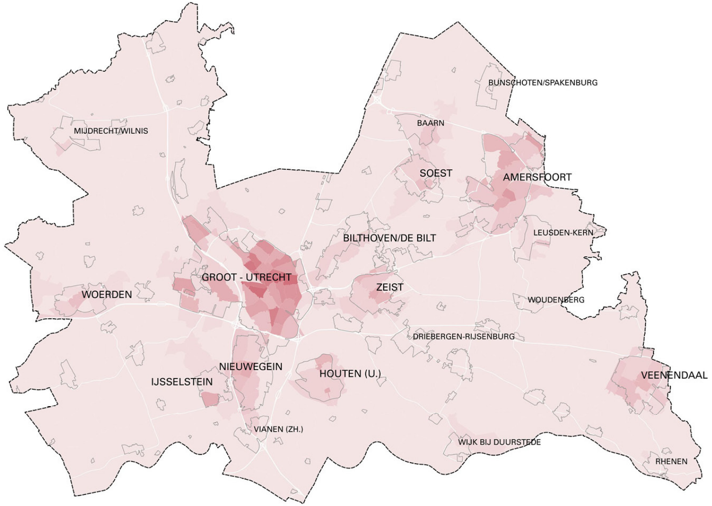
Spatial and Transport Impacts of Automated Driving

AV and spatial transformation potential

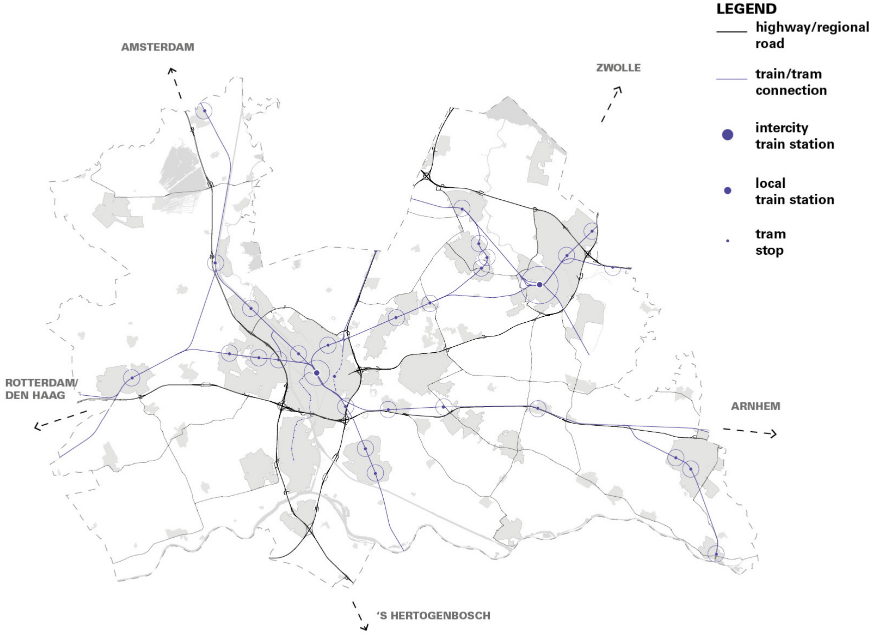
Hollestelle et al (in preparation), *From urban design to transport demand patterns: An integrated approach to study the spatial impacts of automated driving in urbanized regions*



Legend

population density [pers/km2]

< 1000	3000 - 4000	7000 - 8000	11000 - 12000
1000 - 2000	4000 - 5000	8000 - 9000	12000 - 13000
2000 - 3000	5000 - 6000	9000 - 10000	> 13000
	6000 - 7000	10000 - 11000	



Province of Utrecht

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Spatial and Transport Impacts of Automated Driving

