CoEXist

Final Conference

Enabling "*Automation-Ready*" Transport Planning

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Phone or internet connection

Dial-in options

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Participation tools

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Instructions for questions

- Use the question box feature at anytime and the question manager checks it and forwards the question
- Short Q&A (3-5 minutes) after each presentation

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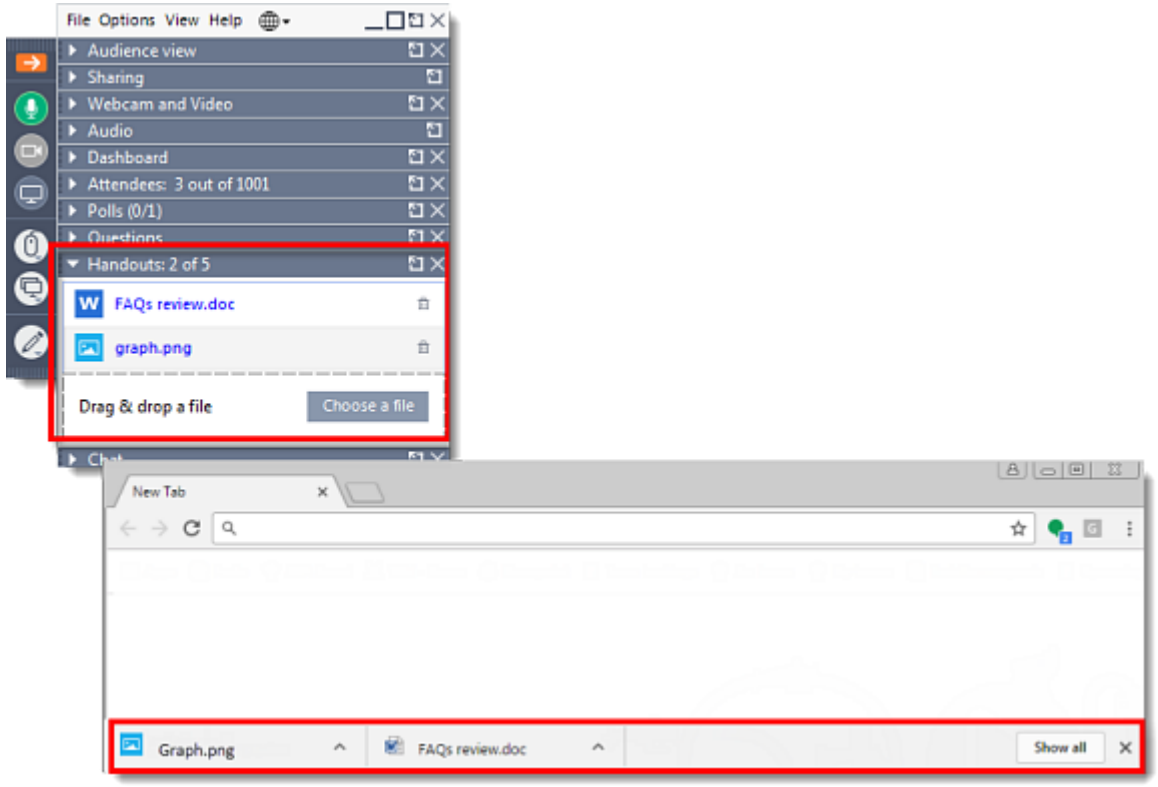
Download handouts



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CoEXist Virtual Final Conference - Part 1:
Automation-ready tools and impact assessment findings

Wednesday 25 March 2020

CET (UTC+01:00) — ***Moderator:*** *Siegfried Rupprecht, Rupprecht Consult*

13:45 Registration and technical support

14:00 **Welcome**, Siegfried Rupprecht, *Rupprecht Consult* & INEA (tbc)

Introduction to CoEXist, *Daniel Franco, Rupprecht Consult*

CoEXist tools

Automation-ready transport modelling and infrastructure assessment

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14:25 Polls - Q&A

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Rachel James, USDOT Federal Highway Administration (FHWA)

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15:30 *Break*

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Potential impact of vehicle automation in four cities, across eight scenarios:

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CoEXist Virtual Final Conference - Part 2:
What next for Cities and CAVs?

TOMORROW!

Workshop: What next for cities and CAVs?

moderated by Siegfried Rupprecht, Rupprecht Consult

14:00 ***Welcome,*** *Siegfried Rupprecht*

14:05 **Automation-ready framework for city authorities,**
Wolfgang Backhaus, Rupprecht Consult

14:20 **CoEXist – Roadmap towards automation-ready cities**
Brian Matthews, Milton Keynes city council
Susanne Scherz, city of Stuttgart
Mikael Ivari, city of Gothenburg
Frank van den Bosch, city of Helmond

10 min per speaker (including 3min Q&A)

15:00 *Poll & self-assessment of automation-readiness*

15:15 **Towards automation readiness - challenges for infrastructure,**
Suzanne Hoadley, Polis

15:30 **Interactive group discussion**
Key issues for cities, including change and expectations management, future proofing sustainable mobility policy, future proofing infrastructure investment and citizens engagement citizens.

15:50 **Lessons learnt and conclusions,** *Wolfgang Backhaus, Rupprecht Consult*

16:00 End of the session

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The webinar team

Moderator:
Siegfried Rupprecht

Project Coordinator:
Wolfgang Backhaus

Poll manager:
Marie Rupprecht

Question manager:
Daniel Franco

Technology manager:
Wolfram Buchta

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Poll question

What part of the world are you joining us from?

- Europe
- North America
- Central or South America
- Africa
- Asia or Australia

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Poll question

What is your profession and background?

- Urban transport planner in public authority
- Consultant / advisor
- Public transport operator / mobility service provider
- Research institution / University / Recent graduate
- Other (e.g. technology company, OEM, etc.)

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Poll question

What are your expectations for this virtual conference?

Fill in your answer into your question box

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Introduction to CoEXist

Daniel Franco, Rupprecht Consult

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What is CoEXist?

- **Programme:** EU H2020-ART05
- **Duration:** May 2017 – April 2020
- **Strategic Aim:**

  To bridge the gap between automated vehicles (AVs) technology and transportation and infrastructure planning, by strengthening the capacities of urban road authorities and cities to plan for the effective deployment of AVs

Enable mobility planning towards "automation-readiness", defined as:
The capability of making structured and informed decisions about the deployment of Connected and Automated Vehicles

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CoEXist approach

Automation-Ready Transport Modelling

Automation-Ready Road Infrastructure

Automation-Ready Road Authorities

www.h2020-coexist.eu

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Overview of the CoEXist impact assessment approach

Johan Olstam, VTI

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Agenda

- Challenges for traffic modelling of AVs
- A way to deal with heterogeneity of AV behavior
- A way to deal with uncertainties w.r.t. evolution of AVs
- A way to assess traffic impacts of automation

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How to model AVs in traffic models?

- What is an automated vehicle?
- How do it behave?
- Are all automated vehicles the same?

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The SAE-levels include some information

SAE level	Short description
0 – No automation	Full-time performance by a human
1 – Driver Assistance	Assistance system of either steering or acceleration/deceleration
2 – Partial Automation	Automation of **some parts** of the driving task
3 – Conditional Automation	Self driving but **driver responsible** and required to intervene if necessary
4 – High Automation	Self driving in **some** environment – driver not responsible
5 – Full Automation	Self driving **everywhere**

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Level of automation

- SAE levels focus on
  - To what extent the vehicle drive itself,
  - Where it can drive itself
  - Who is responsible for the driving

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- but do not specify how driving behavior vary between or within the levels

- **CoEXist focus**: driving behavior when an **automated driving system (ADS) is responsible** for the vehicle operation

  → AVs comply with the road regulation and the rode code, e.g. comply with speed limit

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Challenges

- Limited data on first generation AVs
- No data on future AVs
- Transition towards full automation will be long

⇩

Large uncertainties w.r.t.

- Driving behaviour of AVs
- Evolution of AV technology and penetration rates
- Behaviour of other road users in response to AVs
- Traveller behaviour adaptation (e.g., travel time perception)
- …

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How to handle the uncertainties?

- Scenarios with consistent assumptions
- Conceptual modelling of AV capabilities w.r.t. perception, anticipation, driving logic rather than detailed modelling of a specific AV-function
  - how and where can AVs operate safely (disregarding which technologies make this possible)
- Sensitivity analysis

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Poll question

Which uncertainty factor, do you think, is most uncertain?

- Driving behaviour of AVs
- Evolution of AV technology and penetration rates
- Behaviour of other road users in response to AVs
- Traveller behaviour adaptation (e.g. travel time perception)

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Hierarchical specification of AV driving behaviour

The level of automation is specified in two steps:

- **AV class**
  - Basic
  - Intermediate
  - Advanced
- **Driving logic** (for different road environments)
  - Rail-safe
  - Cautious
  - Normal
  - All-knowing

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AV classes

- **Basic:** Self driving only in one directional traffic with physical separation to active modes.
- **Intermediate:** Self driving in structured traffic.
- **Advanced:** Self driving in most environments

- All three prioritize safety, but the more advanced are able to safely drive more offensively than the less advanced.
- All comply with the road regulation and the rode code, e.g. comply with the speed limit

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Driving logics

- Rail safe
  - Follows pre-defined path
  - Brick-Wall-Stop distance
  - Switch principle
- Cautious
  - Brick-Wall-Stop distance; requirement for manoeuvres
  - Require large gaps; slows down every time its sensors can have blind angles
- Normal
  - Similar to a human driver but with the augmented (and/or diminished) perception due to sensors.
- All-knowing
  - Perfect perception and prediction of the behaviour of other road users. Capable of offensive driving whenever needed, without causing accidents.

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Example relation between AV-class, driving logics and operational design domain (ODD)

Road type	Basic	Intermediate	Advanced
Motorway	Cautious	Normal	All-knowing
Arterial	Cautious	Cautious / Normal	All-knowing
Urban street	Human	Cautious	Normal
Shared space	Human	Rail-safe / Human	Cautious

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Stages of coexistence

Stages characterized by

- AV market shares – how common are they
- AV capabilities – where can they drive
- AV driving behaviour – how do they drive

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Example of AV penetration rates & shares

Stage	AV penetration (%)	Basic AV share (%)	Intermediate AV share (%)	Advanced AV share (%)
Introductory	10-40	70-100	0-30	
Established	30-70	0-20	80-100	0-10
Prevalent	60-90		20-80	20-80

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Poll question

Which mix of Basic, Intermediate and Advanced AVs, do you think, is most likely in the established stage?

- 20 % Basic & 80 % Intermediate
- 50 % Basic & 50 % Intermediate
- 20 % Basic, 60 % Intermediate, 20 % Advanced
- 33 % Basic, 33 % Intermediate, 33 % Advanced

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Assessment of traffic impact of automation

“Automation-ready infrastructure”

infrastructure that **allows the coexistence** of automated vehicles, conventional vehicles and non-motorized road users **without significant decline** in performance

Quantifying traffic impact of automation

Relative improvement of cases with an AV-share and a baseline without any AVs

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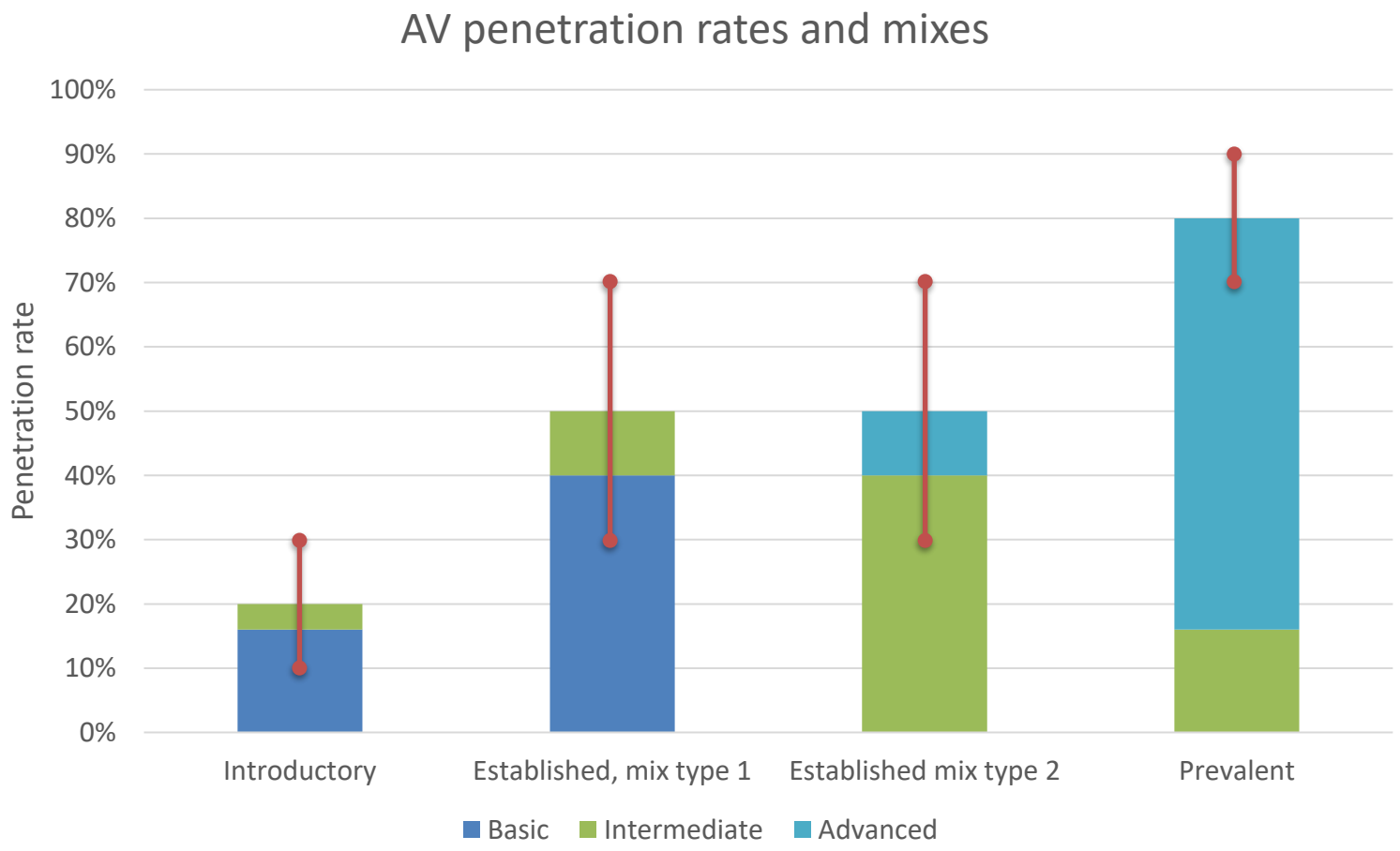
Example experimental design

Uncertainty factors

- Penetration rates
- AV mixes
- Demand levels



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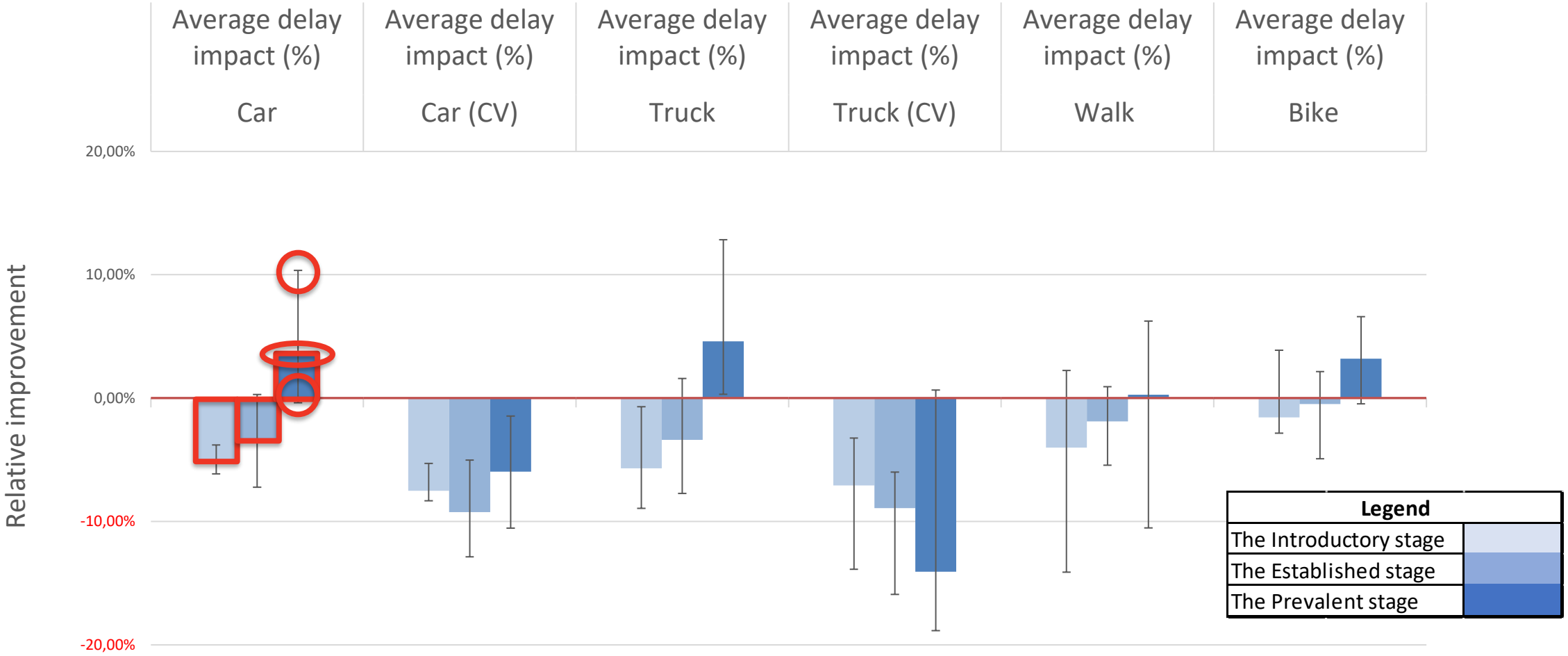
Example of result illustration



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Qualitative safety assessment

	Type of accident	Urban Pilot			
1	Driving accident				2
2	Turning off accident				1
3	Turning-in / Crossing accident				1
4	Pedestrian accident			7	2
5	Accident with parking vehicles			1	6
6	Accident in lateral traffic				3
7	Other accident type				1

Pictogram				
Meaning	The road safety could be negatively impacted	The road safety is not expected to be impacted	The road safety could be positively impacted	The road safety could be very positively impacted

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vti

Johan Olstam

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Automation-ready modelling tools: microscopic traffic flow simulation

Charlotte Fléchon, PTV Group

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PTV GROUP
the mind of movement

Introduction

- Goal: make the tool as flexible as possible for the users

- Modelling tools:
  - The microscopic simulation tool: PTV Vissim
  - A macroscopic modelling tool through scripts (Presentation from Markus Friedrich) and built-in functionalities in PTV Visum

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CoEXist approach - Modelling

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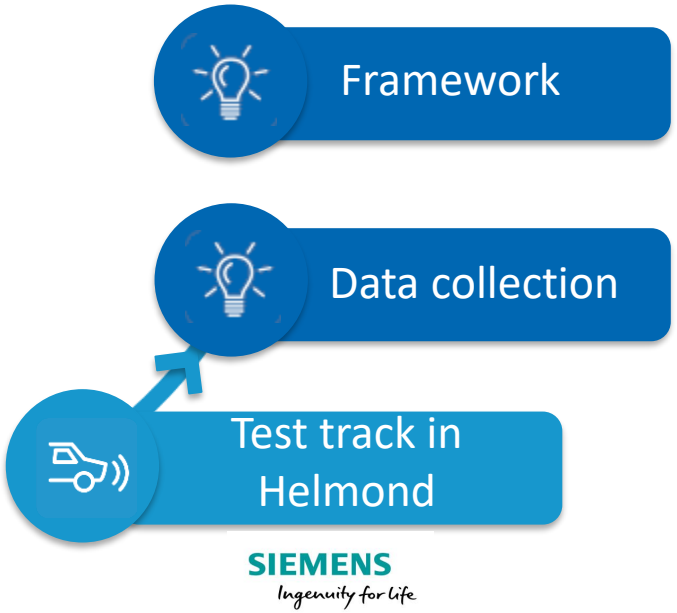

