Vehicle automation modelling and simulation

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723390

Vehicle/Driver Models for (C)AVs

- **Car-following**
  - Adaptive Cruise Control (ACC)
  - Cooperative Adaptive Cruise Control (CACC)
- **Lane changing**
  - Parametrized SUMO lane change model → Automated Vehicles (AVs)
  - Cooperative lane changing → Cooperative and Automated Vehicles (CAVs)
- **Control Transitions (automated ↔ manual)**
  - Transition of Control (ToC) process → Downward & Upwards transitions
  - Minimum Risk Maneuver → Unsuccessful ToCs

Car-following

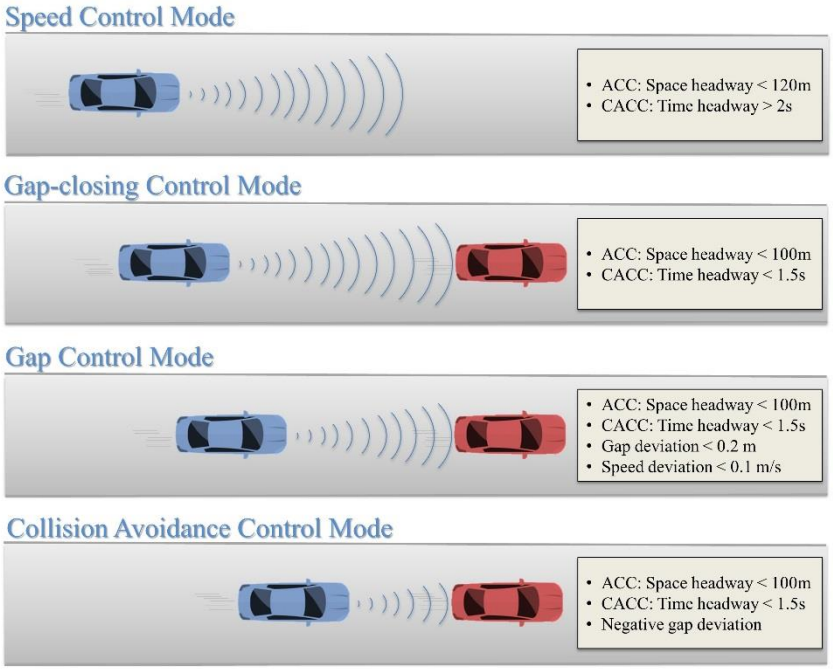
- **(Cooperative) Adaptive Cruise Control – California PATH**

i. **Speed control mode**: is designed to maintain the desired driver speed,

ii. **Gap control mode**: aims to maintain a constant space/time gap between the controlled vehicle and its predecessor,

iii. **Gap-closing control mode**: enables the smooth transition from speed control mode to gap control mode,

iv. **Collision avoidance mode**: prevents rear-end collisions.



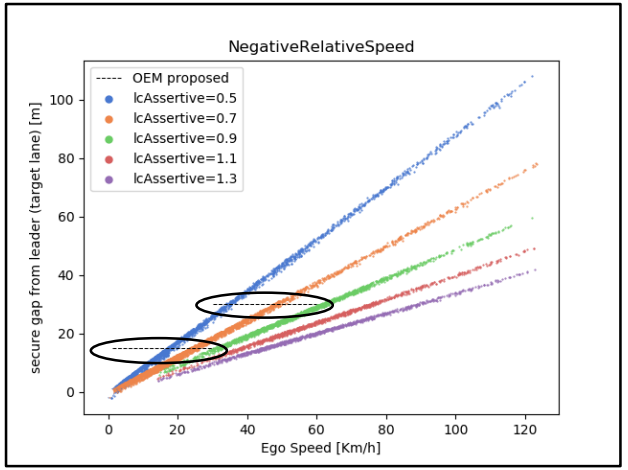
Lane Changing

- **Parametrized SUMO Lane Change Model**

i. **Variance based sensitivity analysis** → Influential lane change calibration parameters