Scenarios

Scenario 1: Transformation of the mobility system Only shared automated vehicles (taxi-bots) on the roads (Level 5). High capacity gains in regional and urban road networks. It's so convenient that all conventional PT disappears. Good travel comfort and experience. Value of Travel Rime (VOTT) decreasing.	**Scenario 2: Growth on private AVs with great experience** Automated driving develops to full automation everywhere but only as a private mode of transport (Level 5). Technology allows vehicles to drive empty to park at specific outside parking areas. Traveling in a private AV is a great experience. Public transport is the same as today's. VOTT in cars decreases
Scenario 3: Constrained usage of private AVs Automated driving is level 4 so only full automation in regional networks (no city centers). Capacity only increases on that part of the network. It does not deliver the comfort that was expected at the outset. Parking is the same as today. VOTT decreases but not as much.	**Scenario 4: Decline of the mobility system** Automated driving becomes Level 5 but it does not lead to capacity increases. No real effect on the comfort. No public transport any more. Everyone using private AVs. VOTT the same as today.

Hollestelle et al (in preparation), From urban design to transport demand patterns: An integrated approach to study the spatial impacts of automated driving in urbanized regions

Parameters for the scenarios

		Scenario			
Category		Transformation	Growth	Constraint	Decline
Induced travel	For road travel by new user groups	All public transport transferred to cars on the road network	+10%	N/A	All public transport transferred to cars on the road network
	By empty ride allocation to pick-up other passengers	+20%	+10%	N/A	+10%
	By empty ride allocation to designated parking zones	N/A	All arrivals in zones with parking restriction policies are directed to designated external parking zones	N/A	N/A
Traffic efficiency	Outer-urban roads	+ 100%	+40%	+40%	-20%
	Inner-urban roads	+ 50%	+20%	+0%	+0%
	Intersection delay factor	All 0.1	All 0.25	+0%	+0%
Travel cost factors	Value of time (all purposes)	-35%	-50%	-15%	+0%

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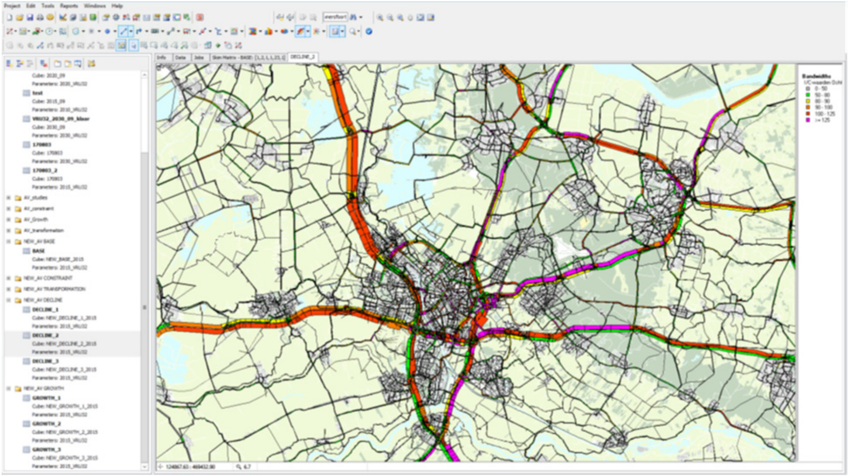
VRU Transport model

Scenario	Mean travel time [min:sec]
0. (Base)	11:48 (ref.)
1. Transformation	14:43 (+24%)
2. Growth	19:24 (+64%)
3. Constraint	11:35 (-1.9%)
4. Decline	20:00 (+69.5%)