SIEMENS
Ingenuity for life

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Data Collection

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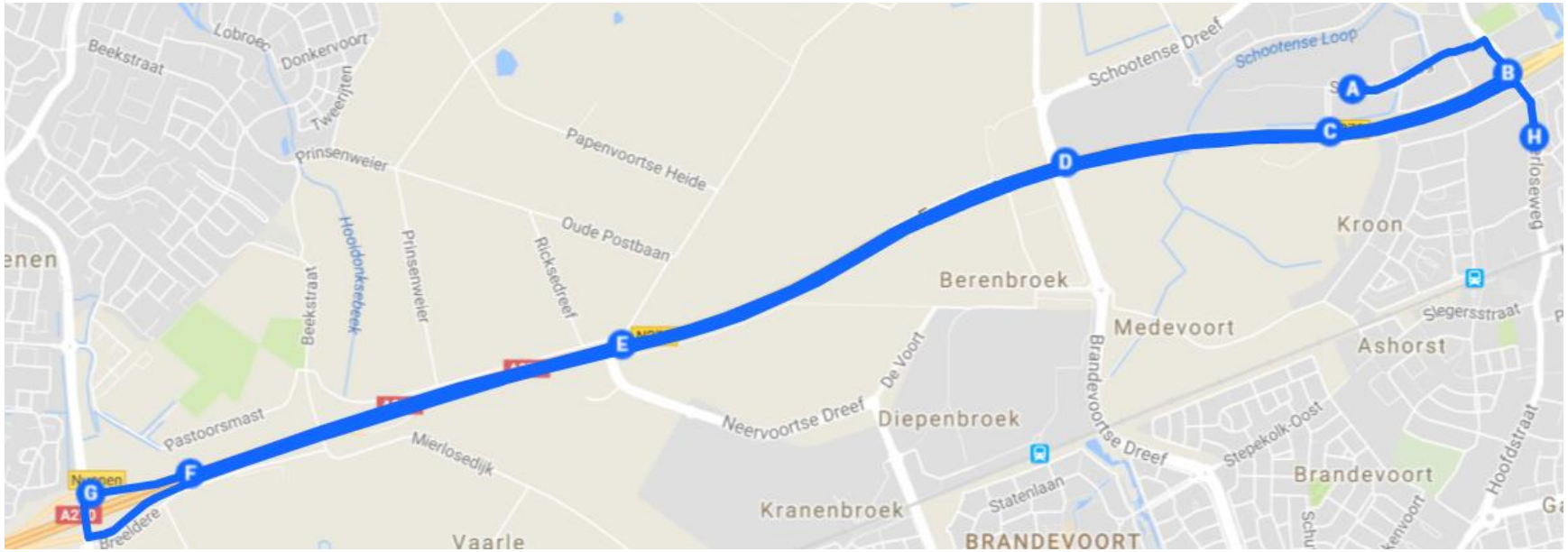

Test track in Helmond

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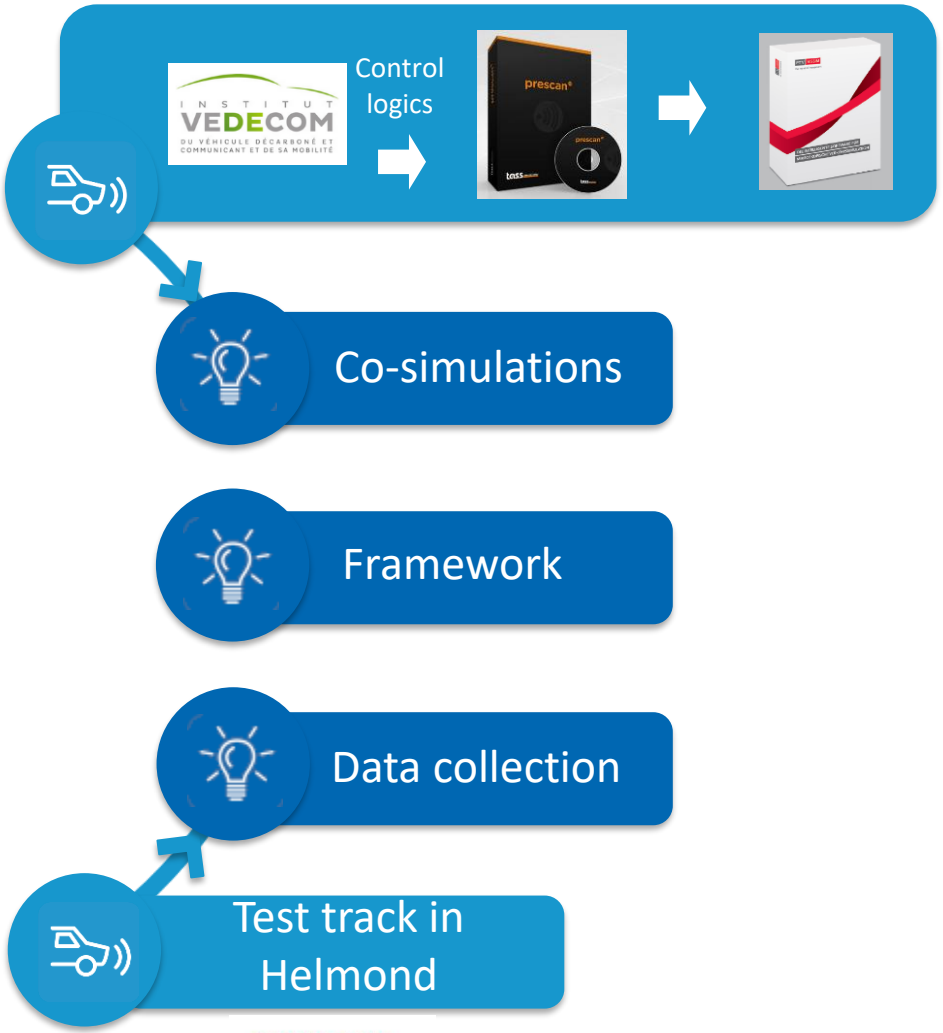

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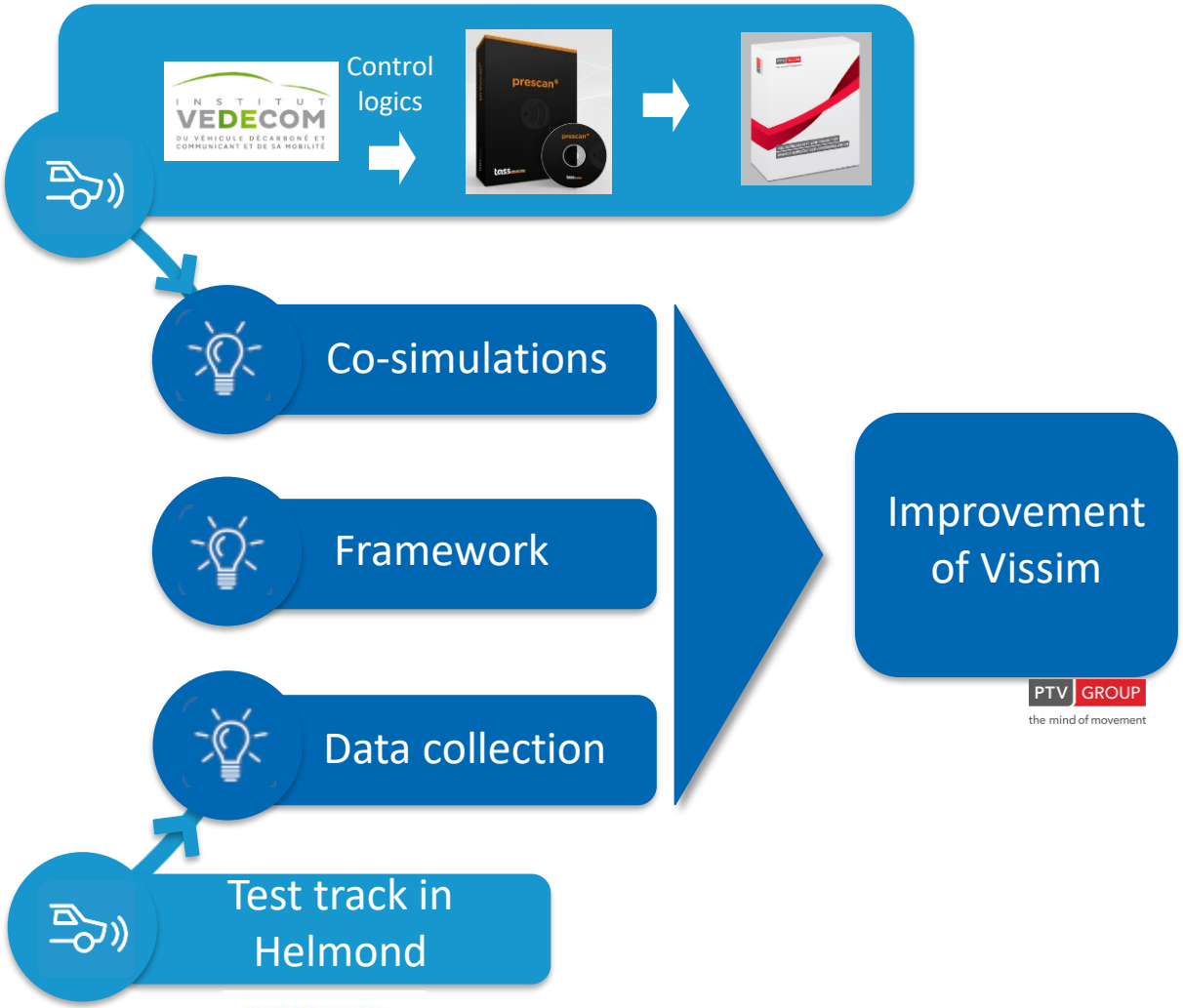

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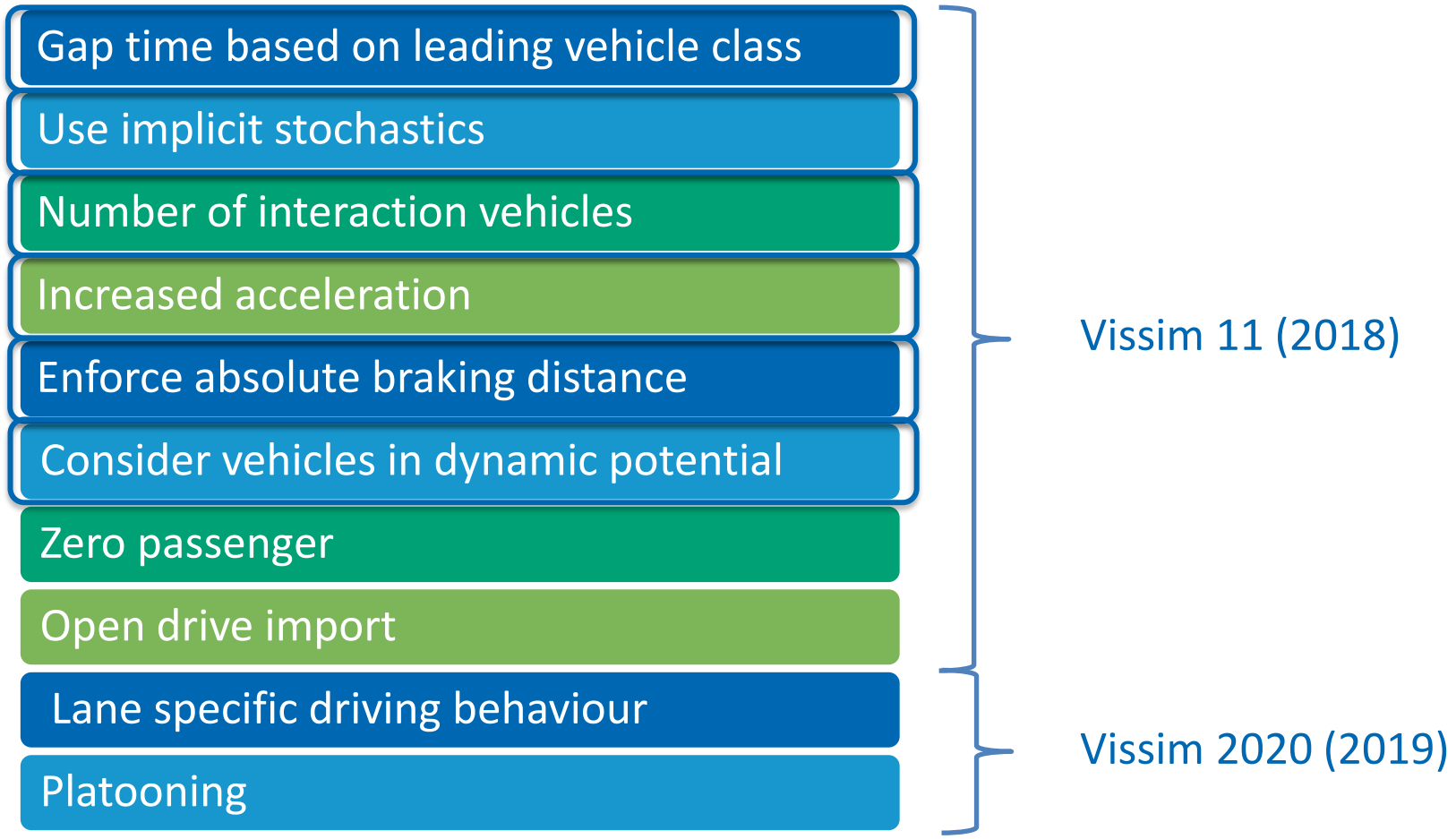
Vissim development



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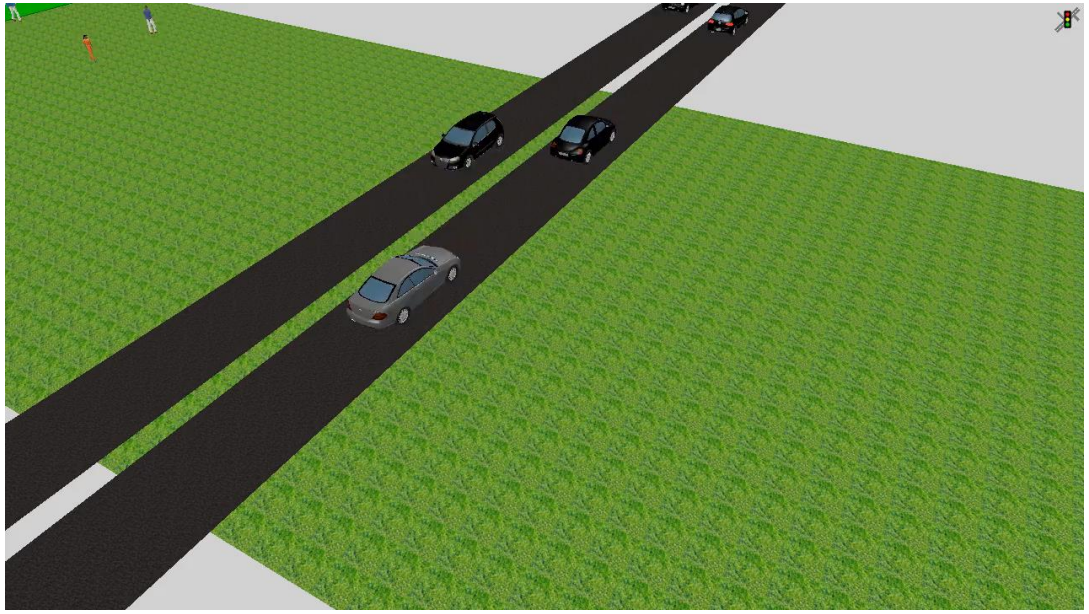
Vissim development (Vissim 11)

Improvement of the pedestrians-vehicle interaction (shared space): dynamic potential

OFF



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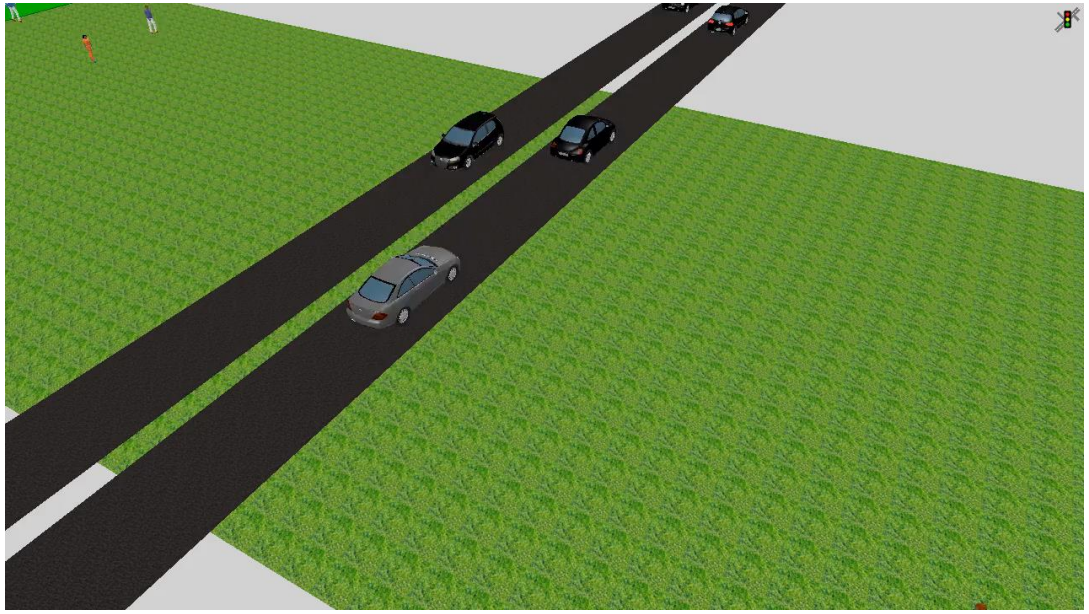