ii. **SUMO lane change output** vs **HMETC lane change data** → Reconciliation

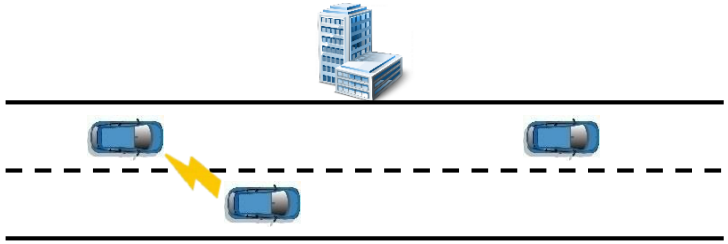
Speed Range [0, 100] (km/h)						
Parameter	Leader gap (ego lane)		Leader gap (target lane)		Follower gap (target lane)	
Sensitivity Index	S_i [%]	ST_i [%]	S_i [%]	ST_i [%]	S_i [%]	ST_i [%]
lcStrategic	0.39	0.62	0.74	2.62	1.14	0.47
lcKeepRight	1.08	0.83	3.32	7.57	1.13	2.26
lcSpeedGain	0.90	8.12	10.92	22.26	0.77	1.37
lcAssertive	59.15	77.03	61.26	80.17	91.40	95.56



Cooperative Manoeuvring

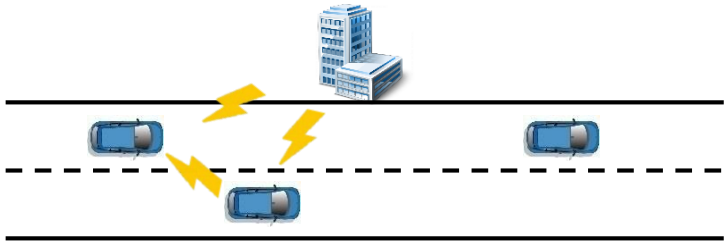
Decentralized Approach

- Local Coordination
- Sub-optimal Performance
- V2V Communication



Centralized Approach

- Enhanced Perception
- Global Coordination
- Optimal Performance
- V2X Communication

