Simulation and field testing

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Simulation

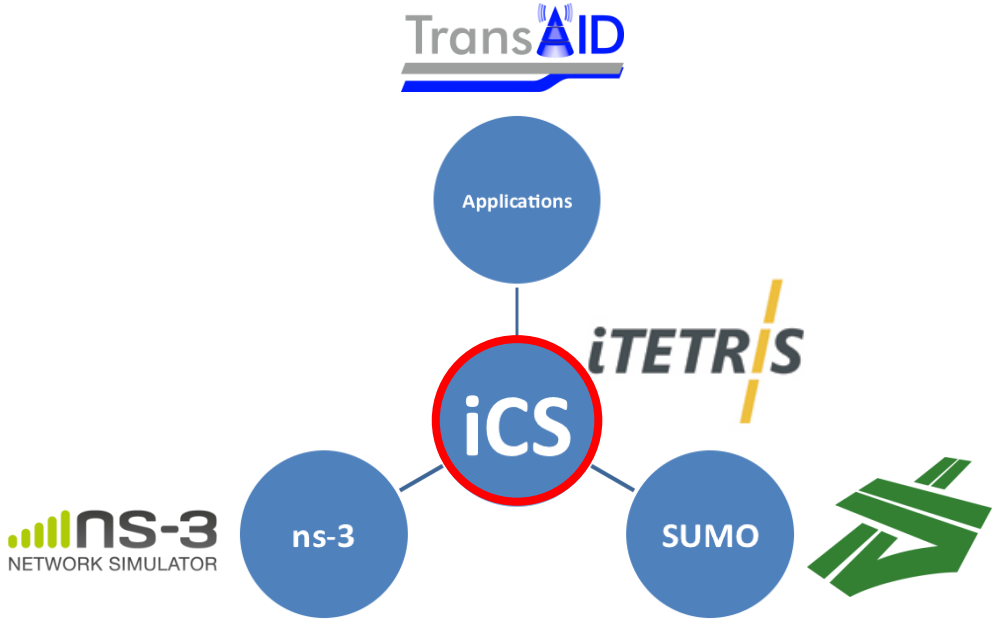
SUMO

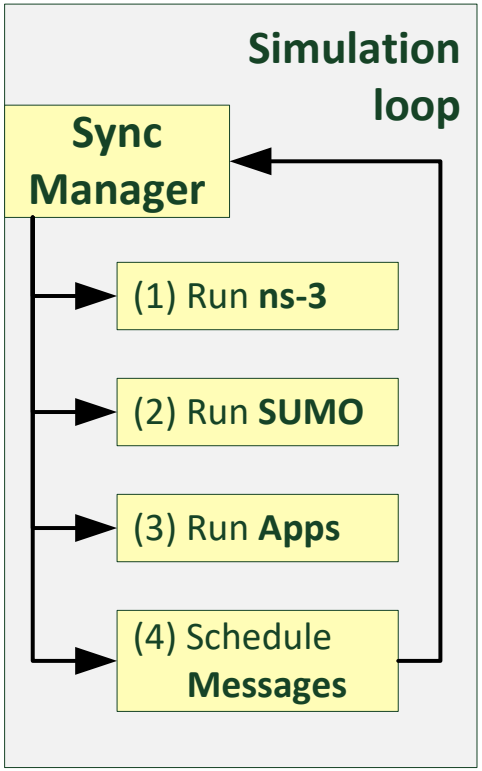
Starting with simple simulations w/o communication

→ More details required
→ What is the effect of communication?