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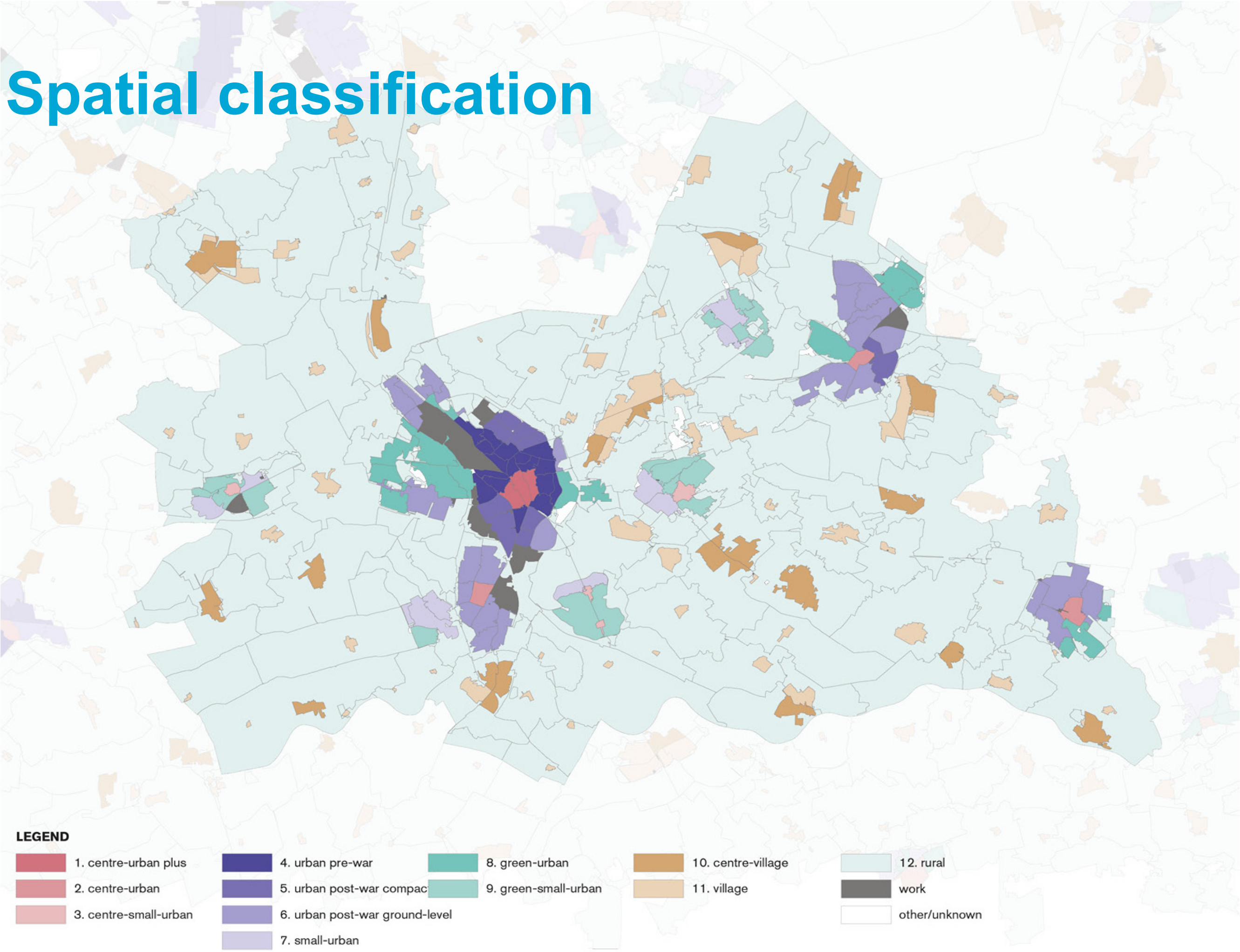
Spatial classification



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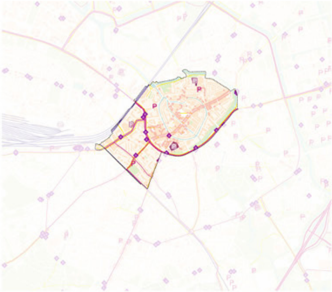
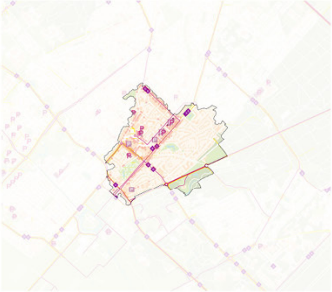
1. Centre urban plus