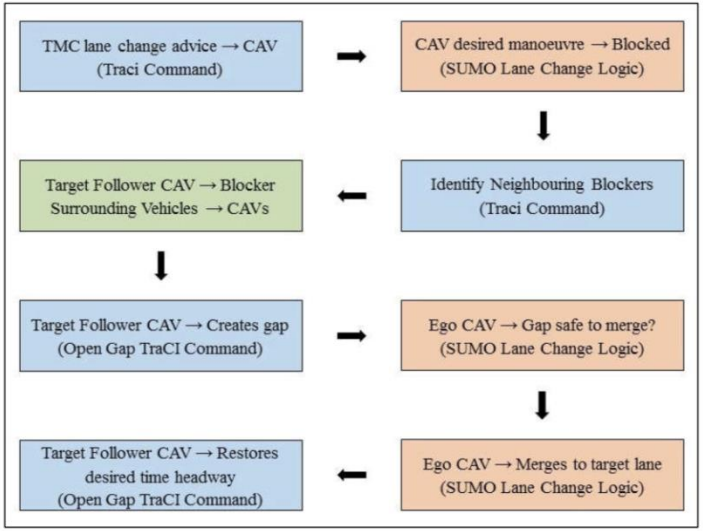


Cooperative Lane Changing

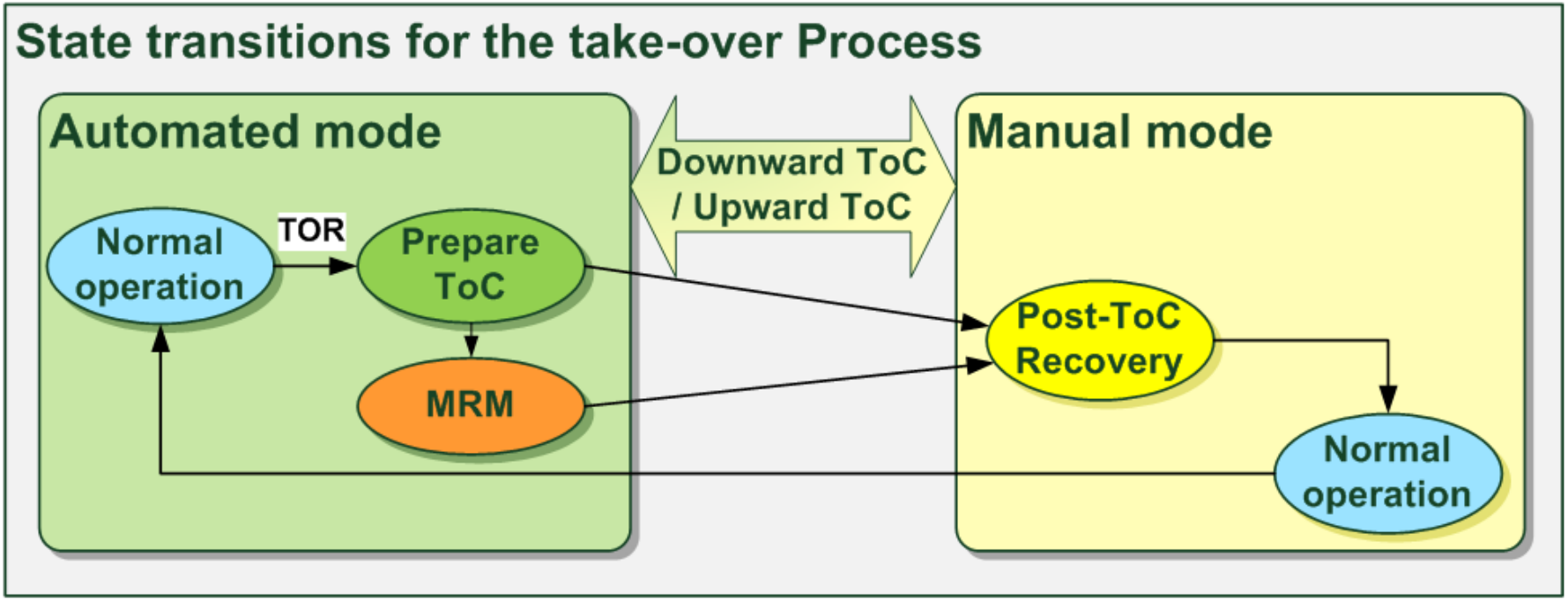
- Decentralized approach
- Cooperation between ego CAV & target follower CAV → **Gap Creation**
- **openGap TraCI function →**
  https://sumo.dlr.de/wiki/TraCI/Change_Vehicle_State#open_gap_.280x16.29

Open Gap Function

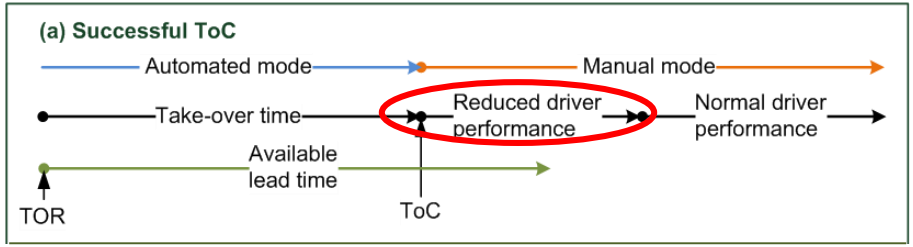
Parameter Name	Value	Description
newTimeHeadway	4 s	The vehicle's desired time headway will be changed to the given new value with use of the given change rate.
newSpaceHeadway	15 s	The vehicle is commanded to keep the increased headway for the given duration once its target value is attained.
duration	5 s	The time period in which the time and space headways will be changed to the given new values.
changeRate	0.5	The rate at which the new headways' effectiveness is gradually increased.
maxDecel	1 m/s^2	The maximal value for the deceleration employed to establish the desired new headways.
referenceVehicleID	ID #	The ID of the reference vehicle.