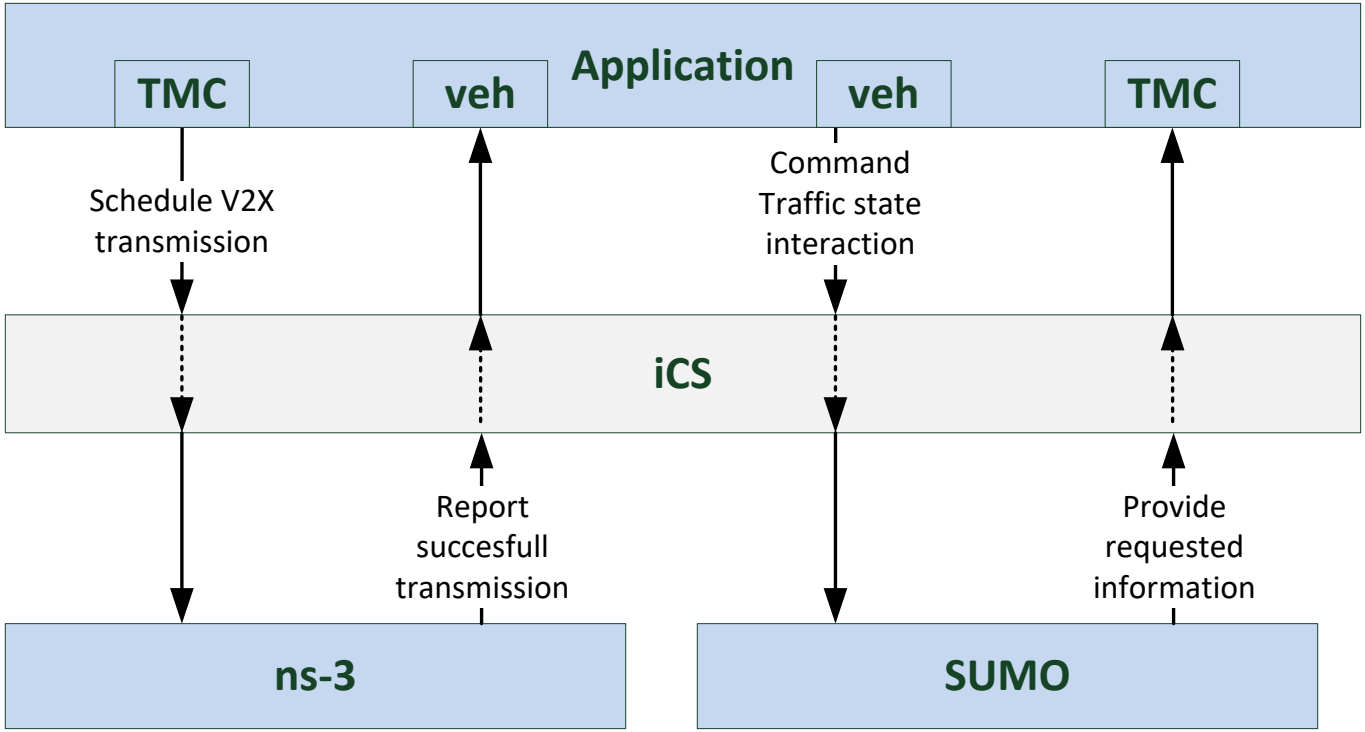
Detailed simulations in built on top of the iTetris framework with communication simulation (lightcomm/ns-3)

