



Cooperative and Automated Driving: from modelling and simulation to prototypical implementation and testing

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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**

Speed Control Mode



Gap-closing Control Mode



Gap Control Mode



Collision Avoidance Control Mode



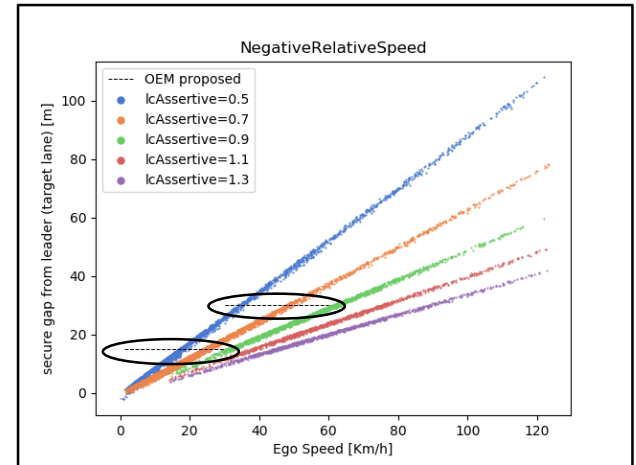
- Speed control mode:** is designed to maintain the desired driver speed,
- Gap control mode:** aims to maintain a constant space/time gap between the controlled vehicle and its predecessor,
- Gap-closing control mode:** enables the smooth transition from speed control mode to gap control mode,
- Collision 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

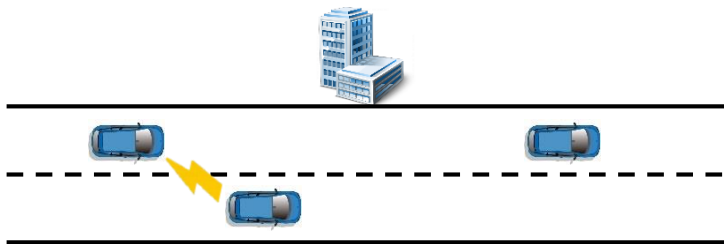
Parameter	Speed Range [0, 100] (km/h)					
	Leader gap (ego lane)		Leader gap (target lane)		Follower gap (target lane)	
	Sensitivity Index	S_i [%]	ST_i [%]	S_i [%]	ST_i [%]	S_i [%]
<i>lcStrategic</i>	0.39	0.62	0.74	2.62	1.14	0.47
<i>lcKeepRight</i>	1.08	0.83	3.32	7.57	1.13	2.26
<i>lcSpeedGain</i>	0.90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