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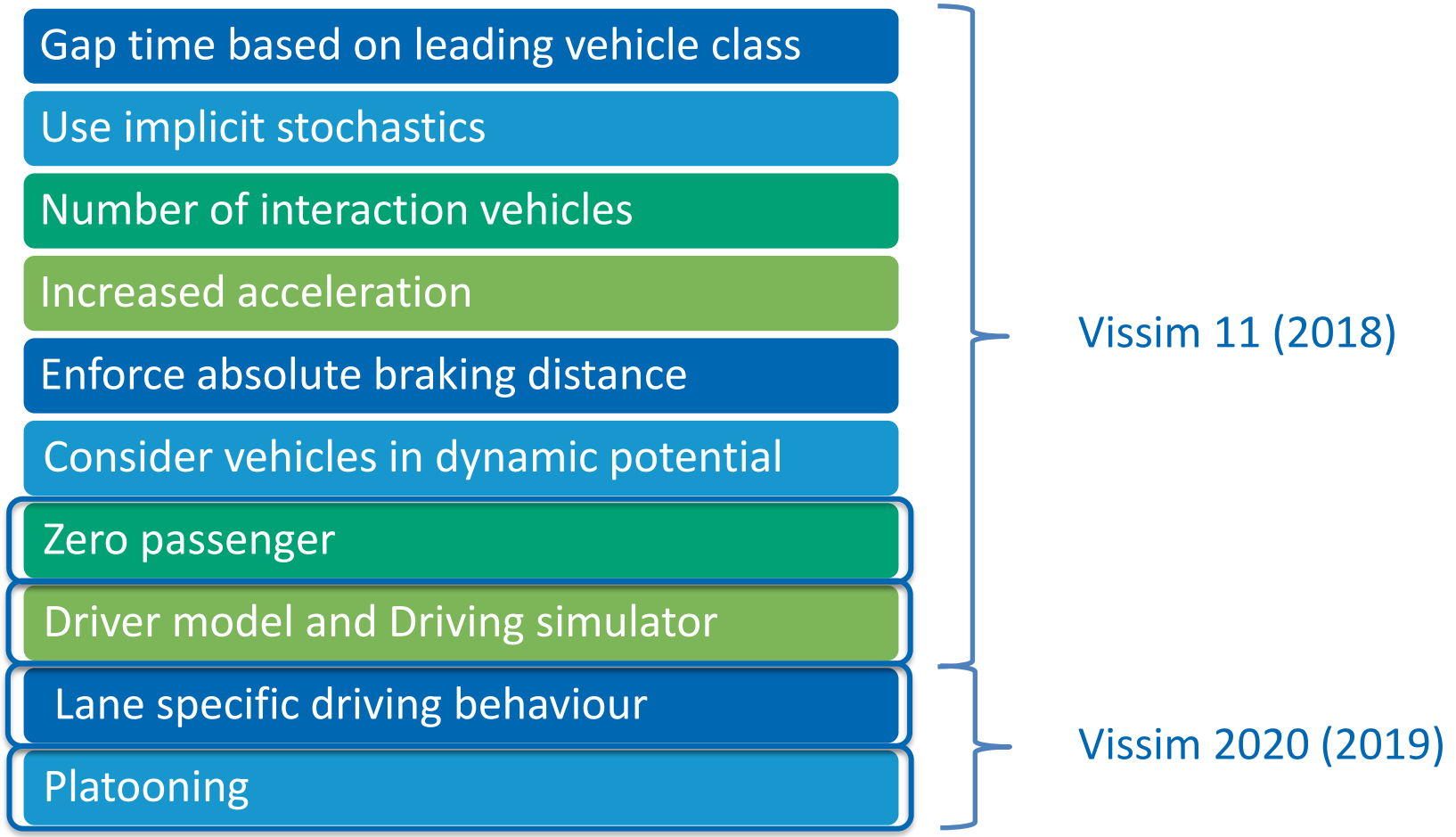

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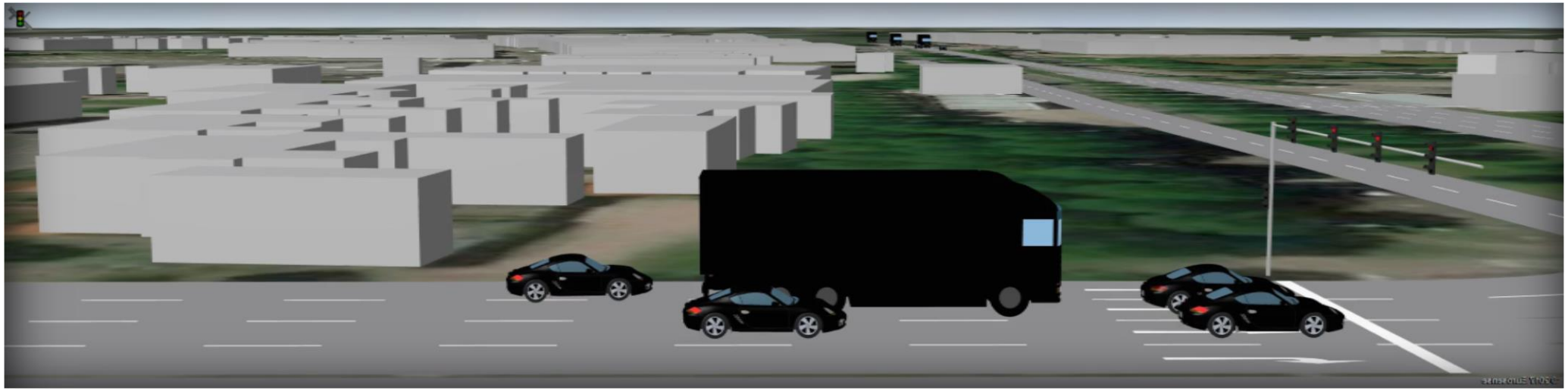
Platooning



Platoon = connected vehicles travelling very closely and safely together, also at high speeds

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Vissim behavioural parameters

Recommendation

			Driving logic				
	model	parameter**	rail safe	cautious	normal	all knowing	default
following behaviour	Wiedemann 99	CC0	1,5	1,5	1,5	1	1,5
		CC1	1,5	1,5	0,9	0,6	0,9
		CC2	0	0	0	0	4
		CC3	-10	-10	-8	-6	-8
		CC4	-0,1	-0,1	-0,1	-0,1	-0,35
		CC5	0,1	0,1	0,1	0,1	0,35
		CC6	0	0	0	0	11,44
		CC7	0,1	0,1	0,1	0,1	0,25
		CC8	2	3	3,5	4	3,5
		CC9	1,2	1,2	1,5	2	1,5
	W74	ax	2	2	2	1	2
		bxadd	2	2	2	1,5	2
		bxmult	3	3	3	2	3

https://www.h2020-coexist.eu/wp-content/uploads/2018/10/D2.3-default-behavioural-parameter-sets_final.pdf

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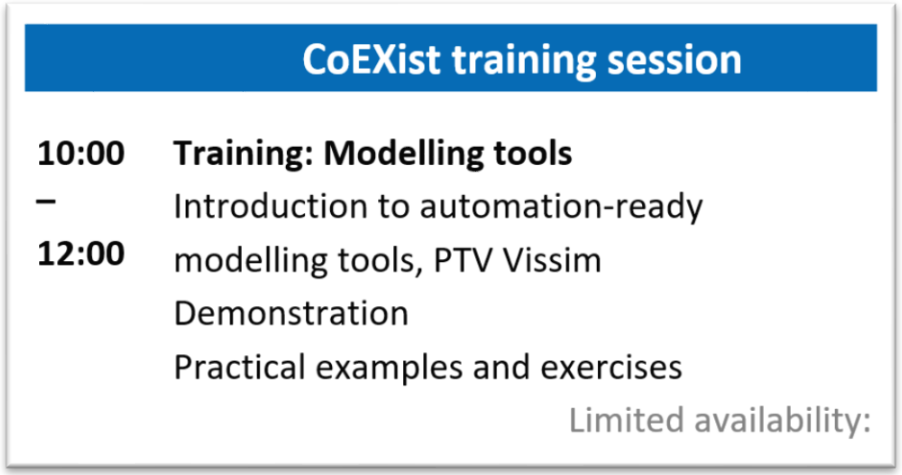
AV-ready modelling tools training

- Tomorrow Thursday 26th March

  Peter Sukennik



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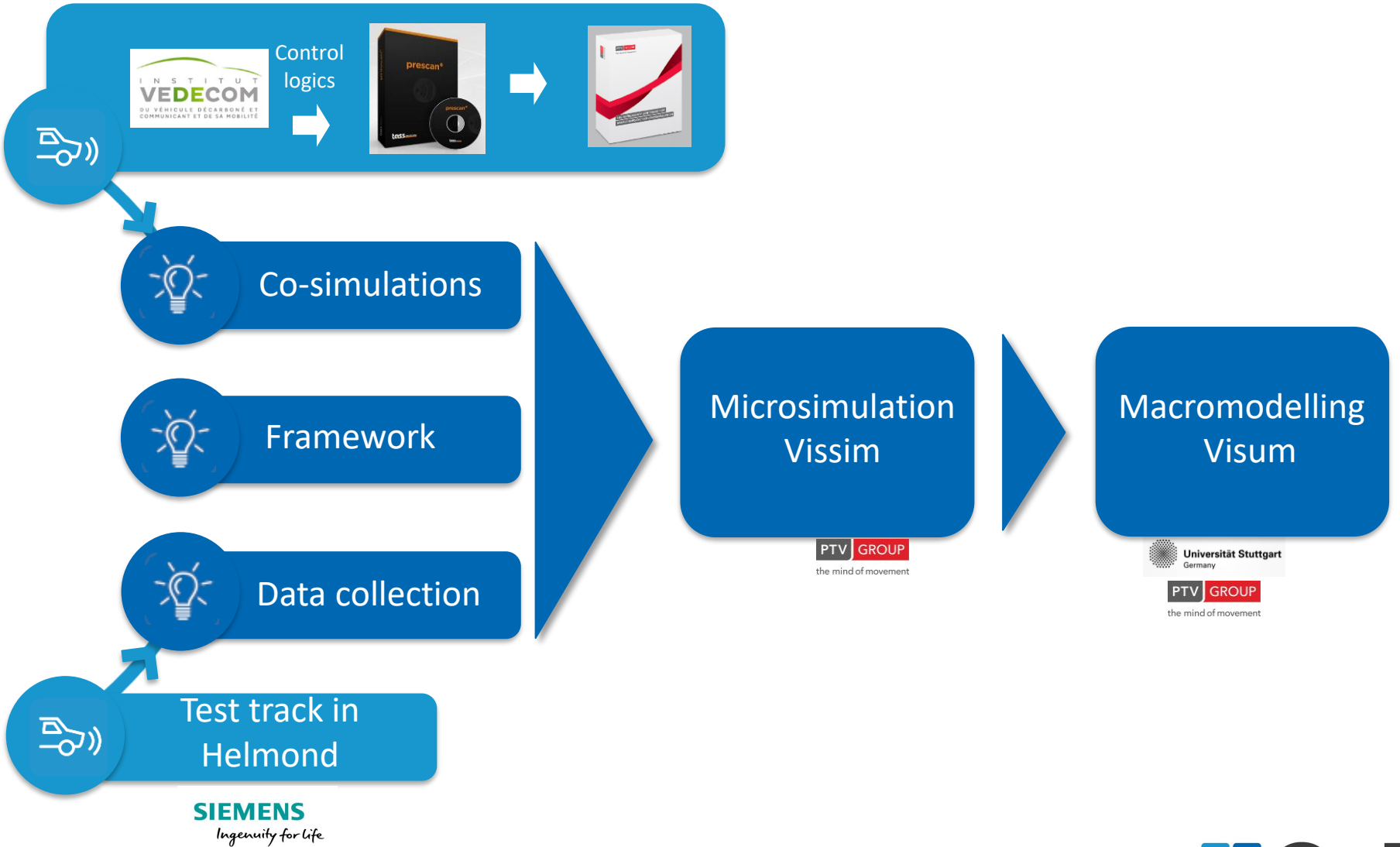
CoEXist

CoEXist approach - Modelling



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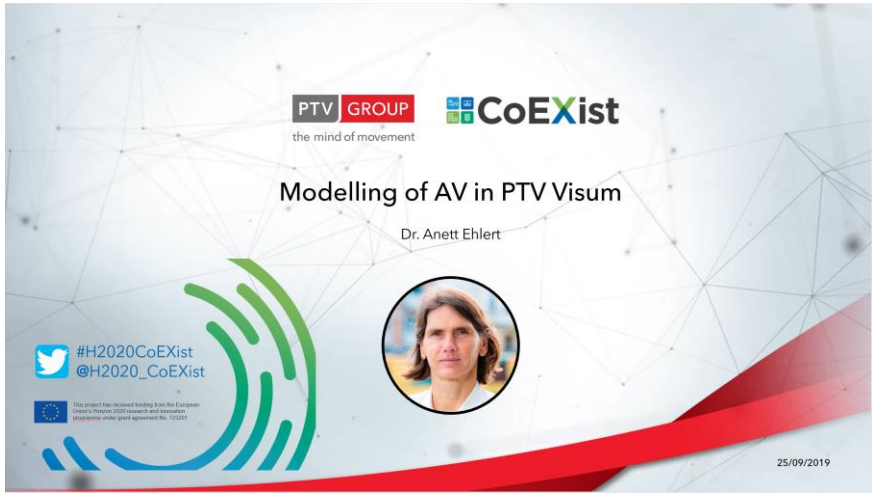
CoEXist

Macroscopic Modelling Tool

- Work from University of Stuttgart presentation from Markus Friedrich
- Development in PTV Visum 2020:

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



D2.9 Built-in AV-ready macroscopic tool and much more on the CoEXist website

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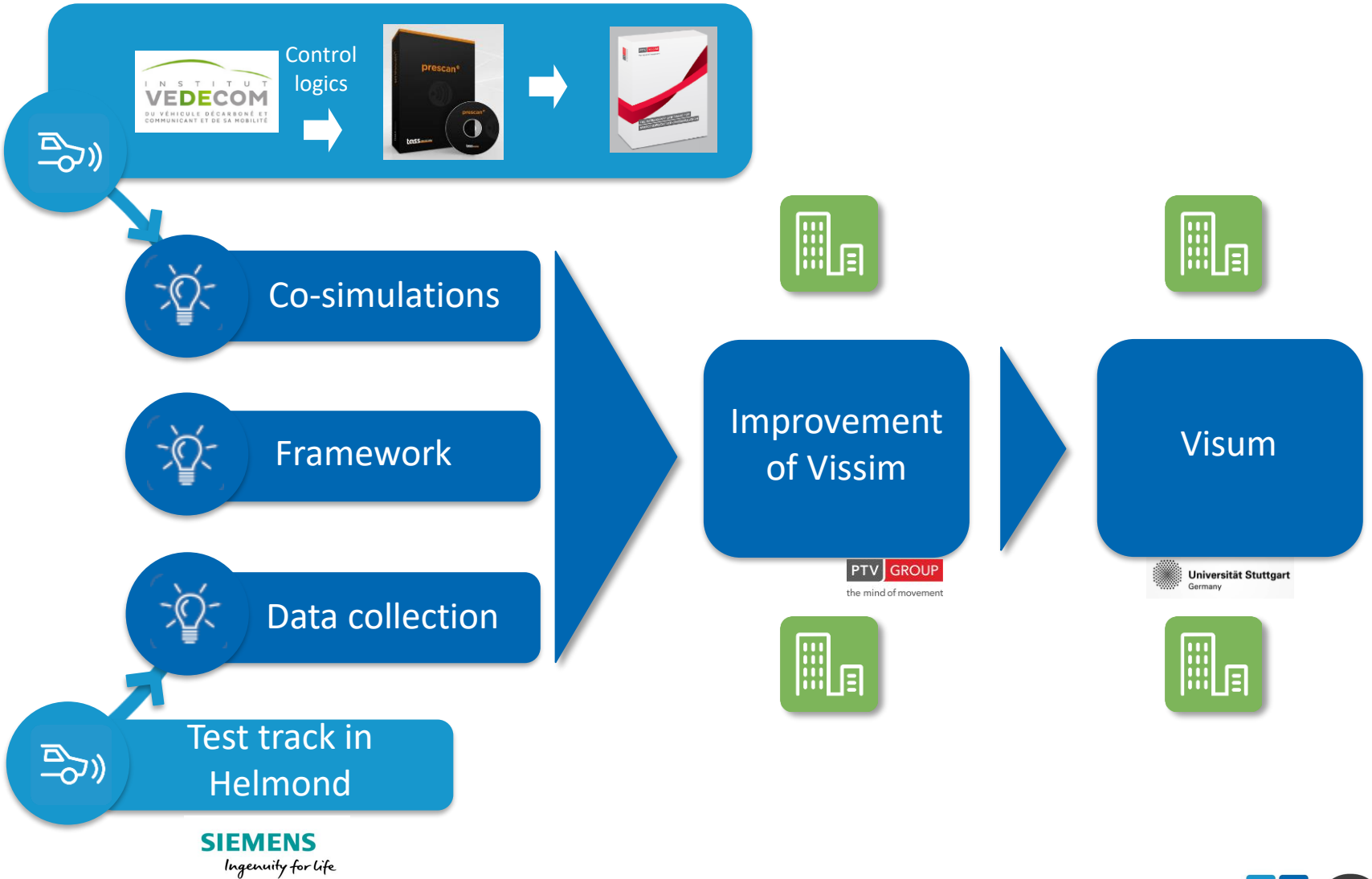
CoEXist

CoEXist approach - Modelling



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CoEXist Material – Modelling tools

- Webinars / videos:
  - PTV Vissim: Autonomous vehicles new features and how-to
    https://www.youtube.com/watch?v=C_bouqPNSw4
  - What‘s new in PTV vissim & Viswalk 11
    https://www.youtube.com/watch?v=yz04_sC9cLo
  - Modelling of automated vehicles in PTV Visum
    https://www.youtube.com/watch?v=PHDeRbvpfkw
  - Automation-ready simulation tool
    https://www.youtube.com/watch?v=aY15DUIiSis
  - Automation-ready transport modeling tools
    https://www.youtube.com/watch?v=Gbht_gZZHM8

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CoEXist Material – Modelling tools

- Deliverables, all available on https://www.h2020-coexist.eu/resources/
  - D2.1 Tested and calibrated control logic, AV-simulator and traffic simulator for closed-loop connection
  - D2.2 Technical report on data collection and validation process
  - D2.3 Default behavioural parameter sets for AVs
  - D2.4 AV-ready microscopic simulation tool
  - D2.5 Guide for the simulation of AVs with microscopic modelling tool
  - D2.6 Technical report on the data collection and validation
  - D2.7 AV-ready macroscopic modelling tool
  - D2.8 Guide for the simulation of AVs with macroscopic tool
  - D2.9 Built-in Av-ready macroscopic tool

  Available soon:
  - D2.10 AV-ready microscopic simulation tool final (including Platooning)
  - D2.11 Guide for the simulation of AVs with microscopic modelling tool (including platooning)

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CoEXist

PTV GROUP

the mind of movement

Charlotte Fléchon
charlotte.flechon@ptvgroup.com

#H2020CoEXist
@H2020_CoEXist

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CoEXist

Poll question

How important, do you think, will be the role of modelling tools to prepare the transition phase (in which conventional cars and automated cars will be sharing the road)?

- Crucial
- Important
- Accessory
- Not important at all

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CoEXist

Poll question

Are you planning to use microscopic simulation tools to simulate automated cars?