Simulation Environment – Components



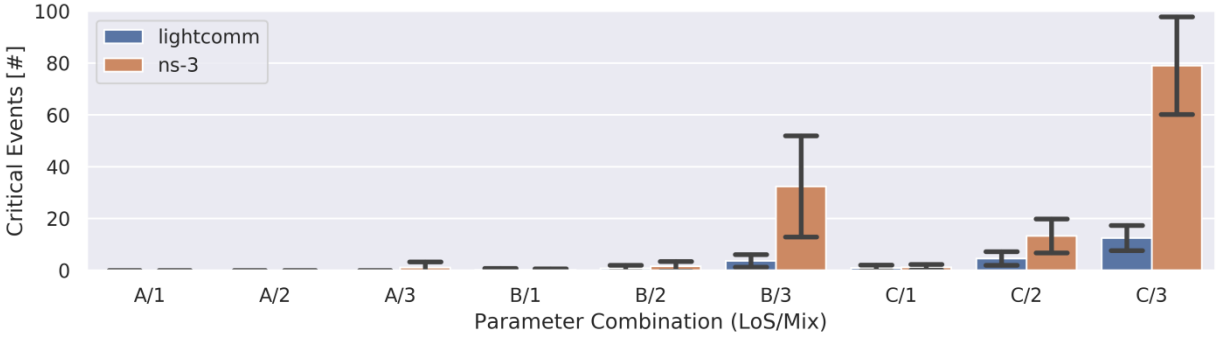


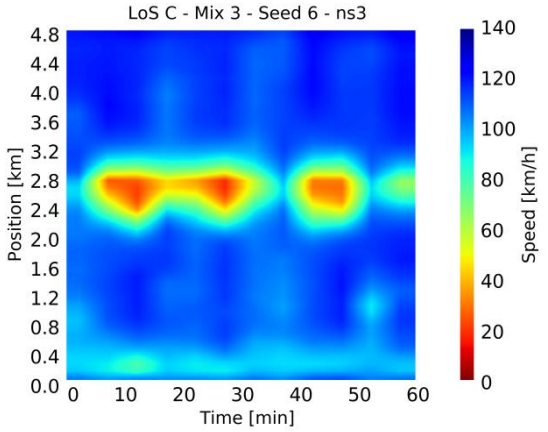
Simulation Environment – Data Exchange



Simulation Environment – Main Findings

- Adding V2X communication to the simulation can significantly impact results, depending on sensitivity of TM algorithm
  - e.g., ToC scheduling depends on robust communication





- Computational overhead of comm. simulation
  - Trade-off computation time vs. realism

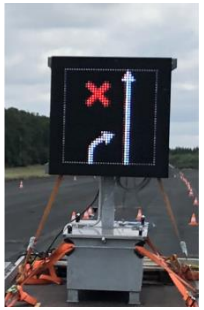
Informing surrounding unequipped vehicles

- Infrastructure support also for unequipped vehicles
- To explain vehicle issues and related infrastructure measures
  - e.g. by VMS:

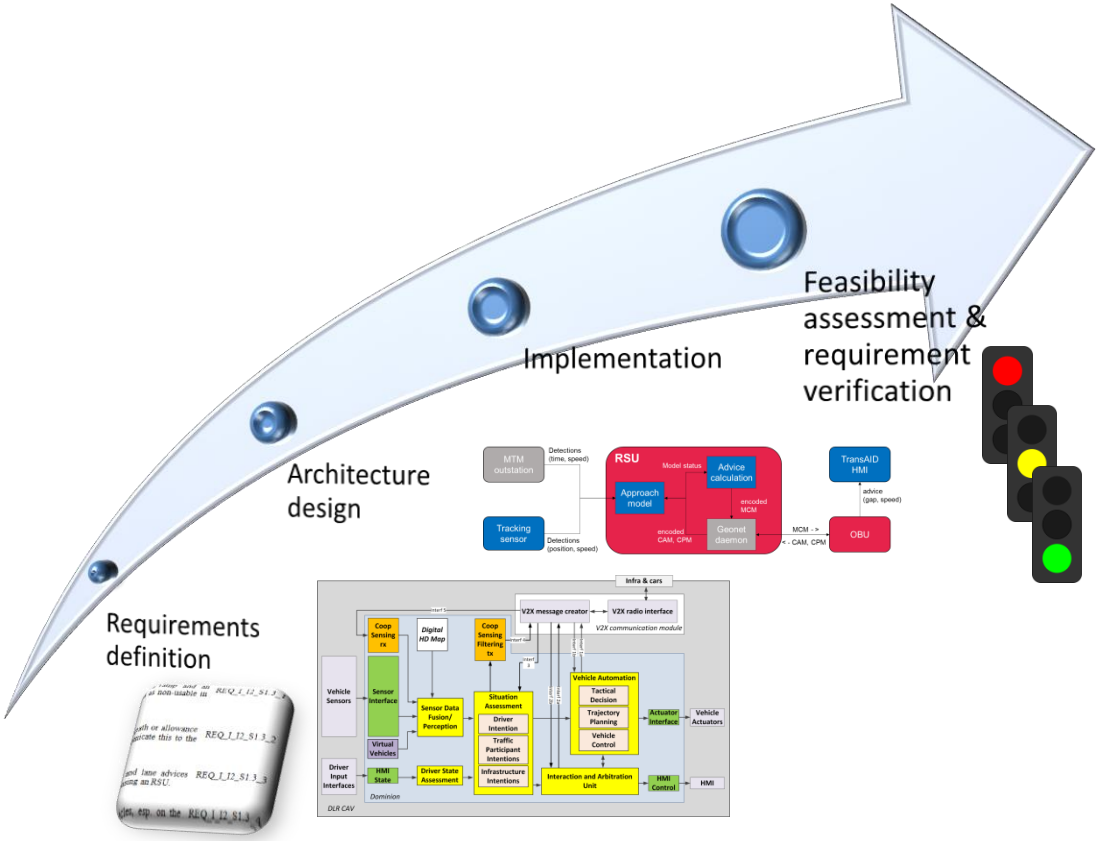
- VR study with 10 participants
- Different dHMIs and eHMIs tested