2. Centre urban



3. Centre small-urban



4. Urban pre-war

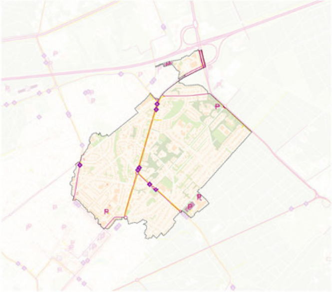
5. urban post-war compact

6. urban post-war ground-level

7. Small-urban

8. Green urban

9. Green small-urban



10. Centre village

11. Village

12. Rural

transformation

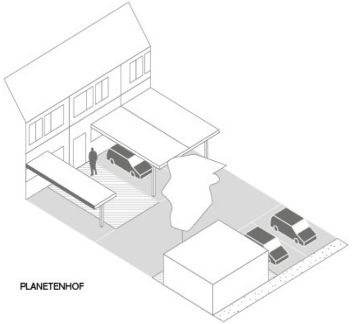
growth

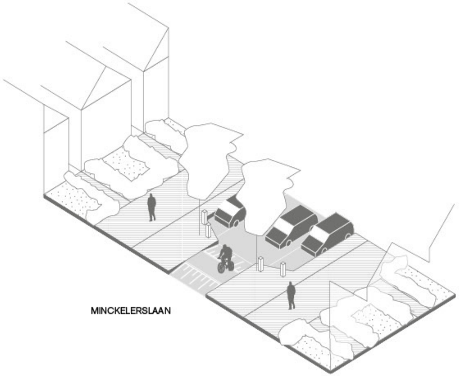
constraint

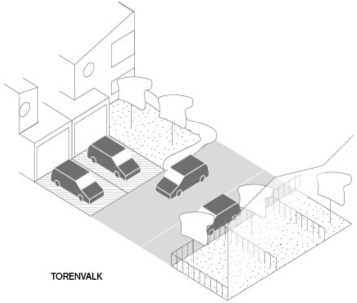
decline

7. small-urban | 9. green-small-urban | 11. village

ase







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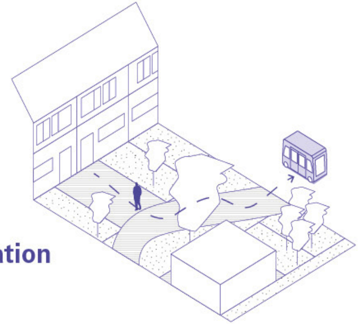