- I am doing it already
- Yes, very soon
- Maybe
- Definitely not

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CoEXist Virtual Final Conference - Part 1:
Automation-ready tools and impact assessment findings

Wednesday 25 March 2020

CET (UTC+01:00) — ***Moderator:*** *Siegfried Rupprecht, Rupprecht Consult*

13:45 Registration and technical support

14:00 **Welcome**, Siegfried Rupprecht, *Rupprecht Consult* & INEA (tbc)

Introduction to CoEXist, *Daniel Franco, Rupprecht Consult*

CoEXist tools

Automation-ready transport modelling and infrastructure assessment

14:10 **Overview of the CoEXist impact assessment approach and automation-ready transport (infrastructure) assessment tool**, *Johan Olstam, VTI*

14:25 Polls - Q&A

14:30 **Automation-ready modelling tools: microscopic traffic flow simulation**, *Charlotte Fléchon, PTV Group*

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14:50 **Automation-ready modelling tools: macroscopic travel demand simulation**, *Markus Friedrich, University of Stuttgart*

15:05 Polls - Q&A

15.10 **Toward the Development of Analysis, Modelling, and Simulation (AMS) Tools for Connected and Automated Vehicles (CAVs),** Rachel James, USDOT Federal Highway Administration (FHWA)

15:25 Polls - Q&A

15:30 *Break*

CoEXist impact assessment findings

Potential impact of vehicle automation in four cities, across eight scenarios:

15:45 **Helmond (NL): (i) multimodal signalised intersection and (ii) highway-urban road transition**, *Frank van den Bosch, city of Helmond*

16:00 Polls - Q&A

16:05 **Gothenburg (SE): (i) shared space; (ii) accessibility during long-term roadworks**, *Iman Pereira & Chengxi Liu, VTI*

16:20 Polls - Q&A

16:25 **Milton Keynes (UK): (i) drop off and waiting for passengers; (ii) priority at roundabouts**, *John Miles, University of Cambridge*

16:40 Polls - Q&A

16:45 **Stuttgart (DE): (i) network level travel time & mode choice; (ii) ridesharing**, *Jörg Sonnleitner, University of Stuttgart*

17:00 Polls – Q&A

17:05 **Lessons learnt & conclusions,** *Wolfgang Backhaus, Rupprecht Consult*

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Automation-ready modelling tools: macroscopic travel demand modelling

Markus Friedrich

University of Stuttgart
Germany

#H2020CoEXist
@H2020_CoEXist

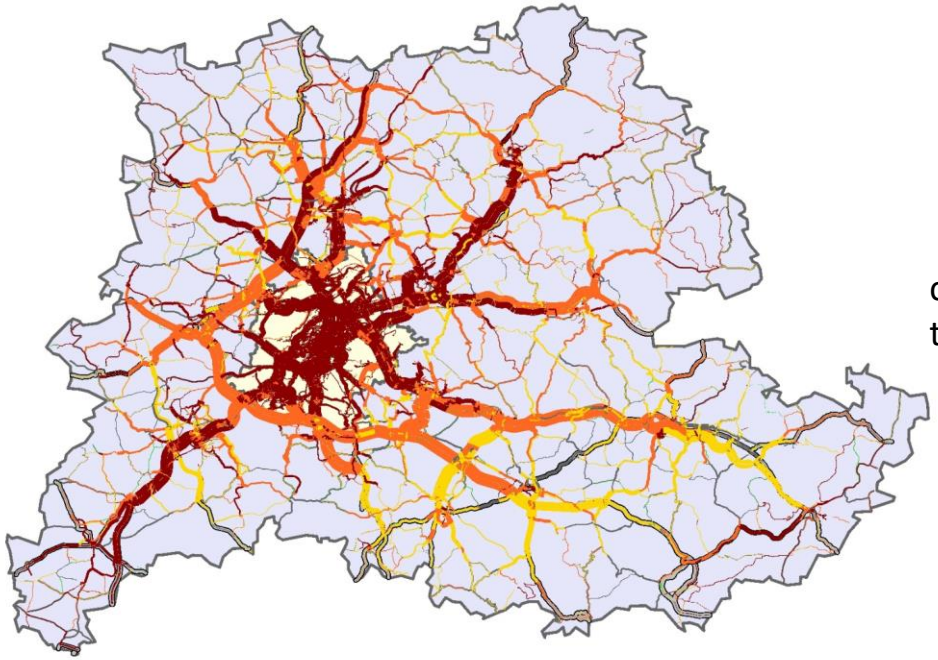
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201-2

How will AV change the way we travel?

- better cars
- more carsharing

- better cars
- more ridesharing
- better public transport

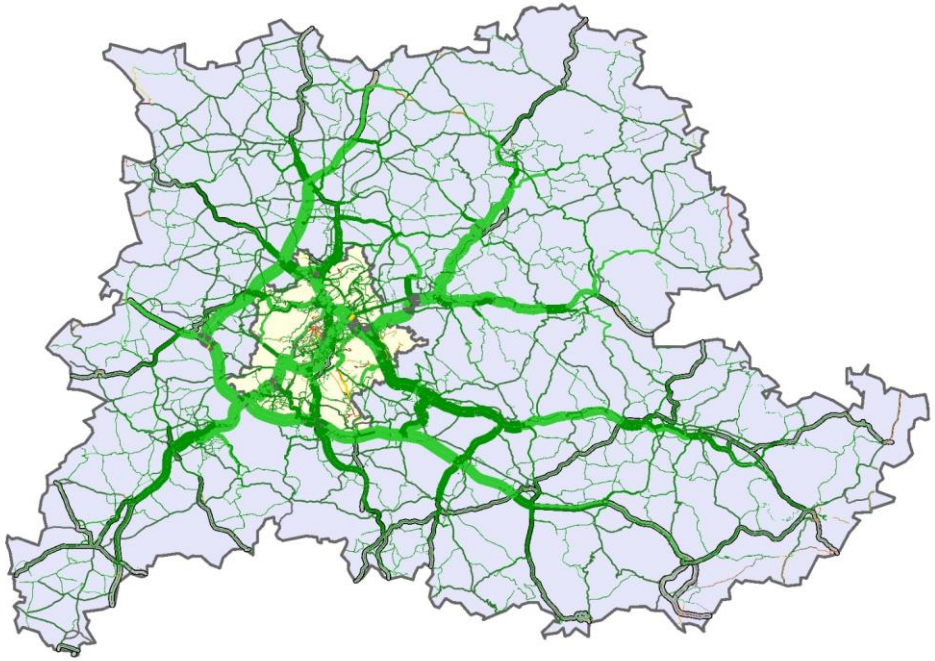
more car traffic



changes compared to base case

- ≤ 75
- ≤ 95
- ≤ 105
- ≤ 120
- ≤ 140
- > 140

less car traffic



Modelling AV with Macroscopic Travel Demand Models

motivation

- many cities run macroscopic travel demand models
  and may want to examine impacts of automated vehicles

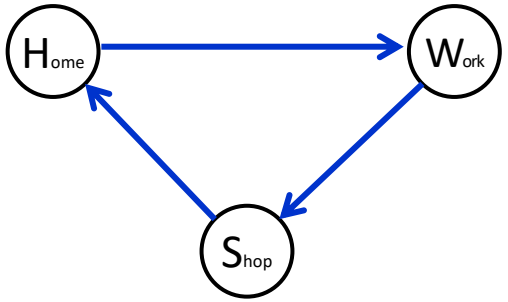
modelling challenge

- people live in zones
- demand is represented not as full trips, but as probability

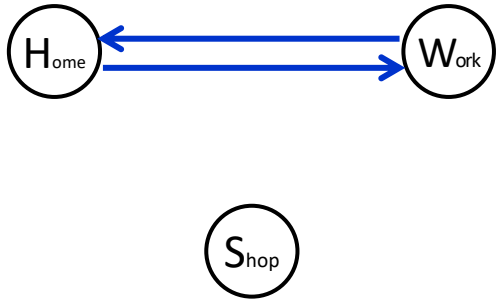
➔ this is challenging for modelling on-demand services

I am 0.4 persons. Is there free space in a sharing vehicle from zone 10 to 20?

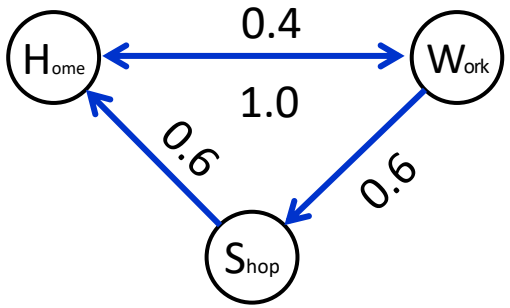
Agent-based: Mon, Wed, Fri



Tue, Thu

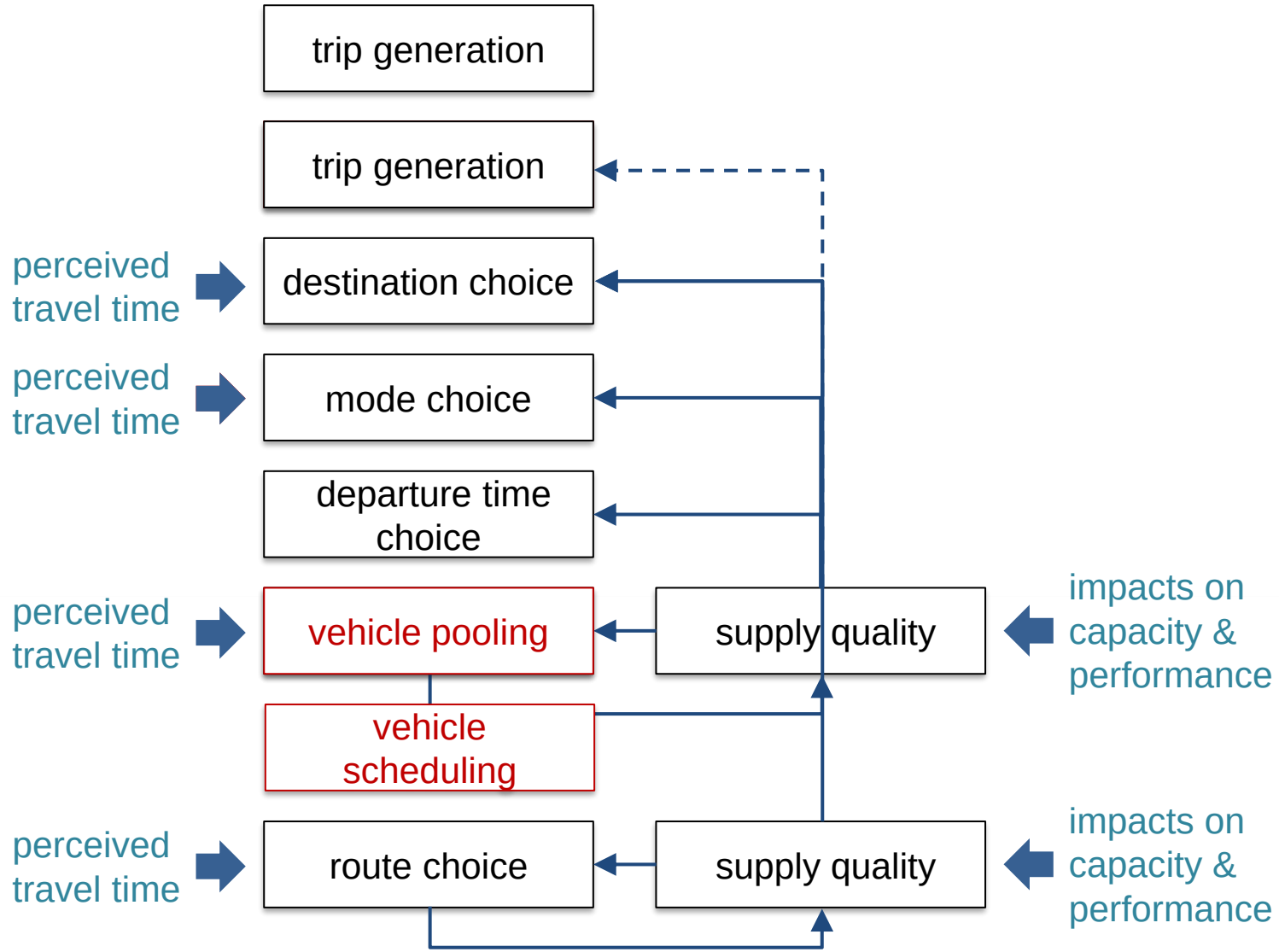


Macroscopic $ADTV_{W5}$



Modelling AV with Macroscopic Travel Demand Models

new modes,
changed utilities



Modelling AV with Macroscopic Travel Demand Models

- **Impacts on supply: volume-delay functions**
- Impacts on demand: without new modes (Level < 5)
- Impacts on demand: with new modes (Level = 5)

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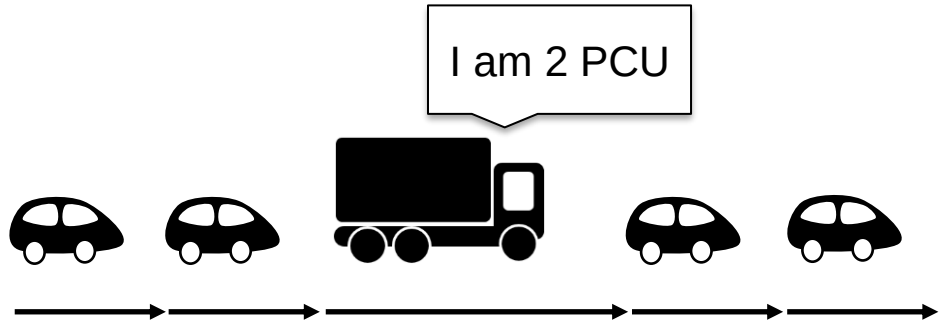
Capacity & Performance

Assignment models use volume-delay functions

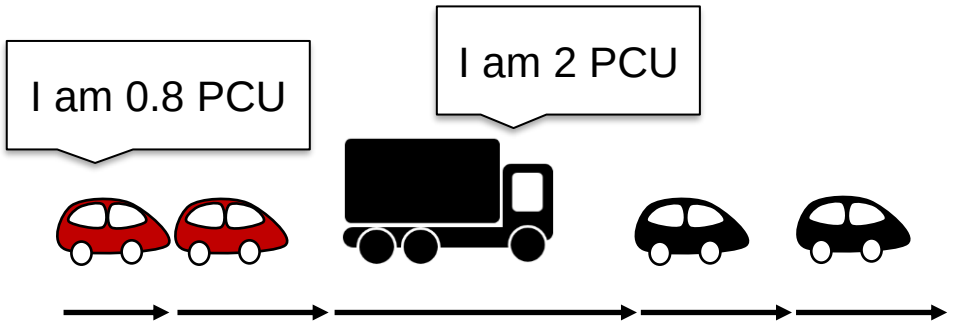
today

- LDV & HDV
- trucks are converted to PCU (Passenger Car Units)



future with AV

- LDV & HDV conventional
- LDV & HDV as AV



Capacity & Performance

- suggested PCU-values from microscopic simulations

Roadway	Cautious	Normal	All-knowing
Motorway	1.20	0.77	0.73
Arterial	1.26	0.81	0.76
Urban street	1.32	0.85	0.79

+

Roadway	Basic AV	Intermediate AV	Advanced AV
Motorway	Cautious	Normal	All-knowing
Arterial	Cautious	Normal	All-knowing
Urban street	Manual	Cautious	Normal

=

Roadway	Basic AV	Intermediate AV	Advanced AV
Motorway	1.20	0.77	0.73
Arterial	1.26	0.81	0.76
Urban street	1.00	1.32	0.85

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Modelling AV with Macroscopic Travel Demand Models

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- **Impacts on demand: without new modes (Level < 5)**
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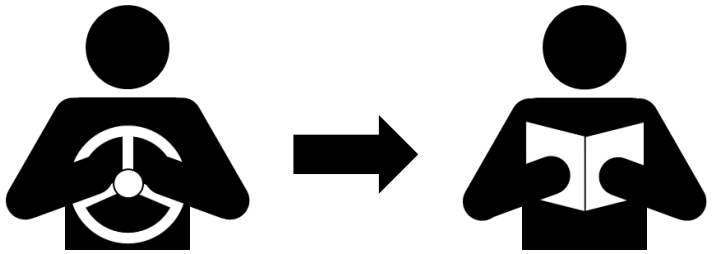
Impacts on demand without new modes

- being driven in automated mode changes the perception of travel time



- Highly, but not fully automated AV

  → changes attractiveness of mode Car

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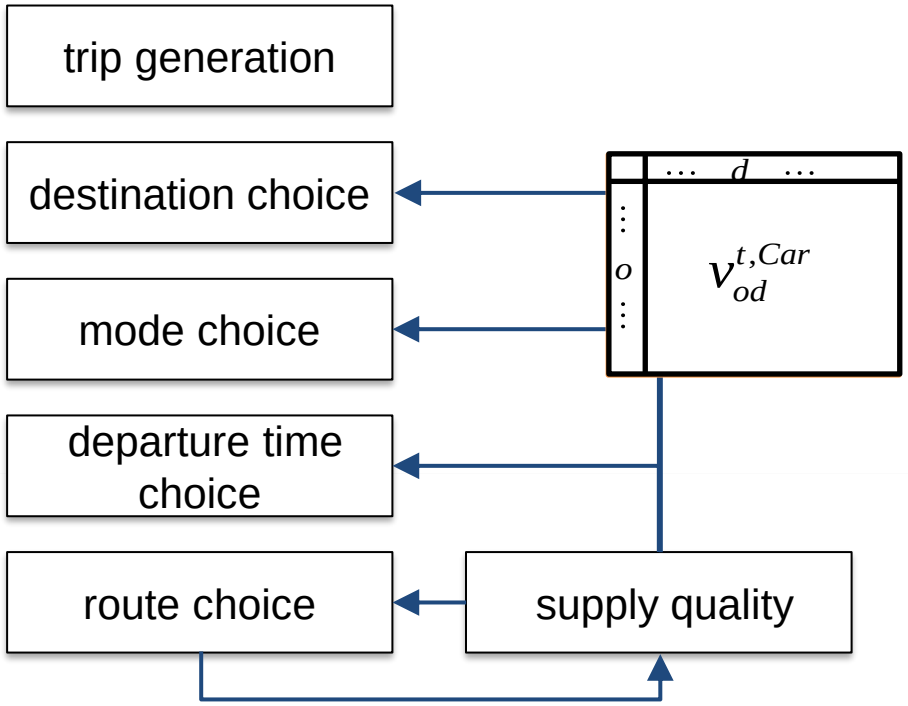
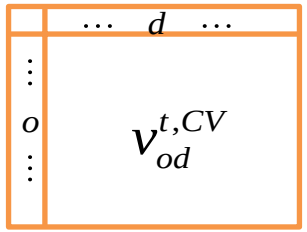
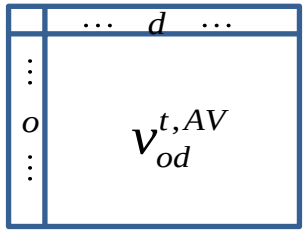
Impacts on demand without new modes



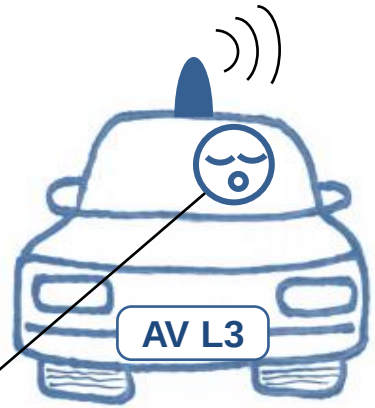
$$v_{od}^{t,Car} = \left(1 - p_{AV}\right) \cdot v_{od}^{t,CV} + p_{AV} \cdot v_{od}^{t,AV}$$