➢ External lights on CAVs enhance understanding of behaviour

Real world test equipment



Feasibility Assessment

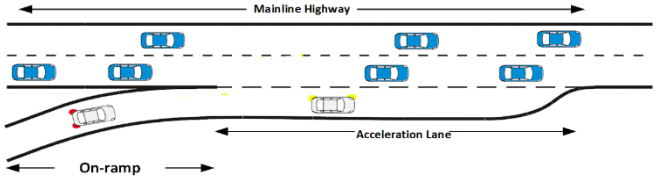


Assessment of the correct functionality of

- Infrastructure
  - Sensors
  - Algorithms
  - Message signs
- Vehicle
  - Sensors
  - Automation behaviour
- Communication

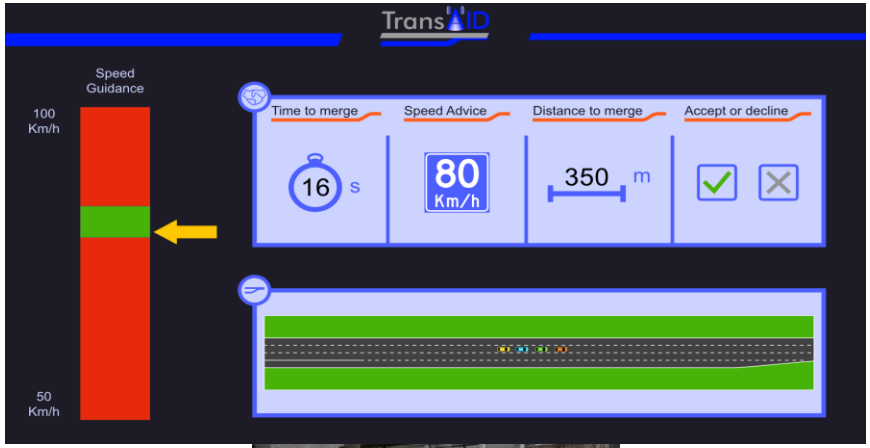
In total: ~50 scenarios

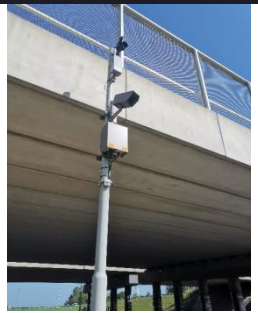
Scenario 2.1: Merging Assistant



- Assistant application for CVs and CAVs.
- Uses cooperative perception and V2X communication to augment the CVs and CAVs sensing capability in the high-speed merging area.
  - Detection of highway traffic with loops and camera
- Provides real-time speed advice to on-ramp vehicle to assist a smooth merge and prevent ToC.
- Public road testing on A13 in the Netherlands