Control Transitions



Transition of Control



General CF Model:

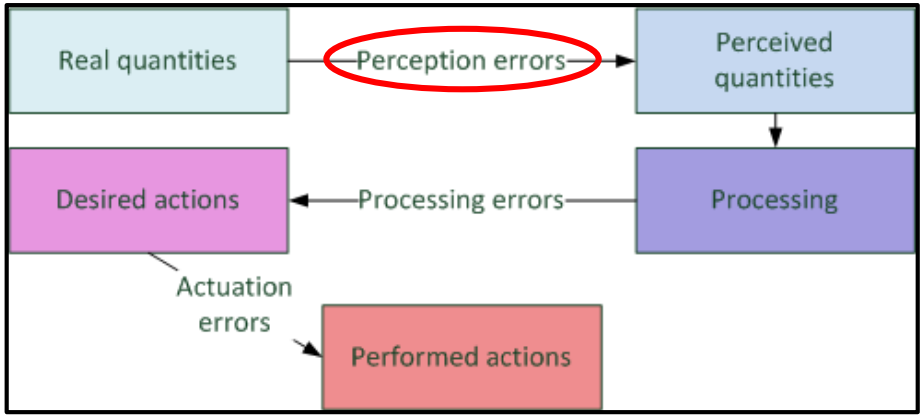
$$\dot{x}(t) = v(t)$$

$$\dot{v}(t) = a(\Delta x(t), \Delta v(t))$$

Perceived quantities:

$$\Delta\tilde{x} = \Delta x + \eta_x$$

$$\Delta\tilde{v} = v + \eta_v$$

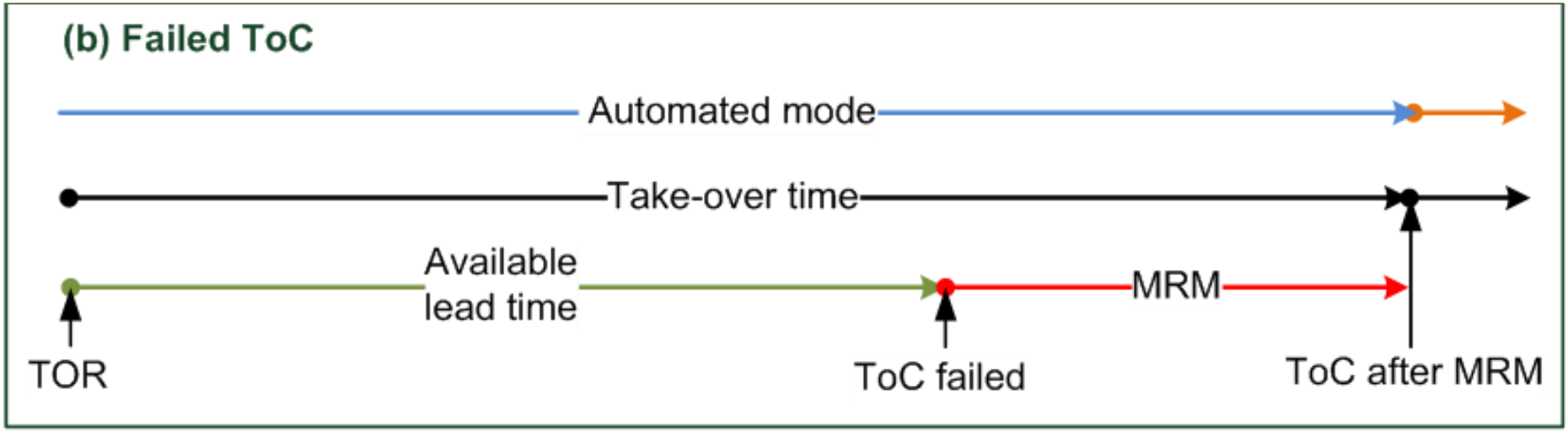


Erroneous CF Model:

$$\dot{x}(t) = v(t)$$

$$\dot{v}(t) = a(\Delta\tilde{x}(t), \Delta\tilde{v}(t))$$

Minimum Risk Maneuver



i. **MRM** → Current lane

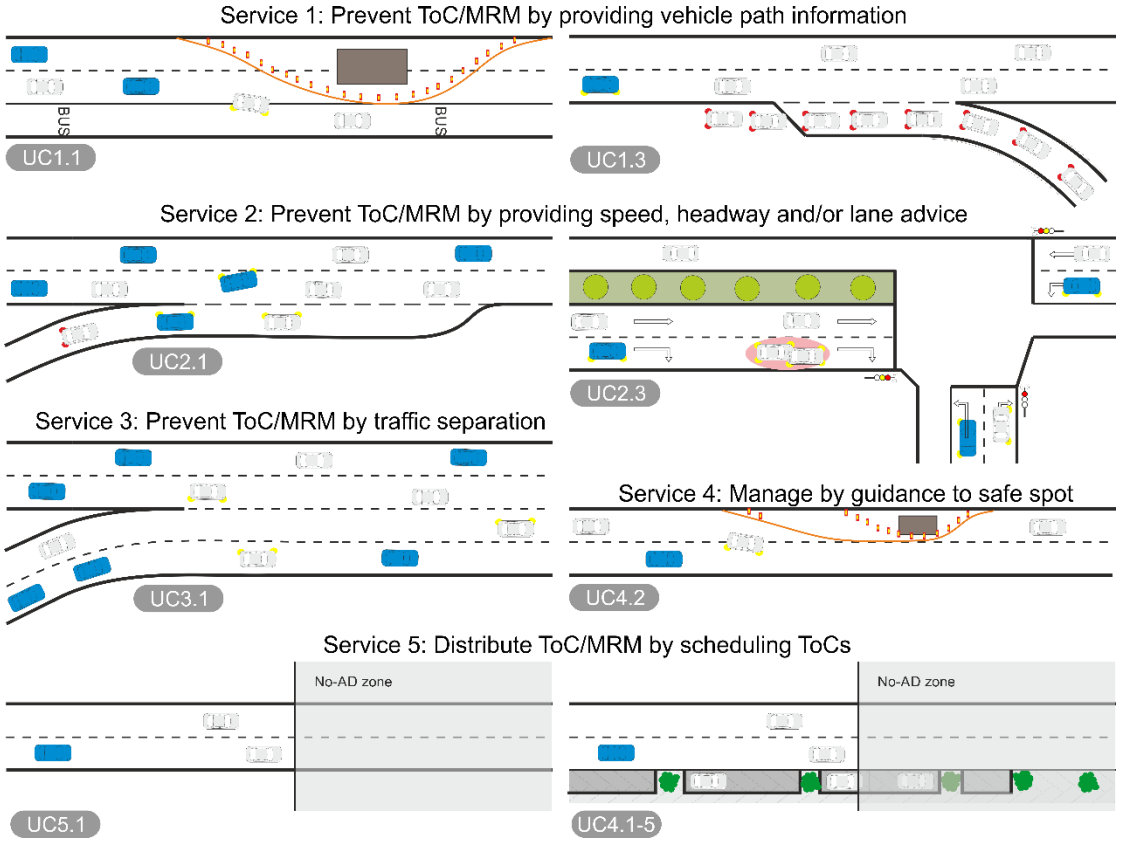
ii. **MRM** → Right-most lane (including lane change maneuver)

iii. **MRM** → Constant deceleration rate (3.0 m/s^2)

Triggering of Take-over Requests (TORs)

- **Fixed TOR location** → Specified through TraCI function
- **Dynamic TOR triggering** → Induced by static blockage (e.g. road works etc.)
  - CAV merging to open lane blocked by neighboring traffic
  - $dynamicToCThreshold * currentSpeed + MRM_{dist} < distanceToBlockage$
  - Situation-specific available lead time
- **ToC Preparation Phase** → Open gap TraCI function
  - Establish safe gap to leading vehicle prior to downward control transition
- **Lane Change Abstinence during:**
  - ToC Preparation Phase
  - Recovery Phase

Simulated Use Cases



Mixed Traffic Simulations

Vehicle Types

Vehicle type	Share on urban roads	Share on motorways
Passenger vehicle	87%	77%
LGV	10%	10%
HGV	3%	13%

Automation/Communication Penetration

Vehicle Mix	Class 1	Class 1 (Conn.)	Class 2	Class 2 (Conn.)	Class 3	Class 3 (Conn.)	Class 4	Class 4 (Conn.)
1	60%	10%	-	15%	-	15%	-	-
2	40%	10%	-	25%	-	25%	-	-
3	10%	10%	-	40%	-	40%	-	-

Traffic Demand Levels

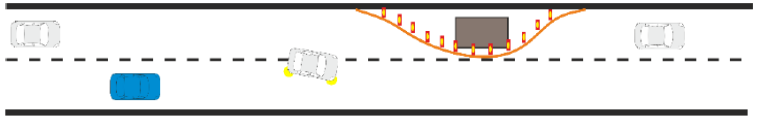
Facility Type	Capacity (veh/h/l)	Level of Service (LOS)		
		B	C	D
Urban (50km/h)	1500 veh/h/l	825	1155	1386
Rural (80 km/h)	1900 veh/h/l	1045	1463	1756
Motorway (120 km/h)	2100 veh/h/l	1155	1617	1940
Intensity / Capacity (IC) ratio		0.55	0.77	0.92