$\left(1 - p_{AV}\right)$



p_{AV}



non-active driving time

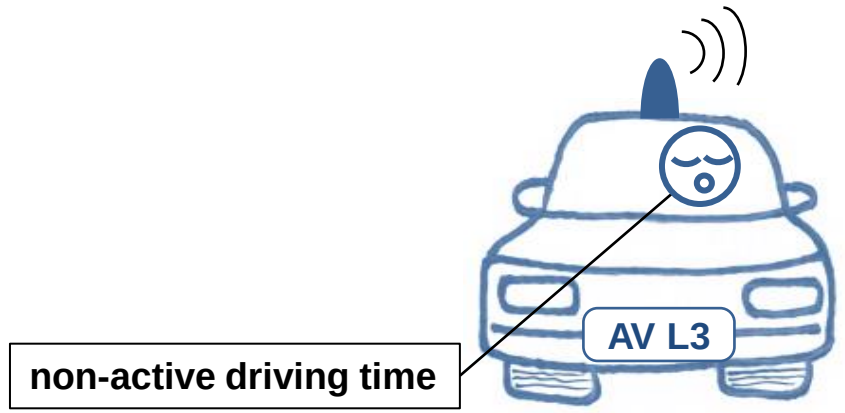
Application Example

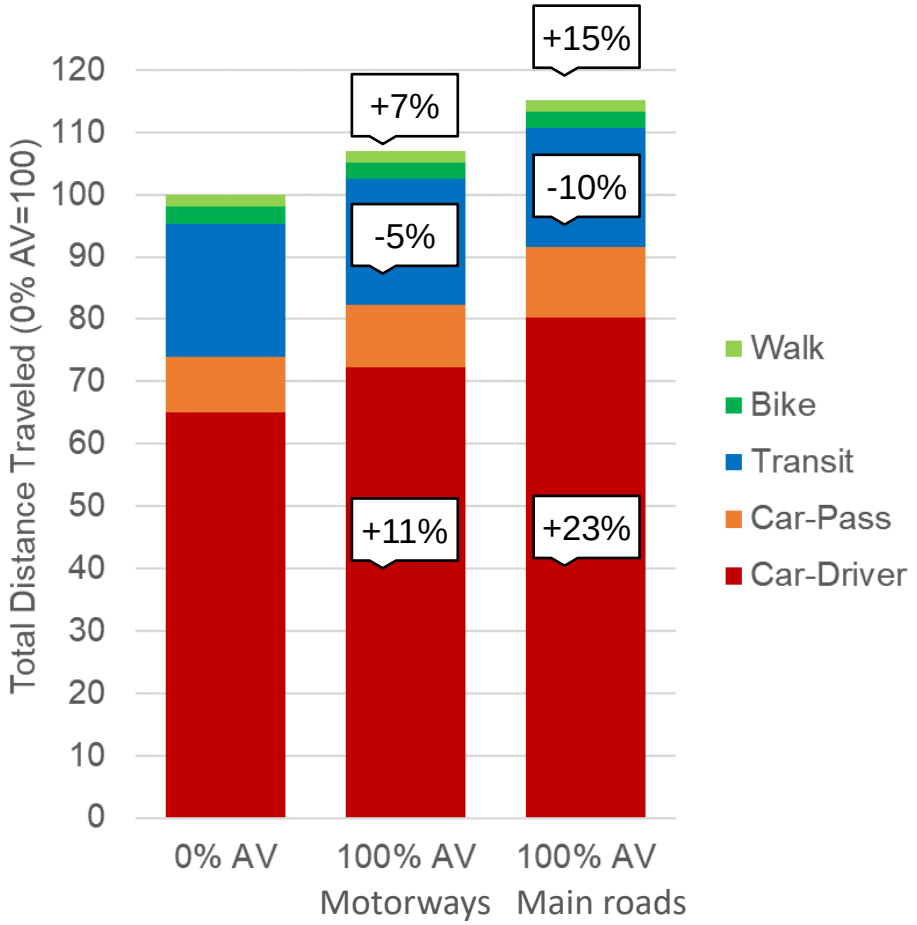
modelling assumptions

- advanced AV
- motorways are AV-ready
- main roads are AV-ready
- reduction of travel time perception by 30% on AV-ready roads

results in the Stuttgart Region model

- PersonKm all modes +7% / +15%
- PersonKm Car +11% / +23%
- PersonKm Transit -5% / -10%





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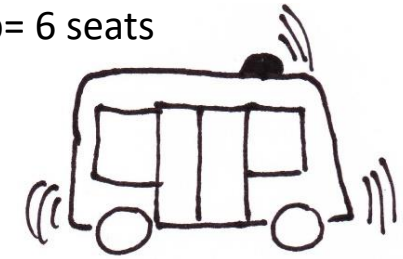
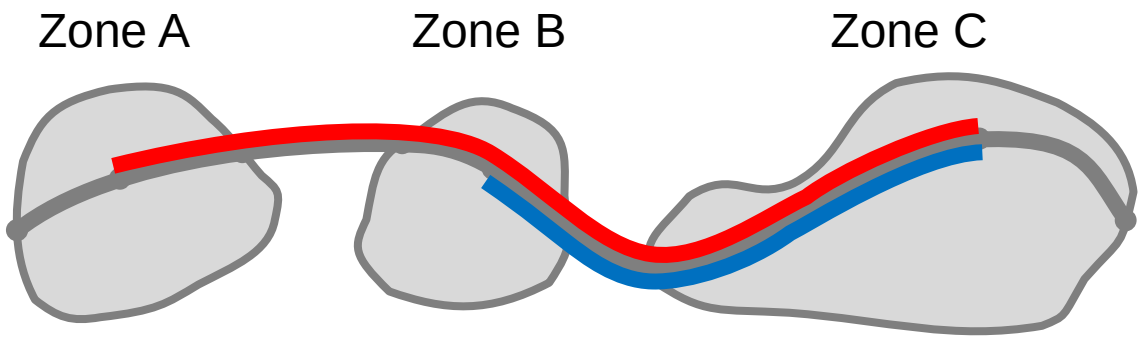
Ridepooling for AV-fleets

ridepooling
integer demand

Cap= 6 seats

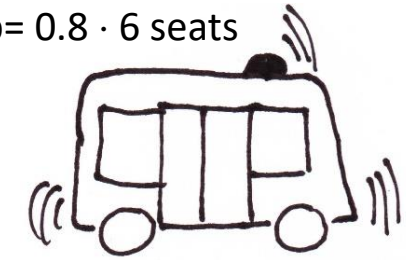


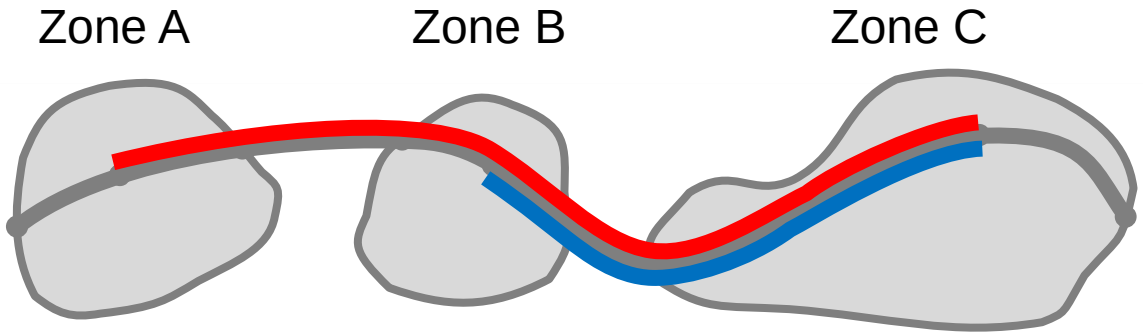


1 person trip + 1 person trip = 1 vehicle trip

ridepooling
non-integer demand

Cap= 0.8 · 6 seats



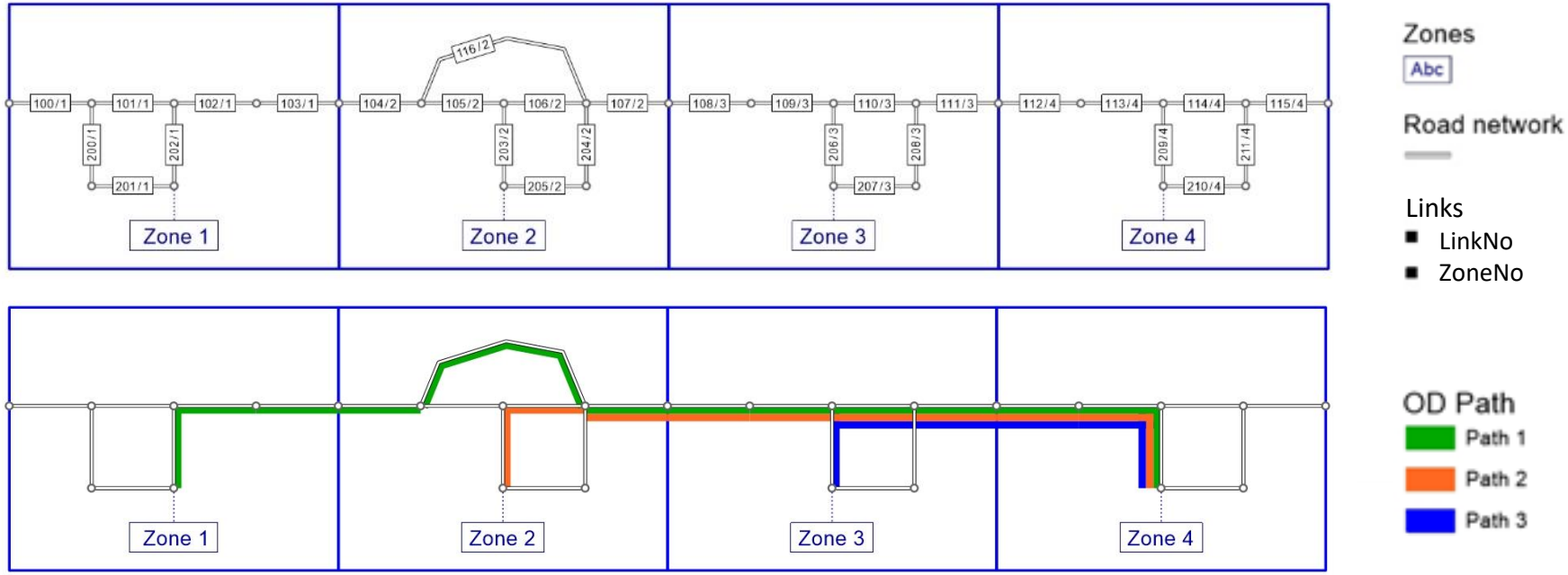


0.8 person trip + 0.6 person trip = 0.8 vehicle trip

Ridepooling – Matching Algorithm

1. Discretise demand into time intervals, e.g. 96 x 15 min

2. Assign ZoneNo to each road link



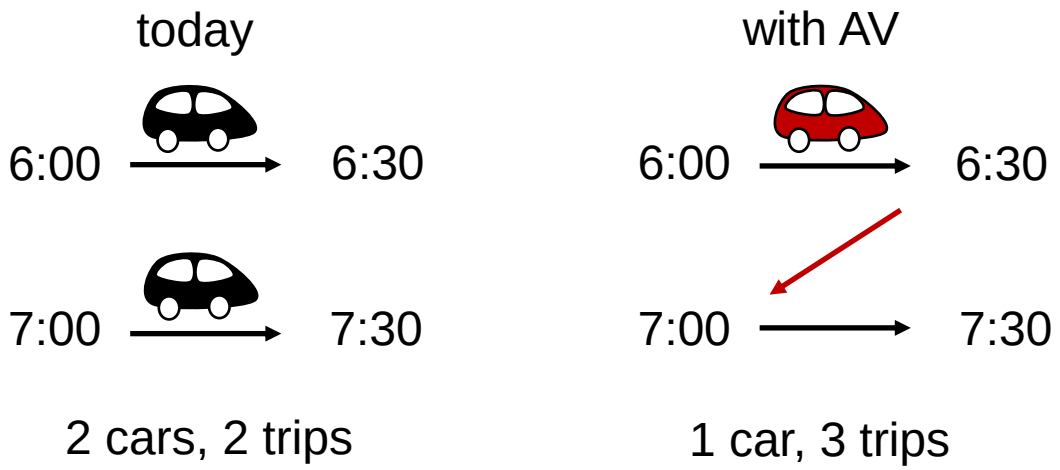
3. Compute one shortest path for each od-pair

4. Describe every path as a sequence of zones

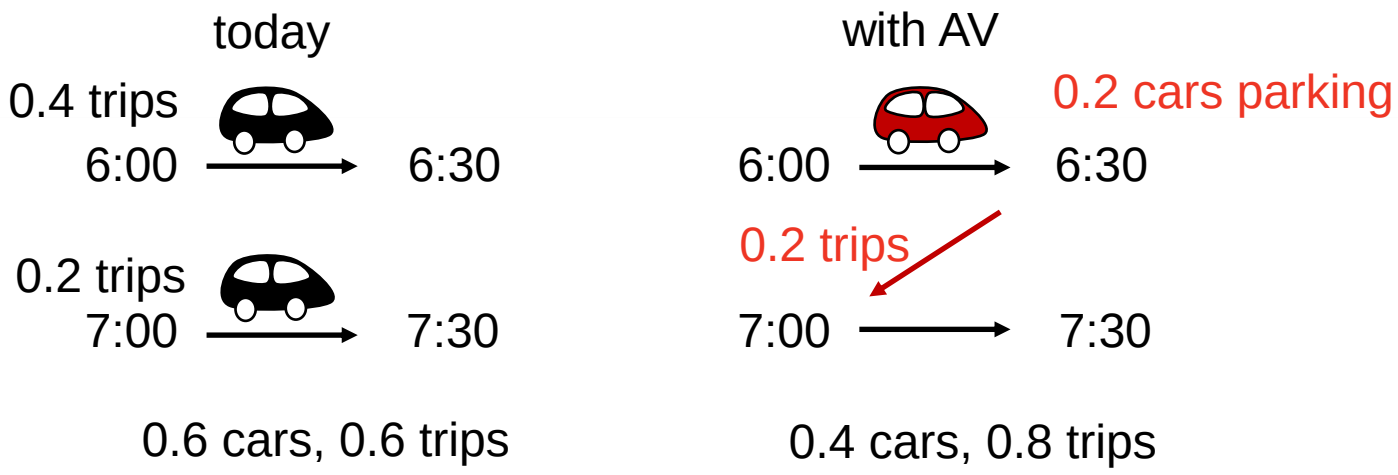
path	from	to	sequence of links (or nodes)	sequence of zones	
				complete	without duplicates
1	1	4	202,102,103,104,116,107,108,109,110,111,112,113,209	1,1,1,2,2,2,3,3,3,3,4,4,4	1,2,3,4
2	2	4	203,106,107,108,109,110,111,112,113,209	2,2,2,3,3,3,3,4,4,4	2,3,4

Vehicle Scheduling for AV-fleets

vehicle scheduling:
integer demand



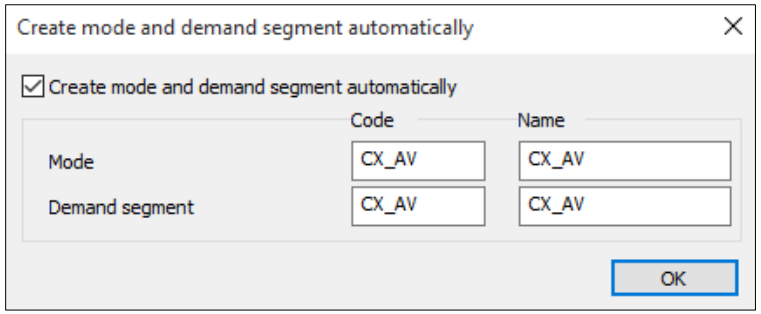
vehicle scheduling:
non-integer demand

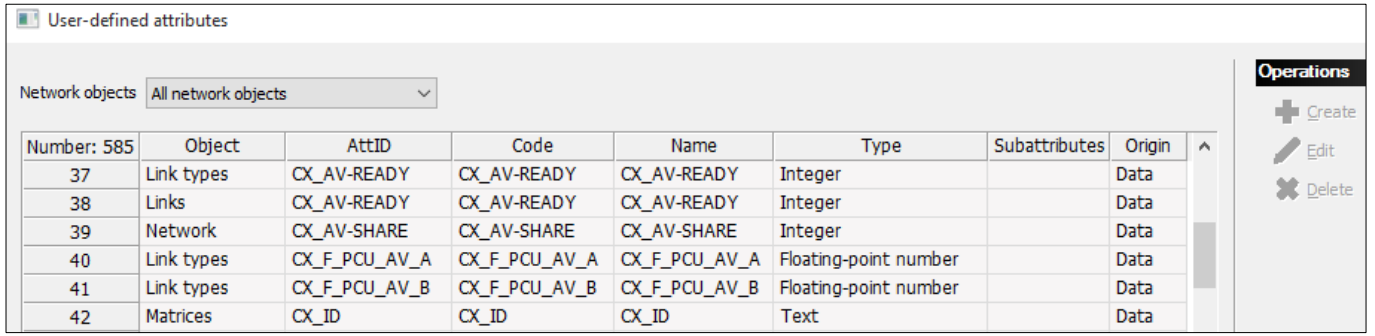


➔ formulation as flow problem

Visum Integration

- All presented extensions can be integrated into the software Visum to support AV-ready travel demand modelling





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39	Network	CX_AV-SHARE	CX_AV-SHARE	CX_AV-SHARE	Integer		Data
40	Link types	CX_F_PCU_AV_A	CX_F_PCU_AV_A	CX_F_PCU_AV_A	Floating-point number		Data
41	Link types	CX_F_PCU_AV_B	CX_F_PCU_AV_B	CX_F_PCU_AV_B	Floating-point number		Data
42	Matrices	CX_ID	CX_ID	CX_ID	Text		Data

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Poll question

How will AVs affect travel demand by 2040?

- AVs are more comfortable and will lead to more car traffic
- AVs can be used for sharing and will reduce car ownership
- AVs will reduce travel by public transport
- Integrating ridesharing will strengthen public transport
- Empty vehicle trips will increase car traffic

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CoEXist tools

Automation-ready transport modelling and infrastructure assessment

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17:05 **Lessons learnt & conclusions,** *Wolfgang Backhaus, Rupprecht Consult*

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CoEXist

Driving Innovation

Toward the Development of Analysis, Modeling, and Simulation (AMS) Tools for Connected and Automated Vehicles (CAVs)

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Federal Highway Administration

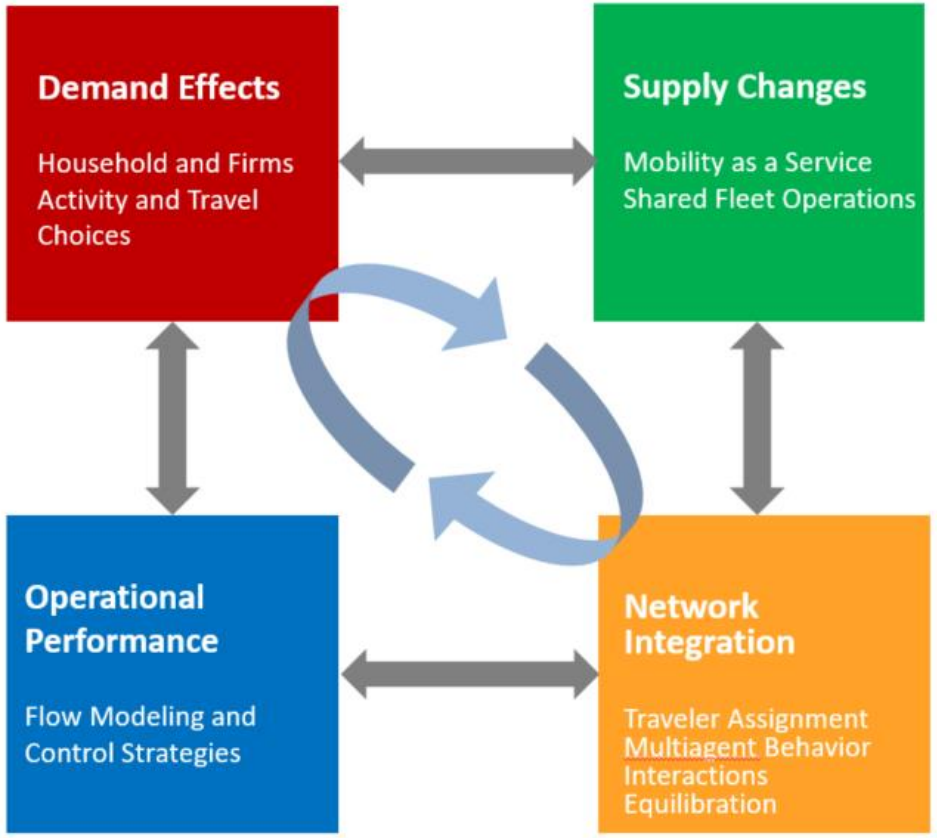
SAXTON LABORATORY

Twinned Projects Overview

- Two FHWA projects were twinned with CoEXist:
  - CAV AMS Framework.
  - Developing AMS Tools for CAV Applications:
    - Case Studies.
    - Tools Development.
- The goals of these projects are to investigate the effectiveness of level 1 automation technology for mitigating or solving existing transportation problems.

Development of a CAV AMS Framework

- Objectives:
  - Build comprehensive methodological framework for developing AMS tools incorporating the impacts of CAVs.
  - Conduct an analysis identifying gaps in existing CAV AMS capabilities.
  - Apply developed framework to conduct a small-scale case study to illustrate how to use this framework for future development activities.