Scenario 2.1:
Merging Assistant Visualization

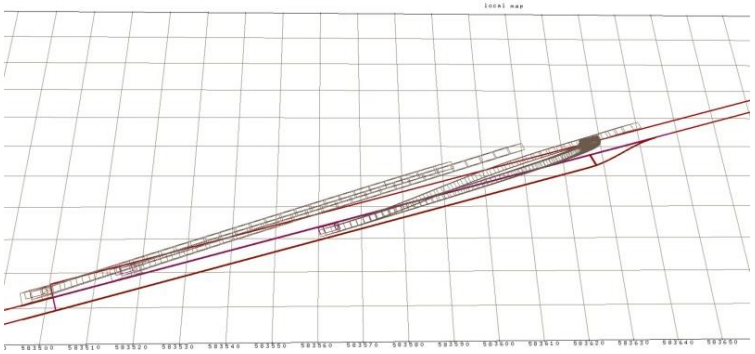




Scenario 2.1:
Merging Assistant CAV testing

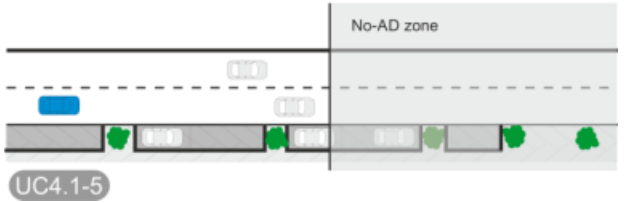
Several extensions for CAVs:

- Infrastructure gives early speed advice to on-ramp vehicle
- and early ToC advice in case of impossible merging
- V2V cooperation when CAVs meet:
  - If possible, highway vehicle changes lane
  - If not, highway vehicle opens gap



Service 4.1-5: I2V assisted ToC

- Integration of TransAID V2X protocols in Hyundai cars
- Validation of Service 4.1-5: distribution of ToC before a no-AD zone and safe spot suggestion
- Comparison between "TransAID" and "baseline" approach



TransAID approach (MCM-based):

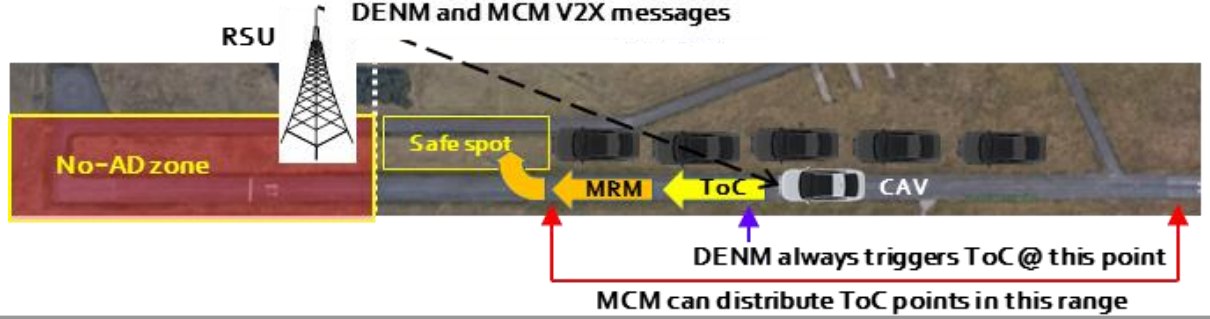
RSU uses MCM to trigger **different ToC points** at different cars with **individual** safe spot advices

- ➢ less risk of cars having ToC at the same point (++)
- ➢ cars are "guided" to safe spots in case of MRM, no risk to stop on ego-lane (++)

Baseline approach (DENM-based):

RSU uses DENM to trigger ToC at relevant distance **without** advising safe spot in case of MRM