Parametrization Schemes

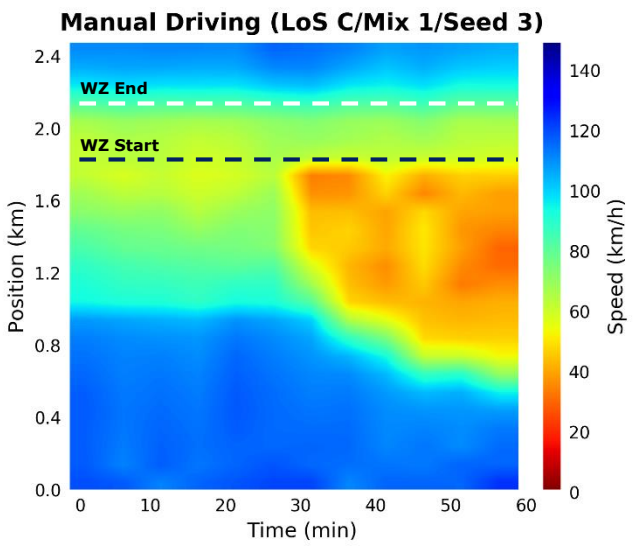
Parametrization Scheme	ACC	SL2015	ToC/MRM	ToC/MRM	ToC/MRM
	Desired time headway	Desired longitudinal gaps	Driver response time	Post ToC driver performance	MRM likelihood
Pessimistic Safety (PS)	Small	Short	Long	Low	High
Pessimistic Efficiency (PE)	Large	Large	Long	Low	High
Moderate Safety and Efficiency (MSE)	Moderate	Moderate	Moderate	Moderate	Moderate
Optimistic Efficiency (OE)	Small	Short	Short	High	Low
Optimistic Safety (OS)	Large	Large	Short	High	Low

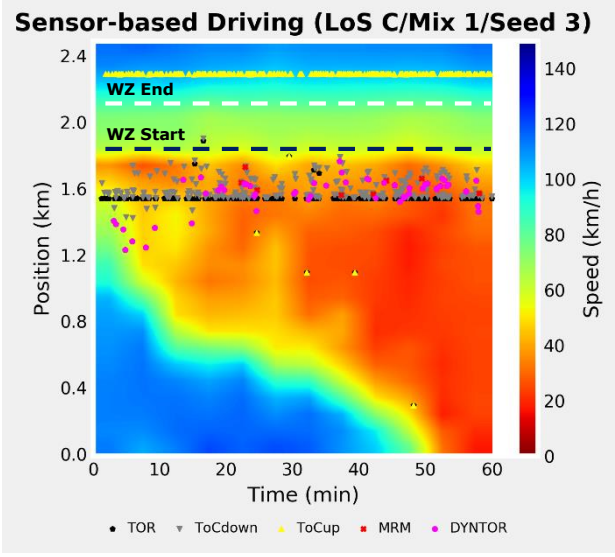
Results

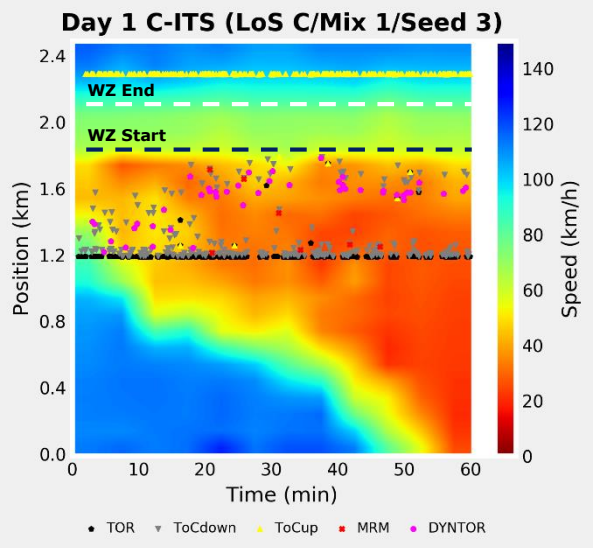
- **Work Zone Use Case** → Motorway Network