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Developing AMS Tools for CAV Applications: Case Studies

- Benefits assessment using *existing* tools and capabilities.
- Arterial case studies:
  - Ann Arbor, Michigan.
  - Conroe, Texas.
- Freeway case studies:
  - California (SR–99).
  - Virginia (I–66).
- Local agencies were involved to ensure simulations represent realistic, near-term deployments.

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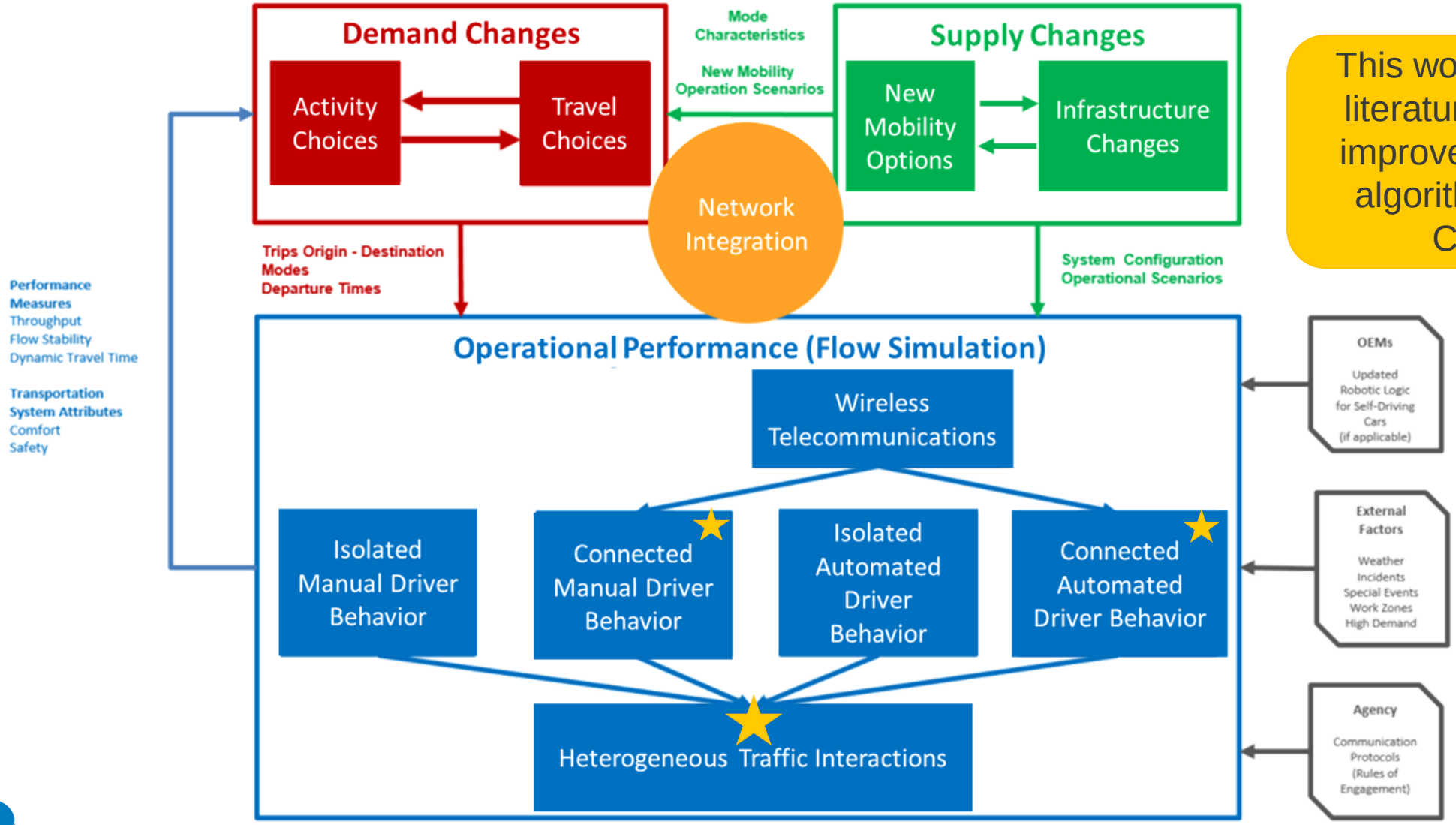
  - **Virginia (I–66).**
- Local agencies were involved to ensure simulations represent realistic, near-term deployments.

SR–99 Case Study: Motivation

- Study impacts of cooperative adaptive cruise control (CACC) on complex corridor.
  - Initial studies suggest potentially significant increases in capacity on idealized corridors.
  - Need to better understand impacts of CACC on real-world freeway corridors.
    - Complex congestion patterns result from the interplay of multiple bottlenecks.
    - Throughput improvement in one bottleneck may aggravate congestion at downstream bottlenecks.
- SR–99, urban corridor serving commuter traffic in California, selected for detailed analysis.

SR–99 Case Study: Framework Contributions

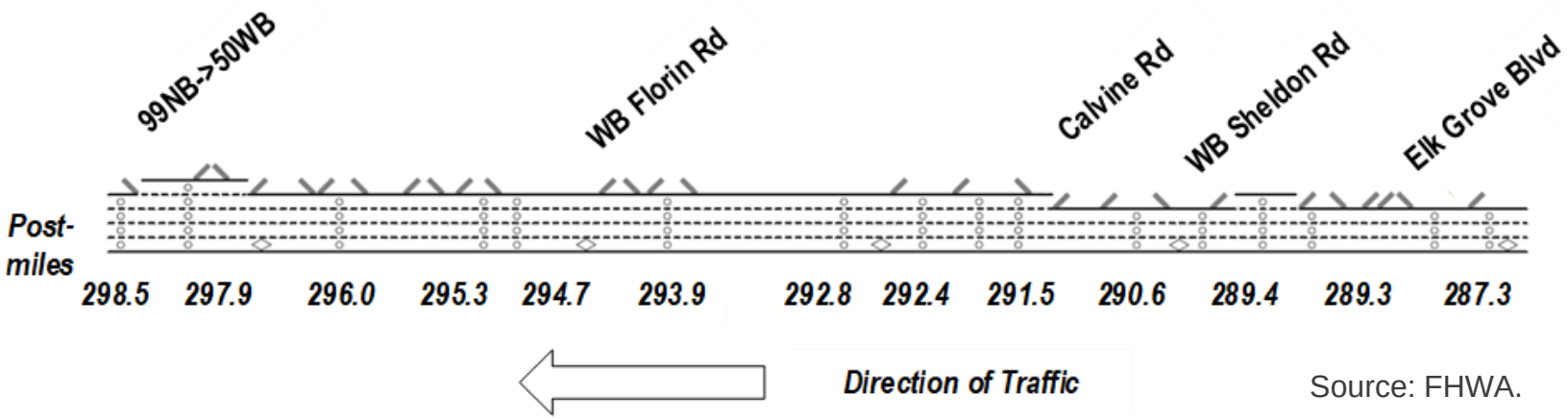


This work contributes to the literature by developing an improved CACC simulation algorithm and quantifying CACC impacts.

OEM: Original equipment manufacturer.

SR–99 Case Study: Objectives

- This study seeks to evaluate the impact of:
  - CACC application.
  - CAV managed lane (ML) operational strategy.
  - Vehicle awareness device (VAD), which provides connectivity for manually driven vehicles.



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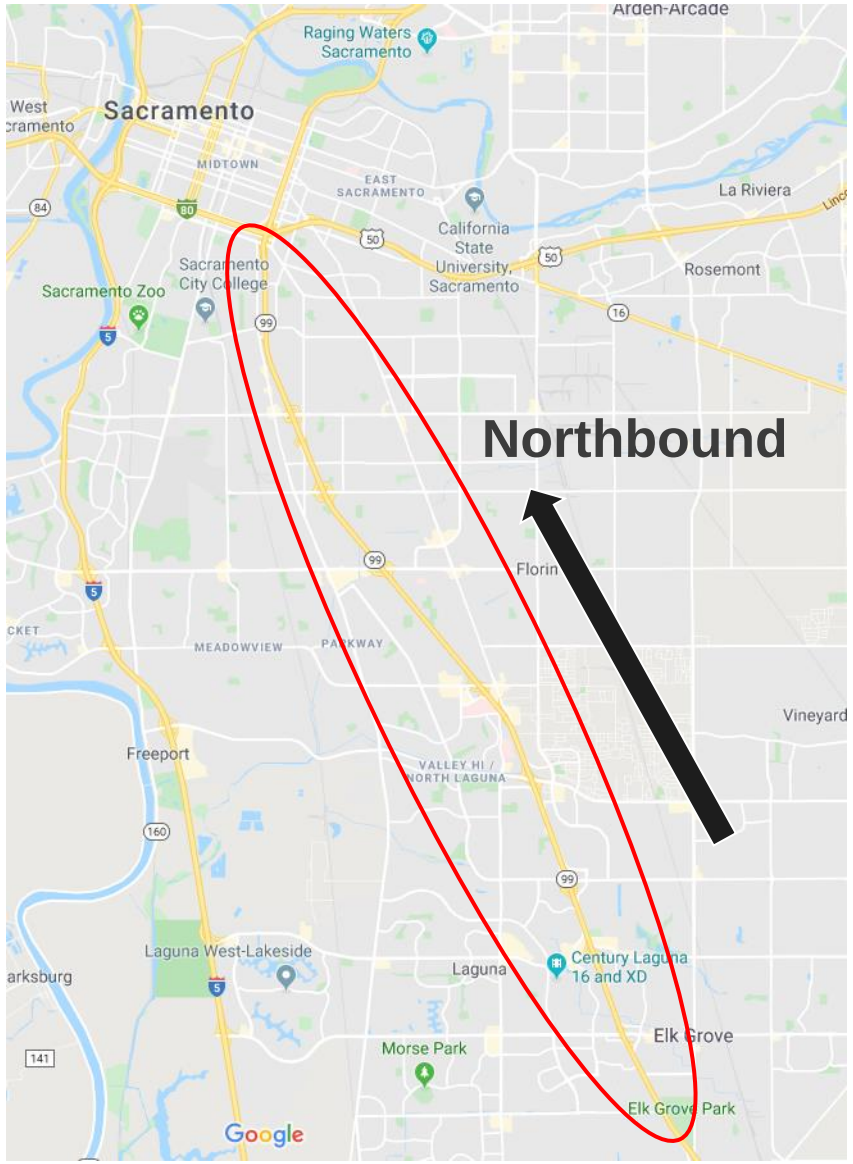
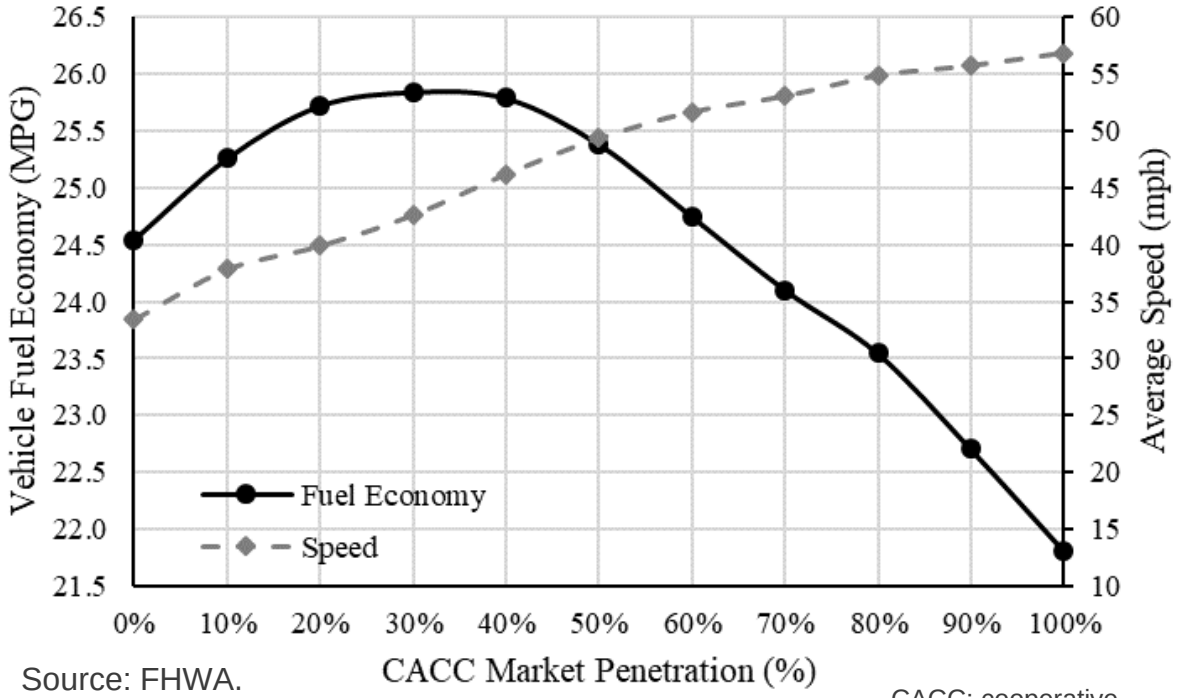


© 2019 Google Maps. Map modifications: FHWA.

SR–99 Study: Results

Effects of CACC market penetration rate (MPR):

- Speed increases with MPR: smoother traffic due to CACC.
- Fuel economy increases then decreases: congestion relief, but then higher speed travel.



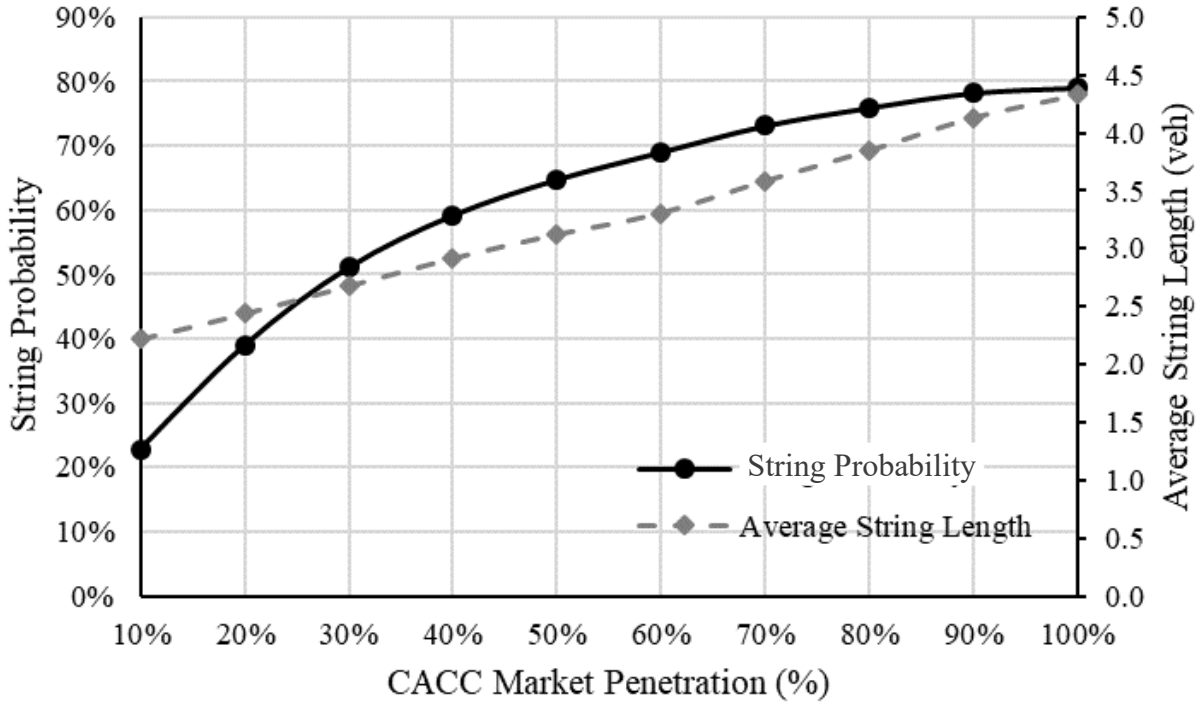
Source: FHWA.

CACC: cooperative adaptive cruise control.

SR–99 Study Results

Effects of CACC MPR:

- Longer strings with MPR, but much shorter than the length limit.
- Low string probability at 100 percent CACC.
- **String formation algorithm** needed to increase probability that CACC-capable vehicles actually drive in CACC strings.



Source: FHWA.

SR–99 Study: Results

Effects of traffic demand increase:

- Corridor capacity identified while maintaining a constant average speed.
- A 30 percent capacity increase under 100 percent CACC MPR.
- Lower capacity benefit compared with the isolated bottleneck case (i.e., 92 percent increase in capacity).

Average Vehicle Speed (mph)

CACC (%)	100% Demand	105% Demand	110% Demand	115% Demand	120% Demand	125% Demand	130% Demand
0	**33.4**	22.8	17.6	14.8	13.1	N/A	N/A
20	39.9	**32.6**	26.1	18.2	16.0	N/A	N/A
40	46.2	39.8	**34.6**	28.7	18.9	N/A	N/A
60	51.6	46.9	42.2	**35.1**	27.3	17.0	14.0
80	54.8	52.5	48.3	43.3	**34.2**	23.5	19.2
100	56.8	54.3	52.5	49.9	44.6	35.2	**32.7**

N/A = Model results were not obtained within 48 hours of run time because of significant network congestion.

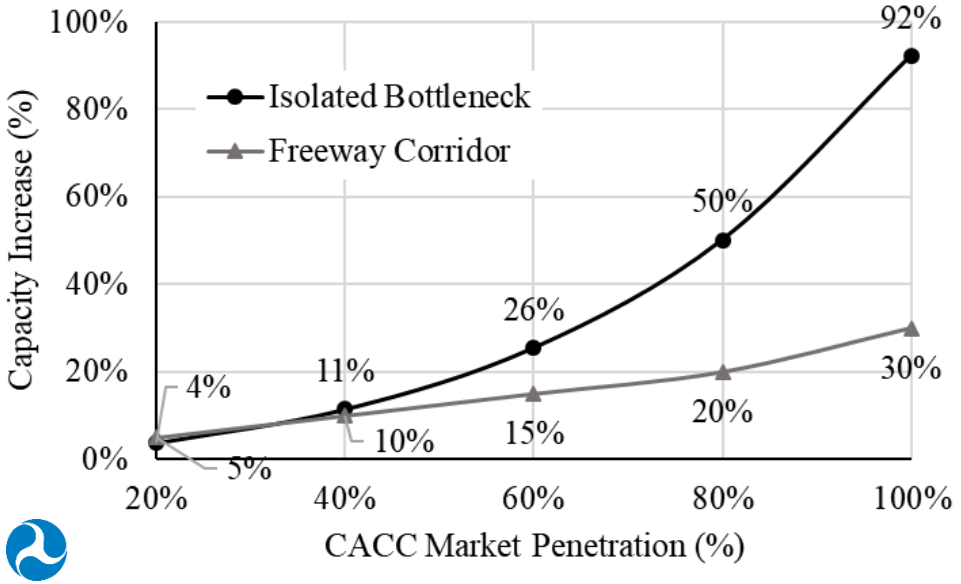
CACC: cooperative adaptive cruise control.

Source: FHWA.

SR–99 Study Results

Why was the capacity benefit lower for the freeway corridor?

- Observe improvement of upstream bottlenecks resulting in worse downstream bottlenecks.
- Might require infrastructure-to-vehicle (I2V) applications (e.g., speed harmonization) with CACC to **maximize the freeway corridor performance**.