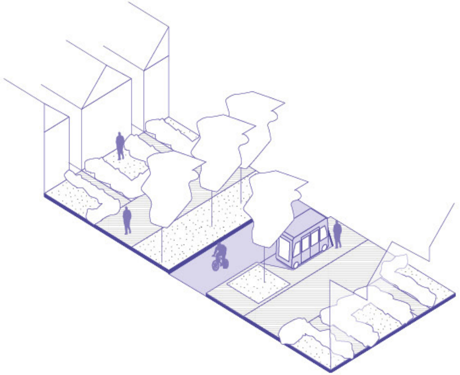

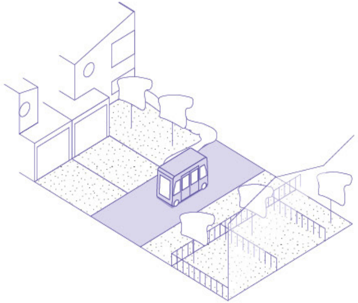

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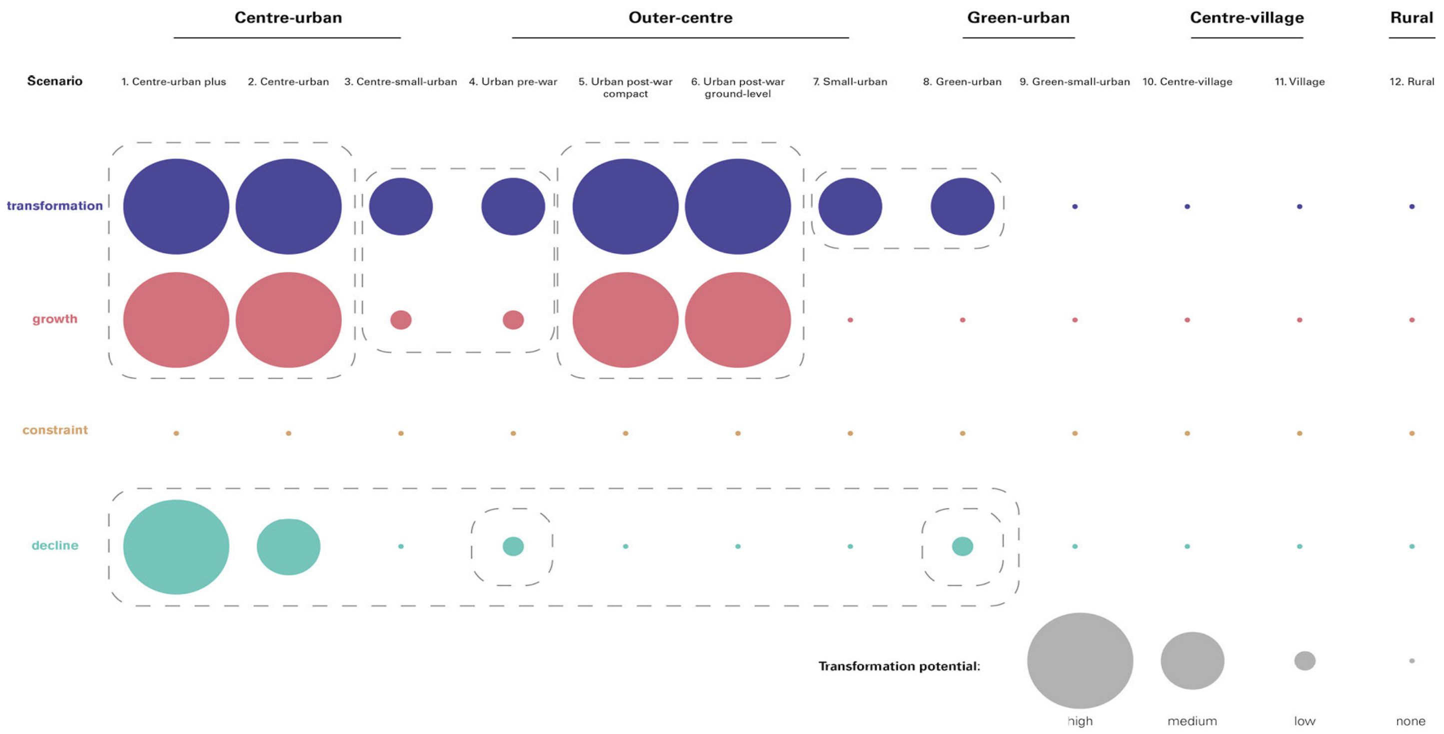