➢ **Impacts of vehicle disengagements on Traffic Efficiency**



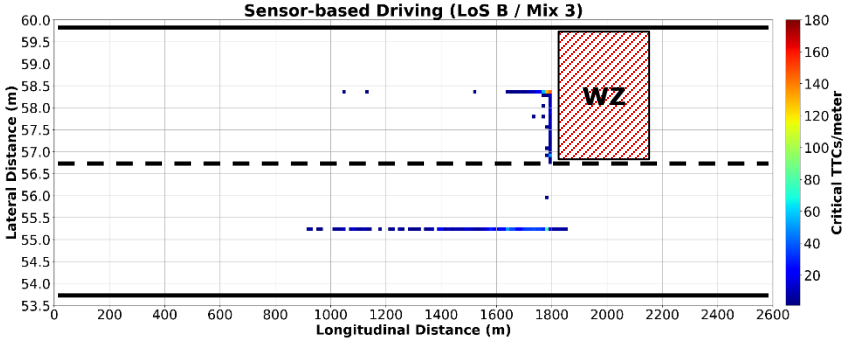


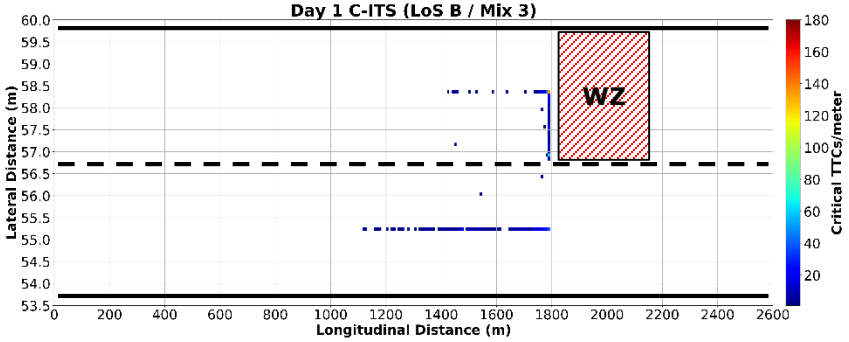


Results

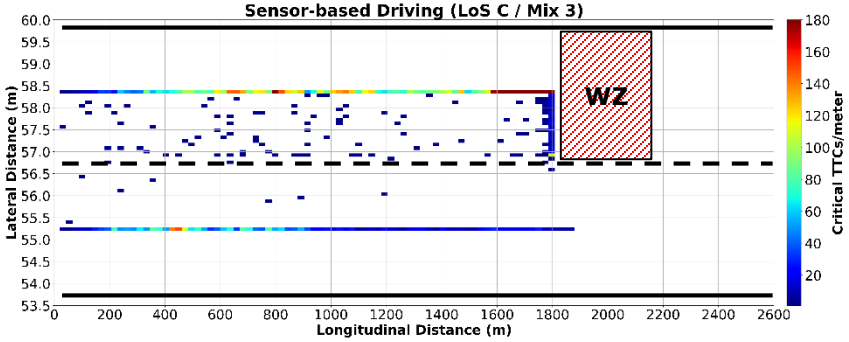
- **Impacts of vehicle disengagements on Conflict Risk** → Critical Events: Time-to-Collision ≤ 1.5 sec