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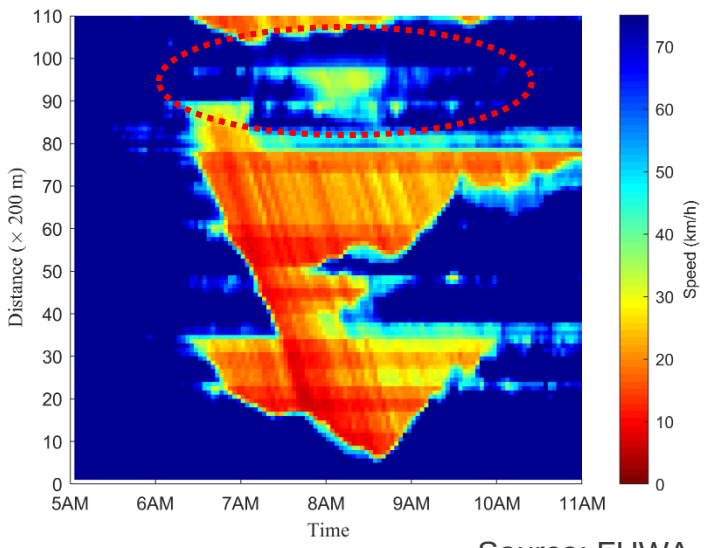
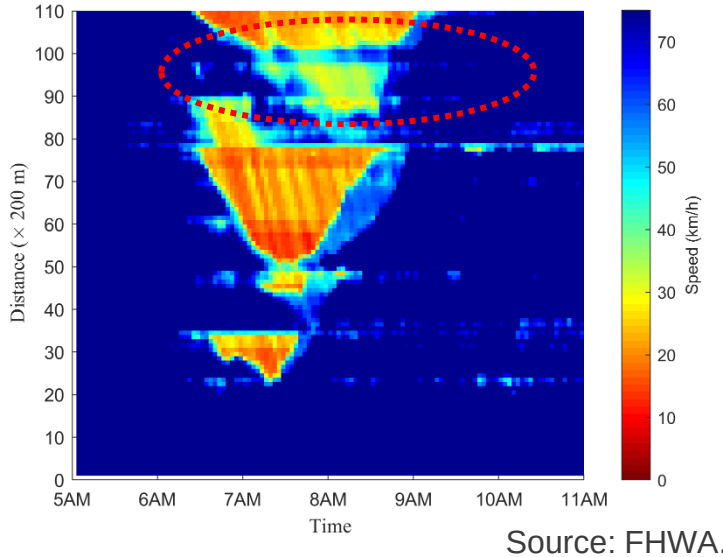


Source: FHWA.

20% CACC
10% demand increase



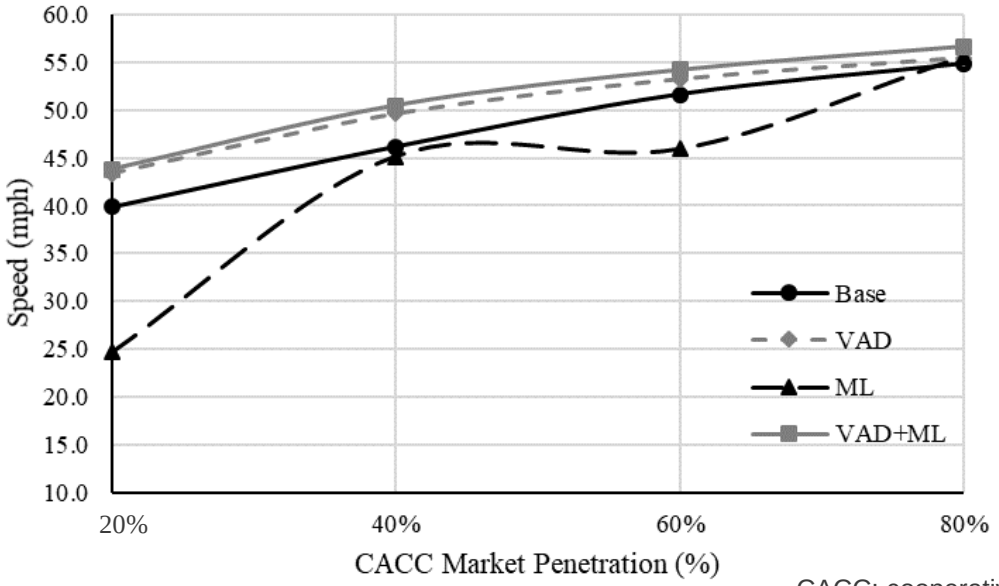
Source: FHWA.

40% CACC
10% demand increase

SR–99 Study: Results

Effects of ML and VAD strategy:

- VAD helps CACC string formation under low to medium MPRs.
- ML strategy makes performance worse, causing induced lane changes.
- Dedicated on-ramps might help ML strategy implementation.



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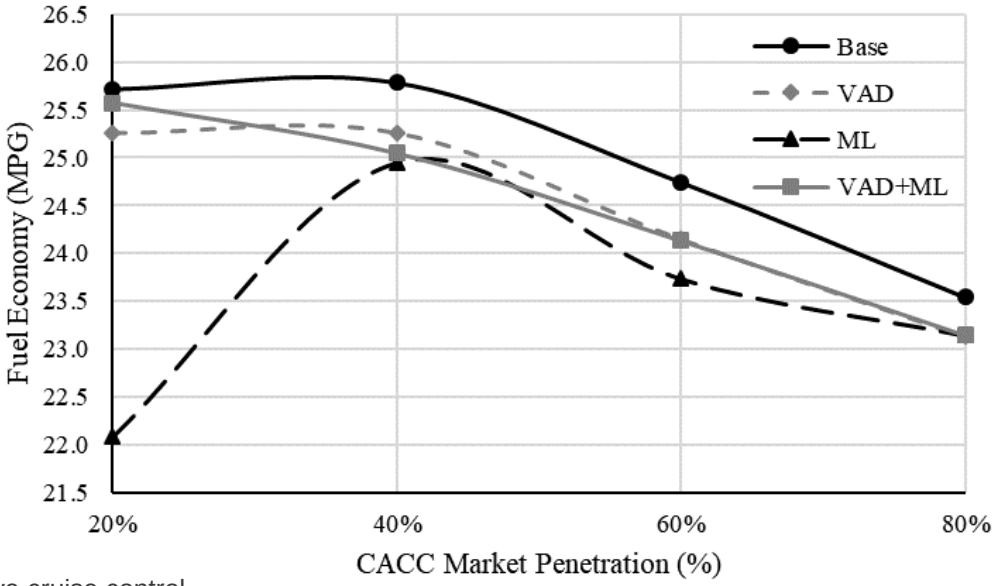
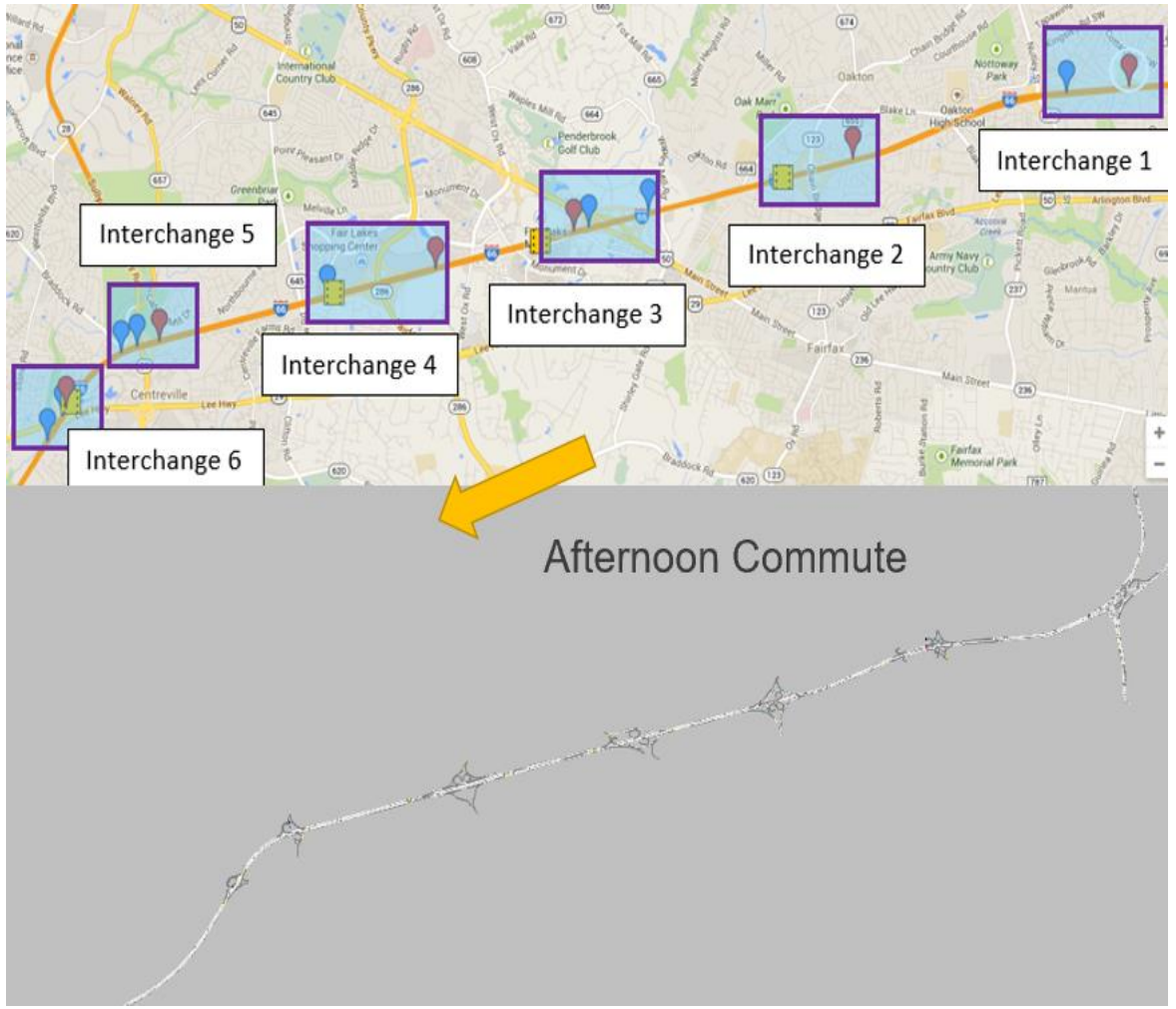


Source: FHWA.

CACC: cooperative adaptive cruise control.
ML: managed lane.
VAD: vehicle awareness device.

I–66 Case Study: Objectives

- The study evaluated the effectiveness of three CAV applications:
  - CACC.
  - Speed harmonization (SH).
  - Cooperative merge (CM).
- The case study also evaluated the potential benefits of changes to the physical infrastructure, including dedicated ramps and a ML.

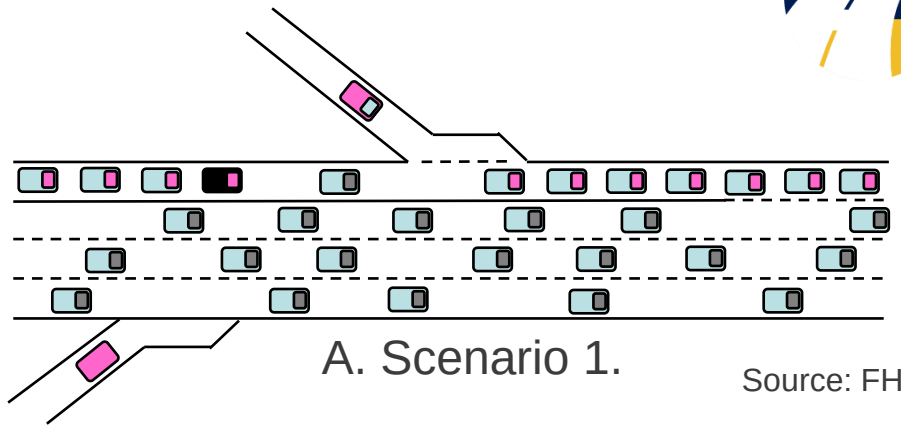


Source: FHWA.

Three ML Scenarios

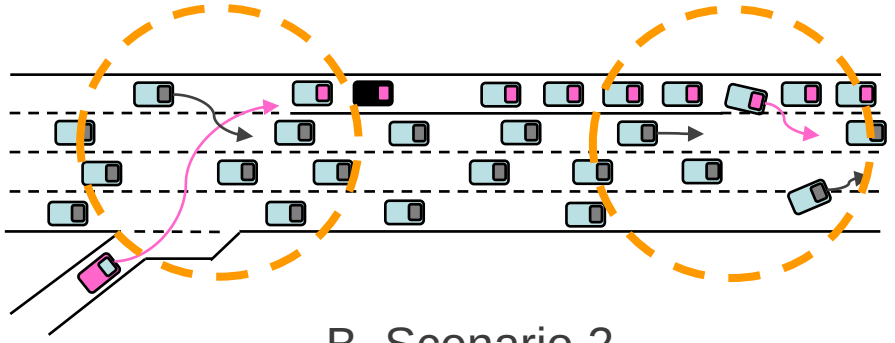
Scenario	ML Access (CV, CAV)	ML Access (HOV)	Dedicated Ramp for ML
1	✓	✓	✓
2	✓	✓	✗
3	✗	✓	✗

HOV = high-occupancy vehicle.



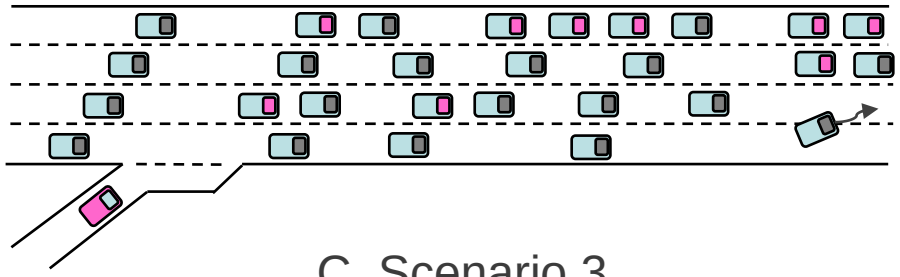
A. Scenario 1.

Source: FHWA.



B. Scenario 2.

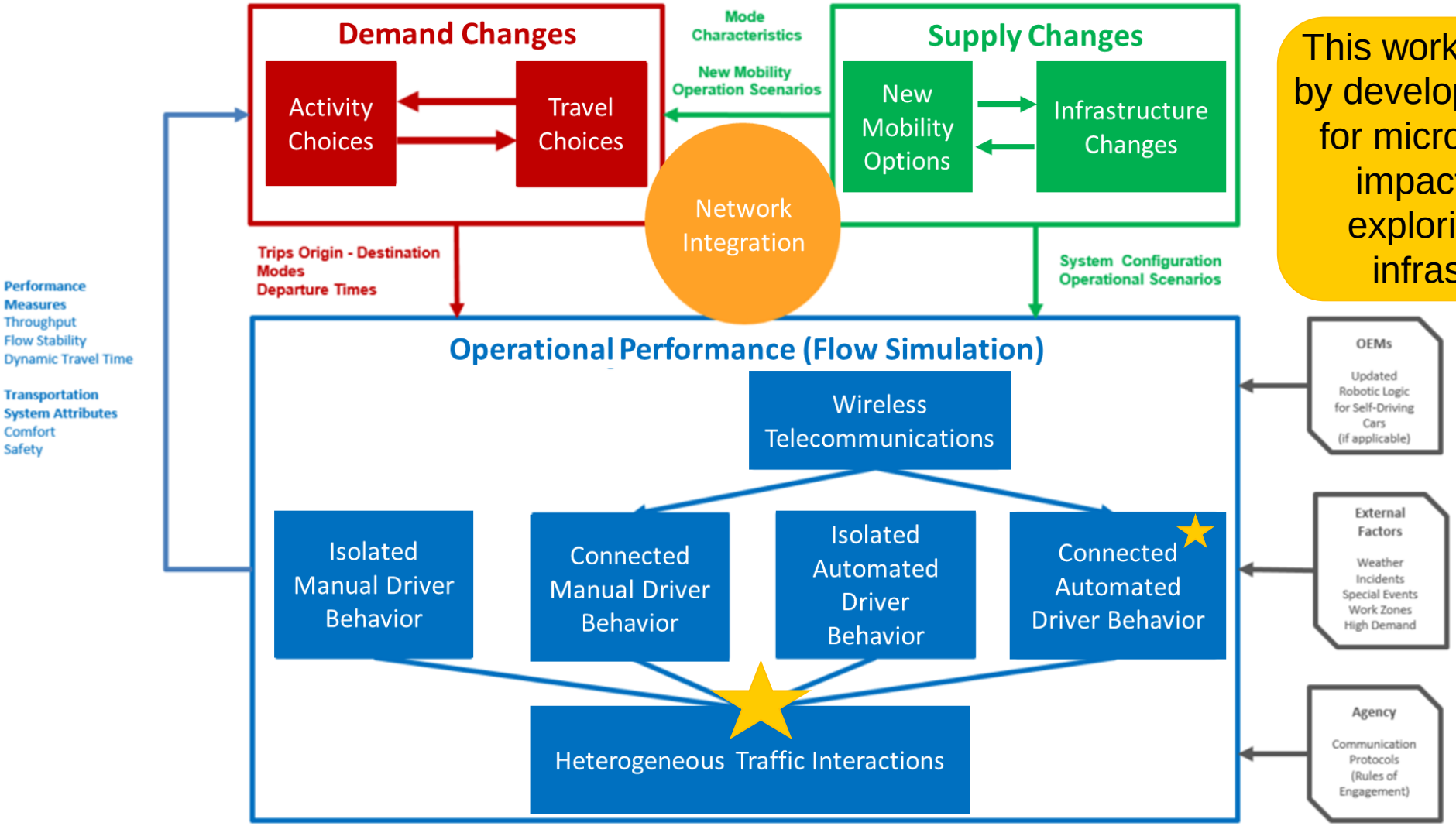
Source: FHWA.



C. Scenario 3.

Source: FHWA.

I–66 Case Study: Framework Contributions

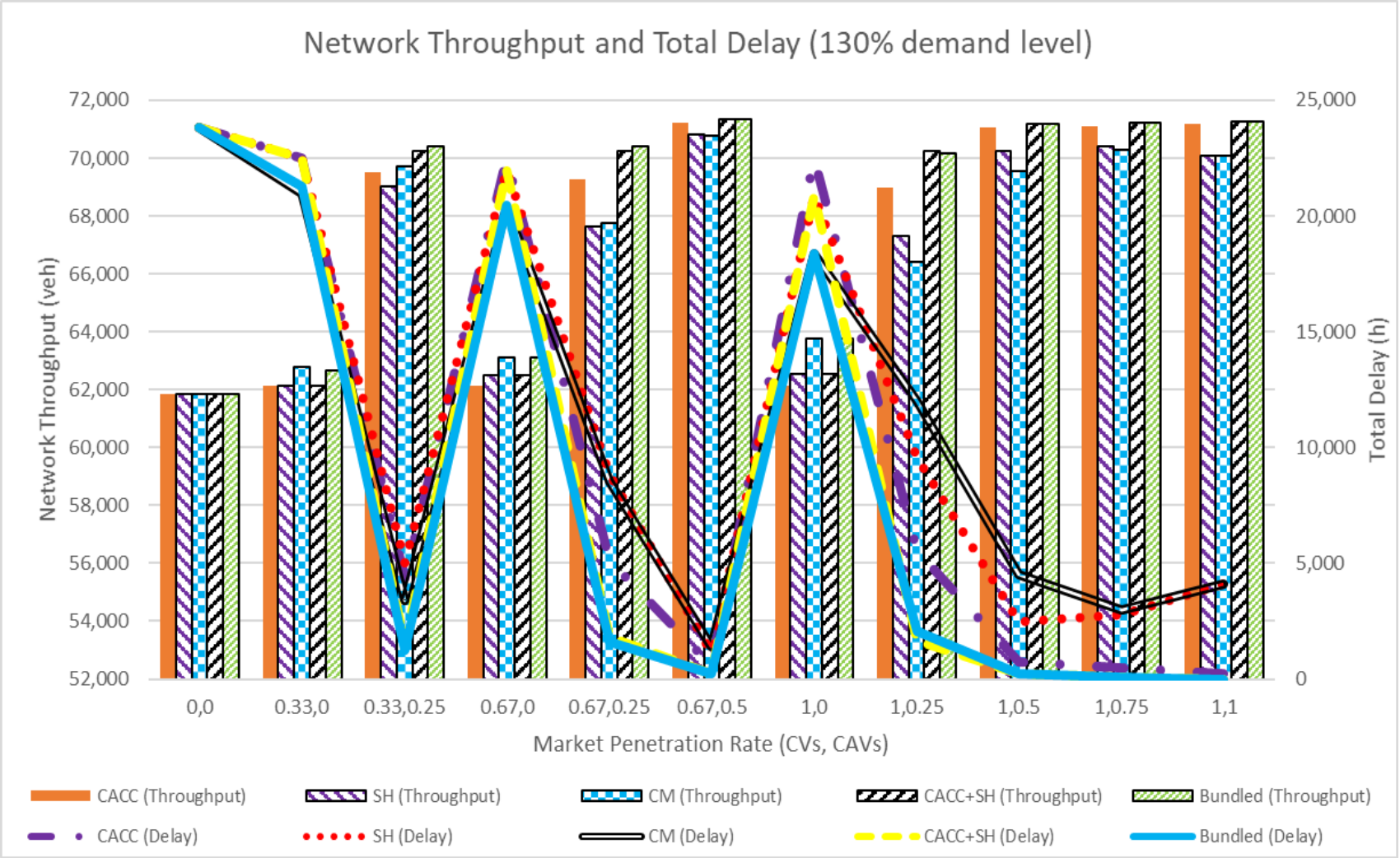


This work contributes to the literature by developing a SH and CM algorithm for microsimulation; quantifying the impact of the applications; and exploring the impact of different infrastructure configurations.