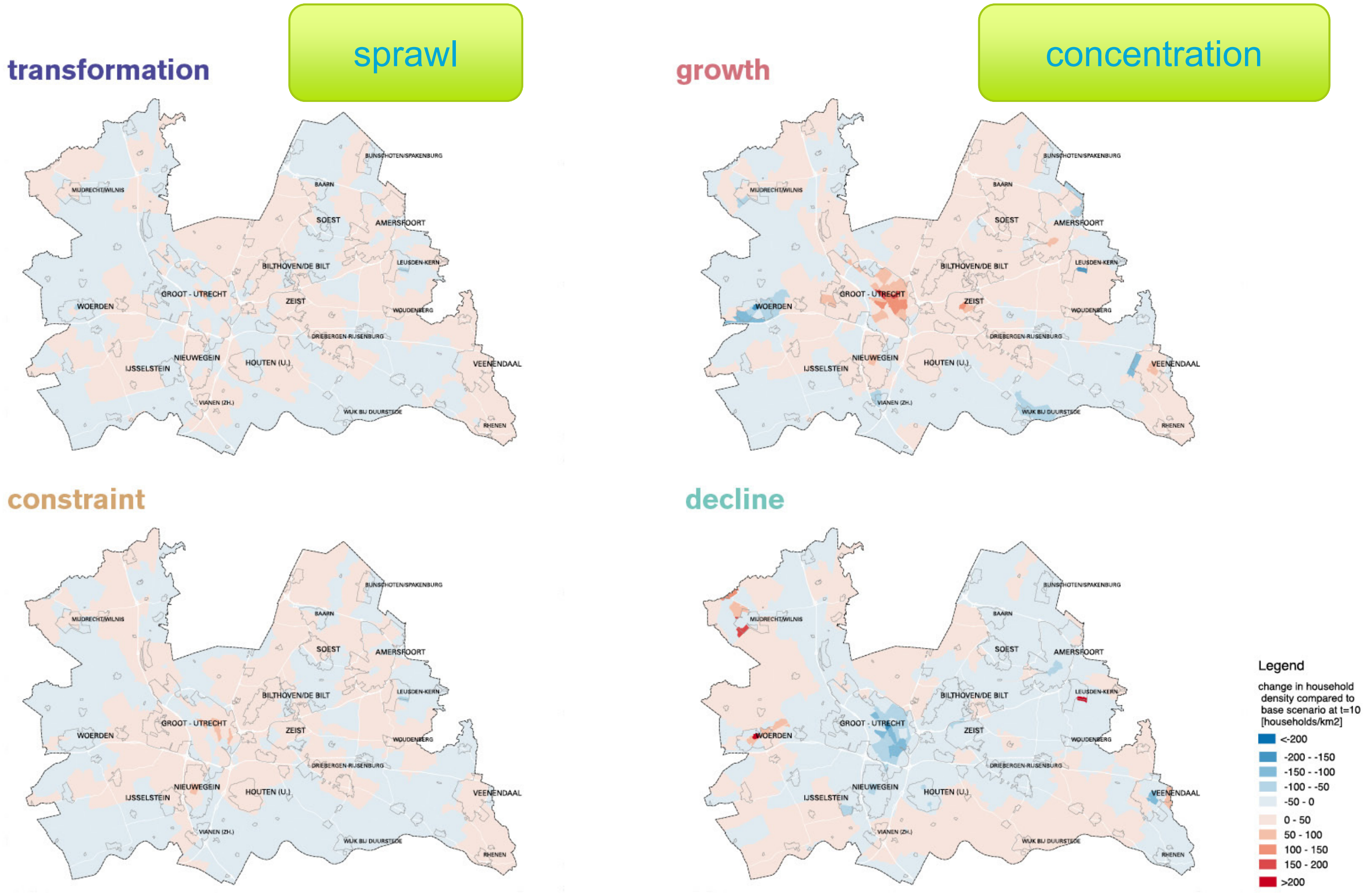
Spatial transformation potential

Spatial and Transport Impacts of Automated Driving

Hedonic pricing

Spatial quality premium house price, based on research by design at (residential) street (0,2) and (arterial) road level (0,8); +5% if street can me made greener, -5% if demand increases too much;

TIGRIS Land use transport interaction model



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POLL 3

Problems on sustainable and affordable housing for a growing population or more pressing than automating driving.

1. We need to redesign our cities, ban human driving and allow low speed automated driving in connection to personal and freight mobilty hubs.
2. We need automated super highways to connect new dwellings to existing conurbations.
3. Shared electric vehicles that are easy to drive are key to future urban mobility. Why automate?

TAKE AWAYS

Progressive deployment of Automated Driving taking place, but less fast as (some) expected).

Automated Vehicles and humans need to learn how to operate safely in shared space.

Automated Driving can support Urban Transformation in combination with public transport, zero-emission vehicles, cycling and new mobility modes.

New methods and models for impact assessment needed to study the fundamental changes in impacts at high levels of automation.

THANK YOU!

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