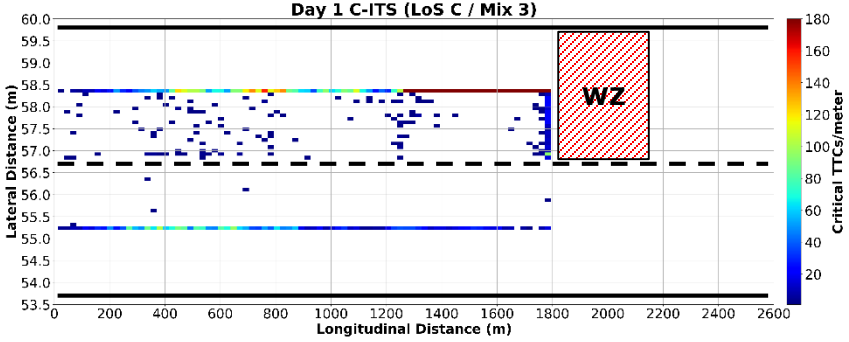
❑ **Uncongested conditions**





❑ **Congested conditions**





Findings

- **Transitions of Control (ToCs)** → traffic flow disruption for increased car-following headways in the ToC preparation phase
  - disruption escalates in case of **CACC driving**, increased **share of CAVs** in the fleet mix, occurrence of **multiple ToCs** within narrow temporal window and spatial domain
- **Unmanaged Minimum Risk Manoeuvers (MRMs)** → increased traffic breakdown probability
  - magnitude of the disruption is affected by the **driver response time**
- **Conservative CAV lane changing** → higher traffic heterogeneity
  - **throughput reduction** for increased **share of CAVs** in the fleet mix
  - **conflict risk increase** in the proximity of **lane drop locations**

Considerations

- **Transitions of Control (ToCs)** → unavailability and scarcity of field data
  - erratic vehicle behavior during the post-ToC phase explicitly concerns longitudinal motion
  - unexpectedness of ToCs/MRMs for manually driven vehicles is not captured comprehensively
- **Mixed traffic** → ambiguous interactions of manually driven vehicles with CAVs
  - low penetration rate of CAVs in the real-world fleet mix
- **Conservative CAV lane changing** → single prototype AV
  - highly automated driving might enable human-like (less conservative) lane changing
- **Simulation Experiments** → abstract simulation networks and hypothetical demand scenarios

Research Outlook

- **Accuracy of CAV-human interactions**
  - how to quantify behavioral processes during vehicle disengagement?
- **Vehicle dynamics and characteristics**
  - what are the actual sensing, perception, planning, maneuvring capabilities of highly automated vehicles?
- **Inter-vehicle interactions**
  - how are CAVs going to interact with manually driven vehicles?
  - how are CAVs equipped with different automation and communication capabilities are going to interact with each other?

Need for Empirical Evidence!

Integration of Models in SUMO

- **(Cooperative) Adaptive Cruise Control Model** → SUMO Source Code
  - https://sumo.dlr.de/wiki/Car-Following-Models/ACC (Sumo Wiki Page)
  - <SUMO_HOME>/src/microsim/cfmodels/MSCFModel_ACC.cpp
  - https://sumo.dlr.de/wiki/Car-Following-Models/CACC (Sumo Wiki Page)
  - <SUMO_HOME>/src/microsim/cfmodels/MSCFModel_CACC.cpp
- **Parametrized Lane Change Model** → Adaptation of existing model params
- **Cooperative lane changing** → Open gap TraCI function
  - https://sumo.dlr.de/wiki/TraCI/Change_Vehicle_State#open_gap_.280x16.29
- **ToC/MRM Model** → ToC Device (SUMO Source Code + TraCI Functions)
  - https://sumo.dlr.de/wiki/ToC_Device (Sumo Wiki Page)

Publications

- **Deliverable D3.1** → Modelling, simulation and assessment of vehicle automations and automated vehicles' driver behaviour in mixed traffic
- **Deliverable D3.2** → Cooperative manoeuvring in the presence of hierarchical traffic management
- Porfyri, K. N., Mintsis, E., & Mitsakis, E. (2018). *Assessment of ACC and CACC systems using SUMO*. EPiC Series in Engineering, 2, 82-93. https://doi.org/10.29007/r343
- Lücken, L., Mintsis, E., Porfyri, K. N., Alms, R., Flötteröd, Y.-P., & Koutras, D. (2019). *From Automated to Manual-Modeling Control Transitions with SUMO*. EPiC Series in Computing, 62, 124-144. https://doi.org/10.29007/sfgk
- Mintsis, E., Lücken, L., Karagounis, V., Porfyri, K. N., Rondinone, M., Correa, A., Schindler, J., & Mitsakis, E. (2020). *Joint Deployment of Infrastructure Assisted Traffic Management and Cooperative Driving around Work Zones*. IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC). (*accepted*)

Questions? Let's stay in touch!

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723390