OEM: Original equipment manufacturer.

I–66 Case Study: Results

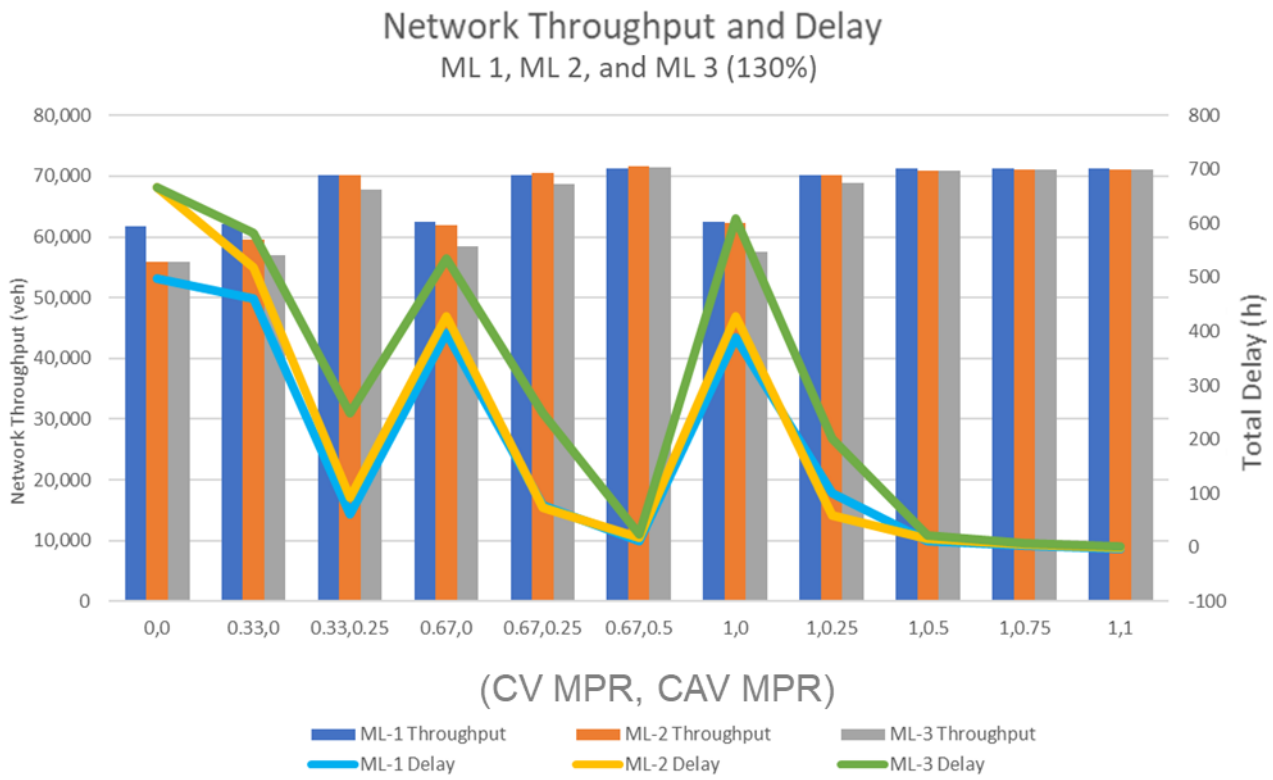
- CACC platooning generates most of the traffic flow benefits.
- SH and CM bundling further increases traffic flow benefits when CAV market penetration rates are low to medium.



Source: FHWA.

CACC: cooperative adaptive cruise control.
CAV: connected and automated vehicle.
CM: cooperative merge.
CV: connected vehicle.
SH: speed harmonization.

I–66 Case Study: Results

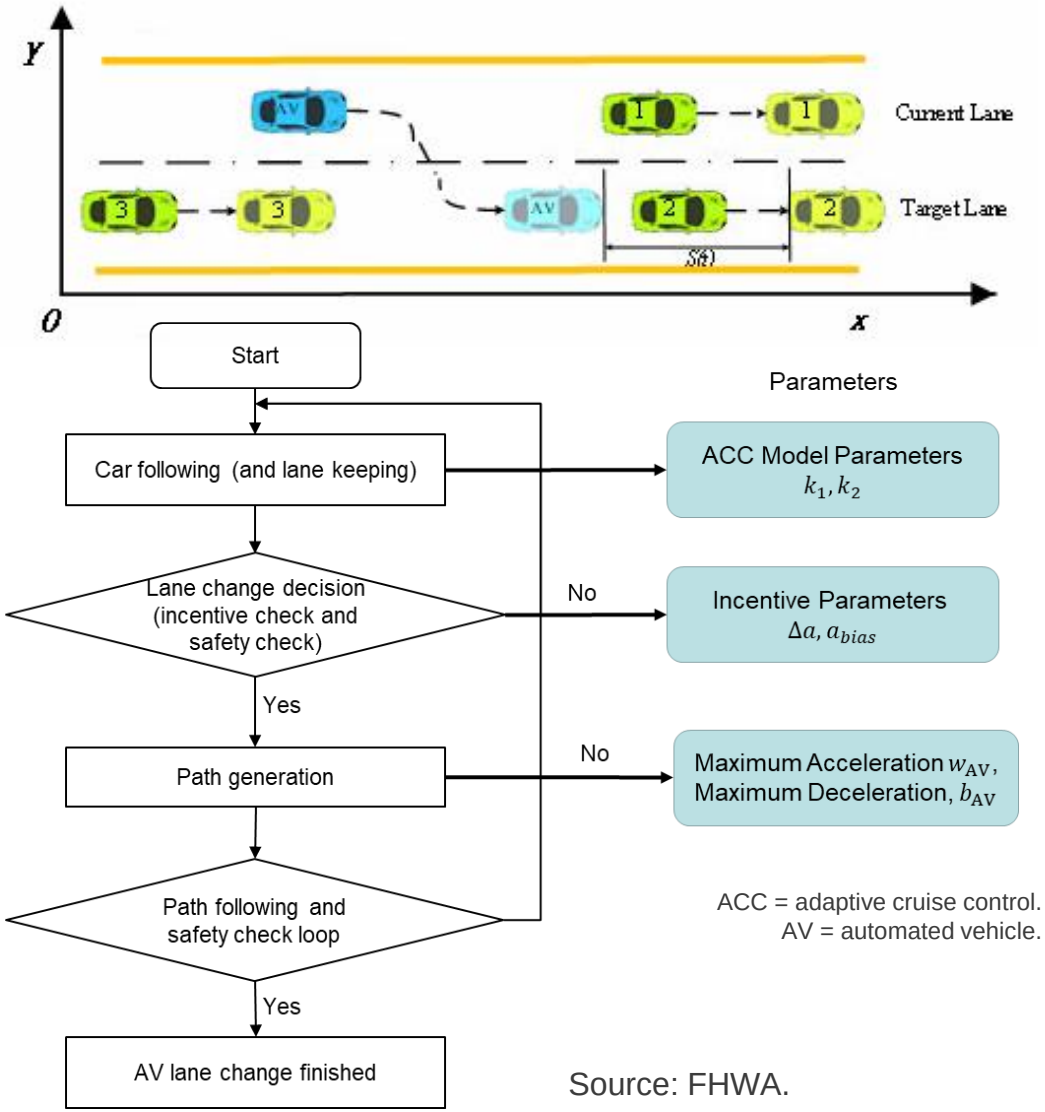


Source: FHWA.

- In low and moderate MPR cases, ML 1 performs best. ML 3 results in the worst performance.
- ML 2 outperforms ML 3.
- Dedicated ramps help improve the traffic performance.

Developing AMS Tools for CAV Applications: Tools Development

- Focus is on developing new tools to enable more robust impact assessments.
- Open-source tools are being developed:
  - New automated vehicle (AV) lane-changing algorithm.
  - Improved CACC and human driver connected vehicle (CV) car-following algorithms.
  - Improved speed harmonization algorithm.
  - New cooperative merge algorithm.



ACC = adaptive cruise control.
AV = automated vehicle.

Source: FHWA.

Conclusions

- Two projects funded by the Federal Highway Administration were twinned with the CoEXist project.
- CAV AMS Framework:
  - Developed comprehensive methodological framework for developing AMS tools incorporating the impacts of CAVs.
- Developing AMS Tools for CAV Applications:
  - Conducted four case studies on complex freeways and arterials in the United States.
  - Developed four new models of CAV driving behavior for incorporation in microsimulation software.

References

1. Mahmassani, Hani, S. et al. (2018). *Development of an AMS Framework for Connected and Automated Vehicles.* United States Department of Transportation. Washington, DC.
2. Ma, Jiaqi, Yi Guo, Zhitong Huang. (*forthcoming*). *Developing Analysis, Modeling, and Simulation (AMS) Tools for Connected Automated Vehicle Applications: A Case Study for Interstate 66 in Virginia.* Federal Highway Administration. Washington, DC.
3. Liu, Hao, et al. (*forthcoming*). *Developing Analysis, Modeling, and Simulation (AMS) Tools for Connected Automated Vehicle Applications: A Case Study for SR 99 in California.* Federal Highway Administration. Washington, DC.

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Questions?

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Source: FHWA.

U.S. Department of Transportation
Federal Highway Administration

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Poll question

What performance metrics are the most valuable (for your agency or locality) when making decisions in roadway infrastructure / traffic planning?

- Operations (e.g. throughput, delay)
- Safety surrogates (e.g. time to collision, nr. of conflicts)
- Environmental (e.g. CO2, NOx)
- Any other significant metric (specify in the question box)?

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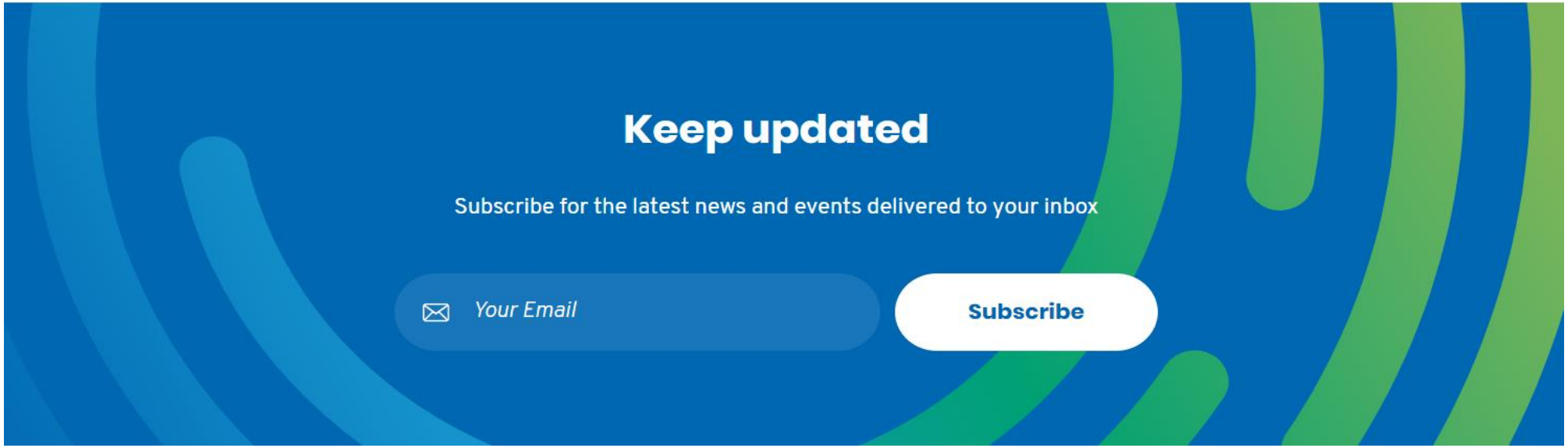
Automation-ready road infrastructure assessment

Learn more from CoEXist's automation-ready infrastructure assessment tool and safety assessment methodology!

To be scheduled: **April 2020**
https://www.h2020-coexist.eu/events/#upcoming-events



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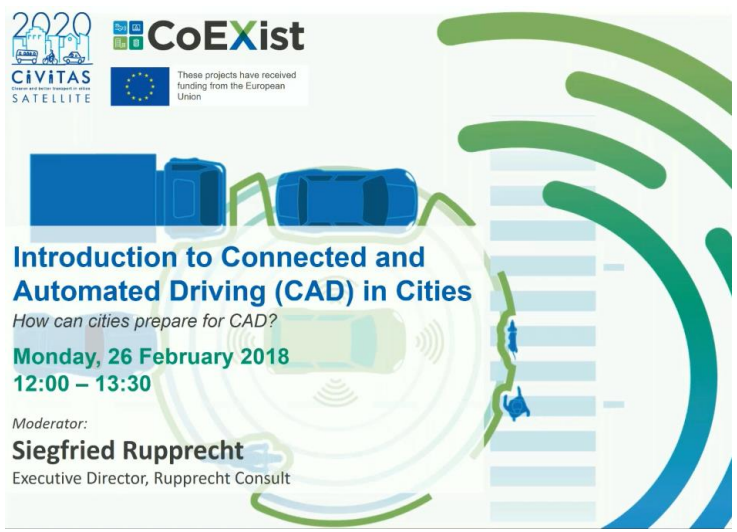

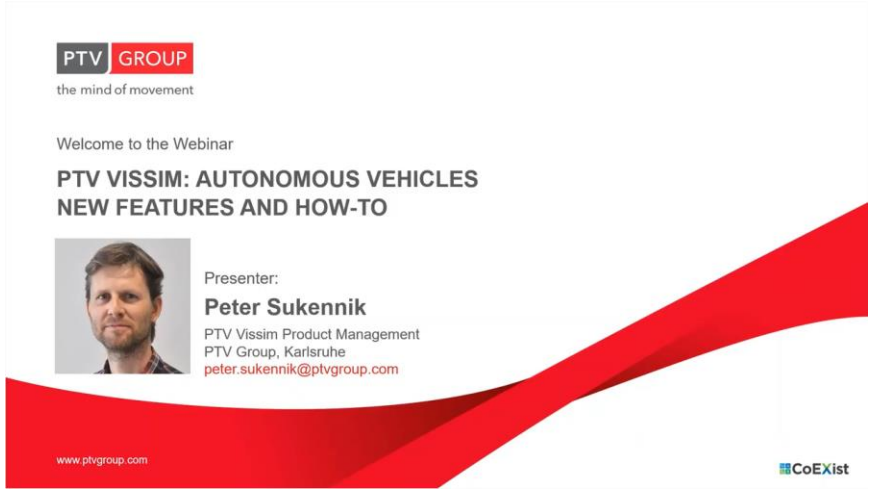

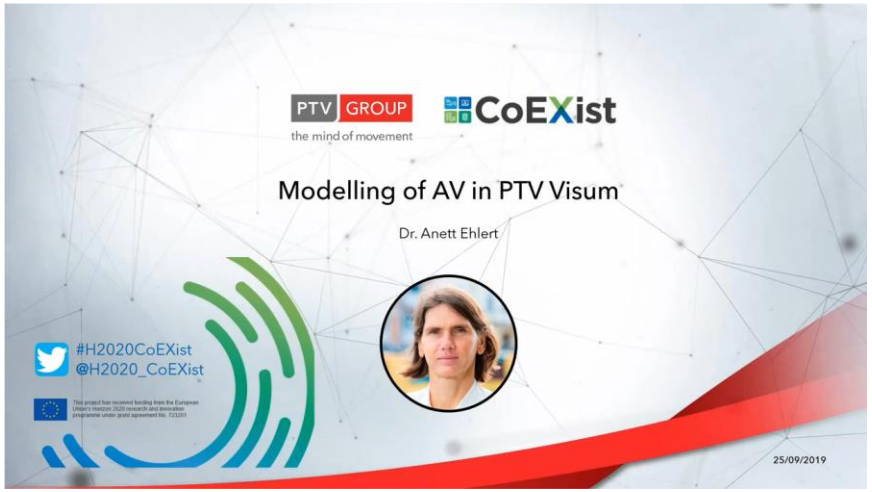

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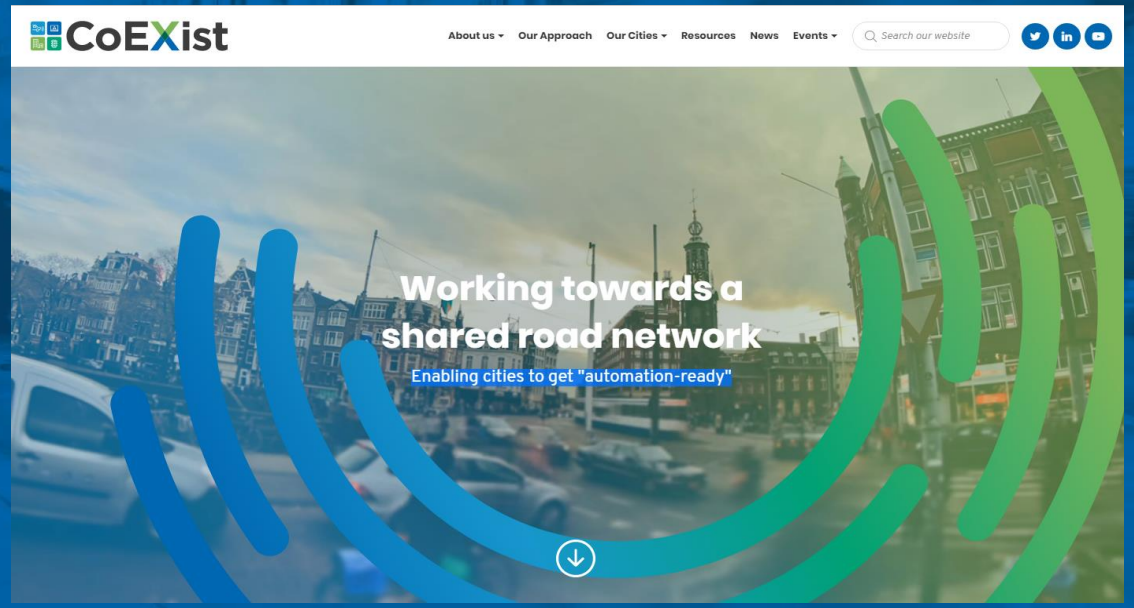
Get in touch with us!



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