- ➢ multiple cars can have erratic behavior at same point due to ToC (--)
- ➢ cars have to "search" a safe spot with own sensors in case of MRM and might stop on ego lane (--)



Service 4.1-5: I2V assisted ToC

Empirical results (1)

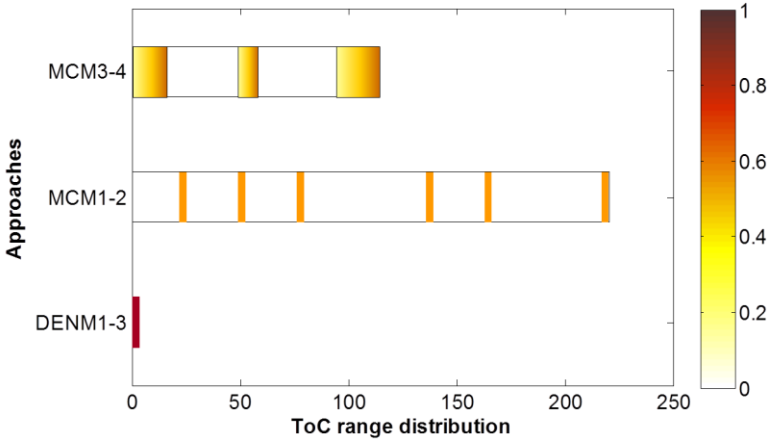
- Safe MRM:

	DENM1	DENM2	DENM3
Stopping when no safe spot is found in…	0m	50m	until no-AD zone

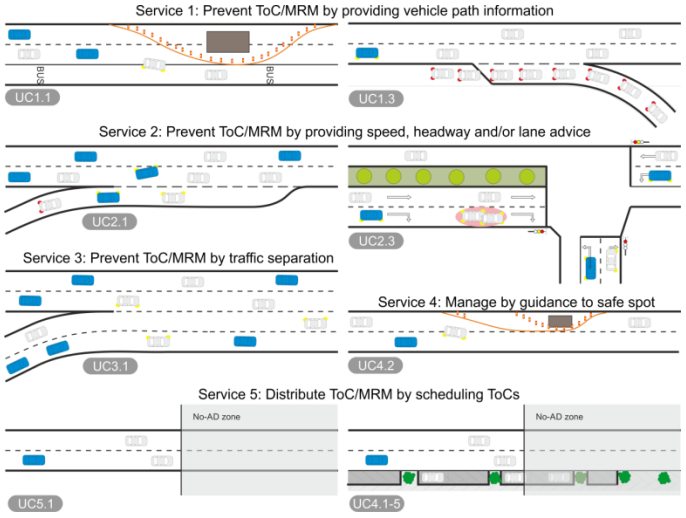
	MCM1	MCM2	MCM3	MCM4
Strategy	Min. distance driven in MRM		Max. spatial distribution of safe spots	
Slow down	instantly	@ spot	instantly	@ spot

Empirical Results (2)

- ToC Distribution:
  prob. to trigger ToC @ distance x from baseline ToC point



More assessment impressions



Feasibility Assessment Results

- Implementations are working
  - Infrastructure can detect vehicles and generate messages with 10 Hz
  - All messages are sent and received as desired
  - Vehicle automation is able to process advice and use it in planning

- Effects
  - CAV behaviour gets much smoother when infrastructure advice is used
  - Different behaviour of CAVs, when it knows more, and knows it earlier, e.g.
    - When entering the highway → ramp not used
    - Early speed reduction at traffic lights

- Some parts need more research
  - Exact maneuvering requires high sending frequencies. Esp. CPM and MCM are large messages, consuming the bandwidth largely. Scalability is important.
  - V2V-MCM can result in behaviour jittering
  - Definition of best behaviour when driving to dedicated safe spot.

- Tests are ongoing (COVID-19 related)

Possible demonstration

Questions? Let's stay in touch!

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