Cooperative Manoeuvring

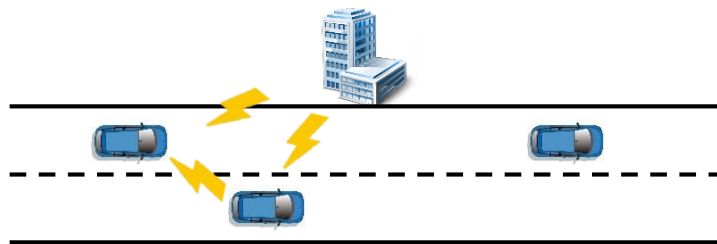
Decentralized Approach

- Local Coordination
- Sub-optimal Performance
- V2V Communication



Centralized Approach

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



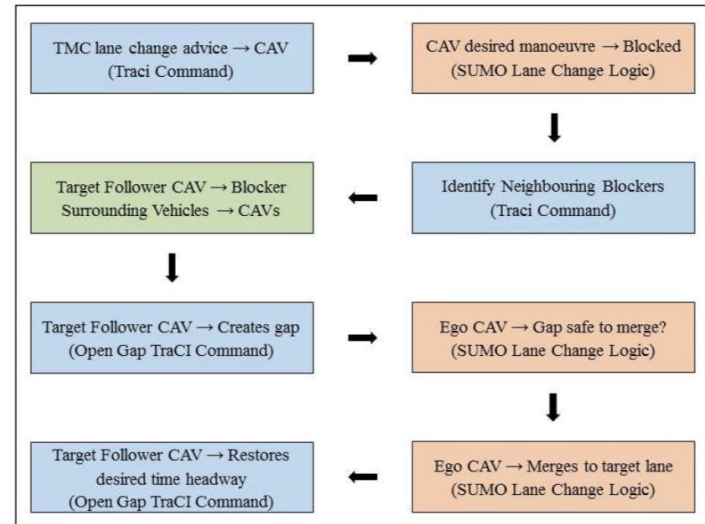
Cooperative Lane Changing

- 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

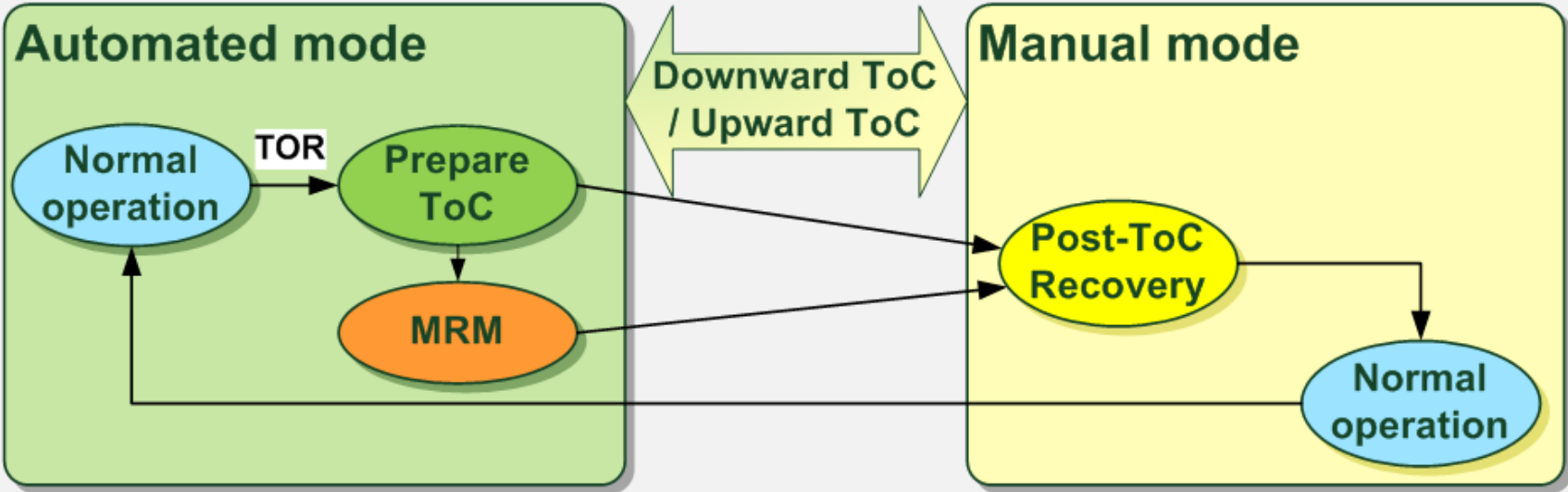
Open Gap Function

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.

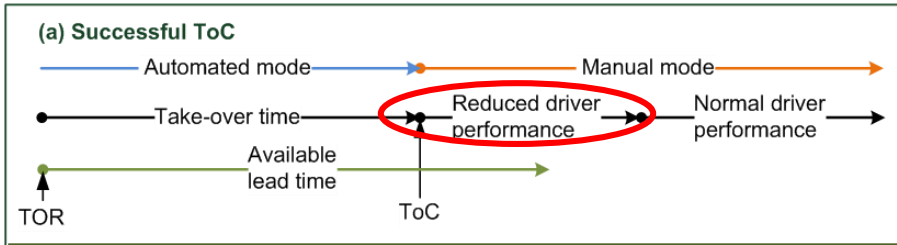


Control Transitions

State transitions for the take-over Process



Transition of Control



General CF Model:

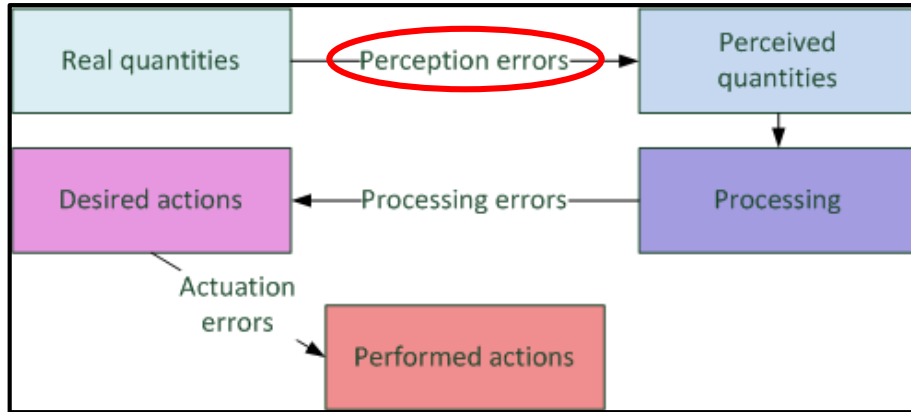
$$\dot{x}(t) = v(t)$$

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

Perceived quantities:

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

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

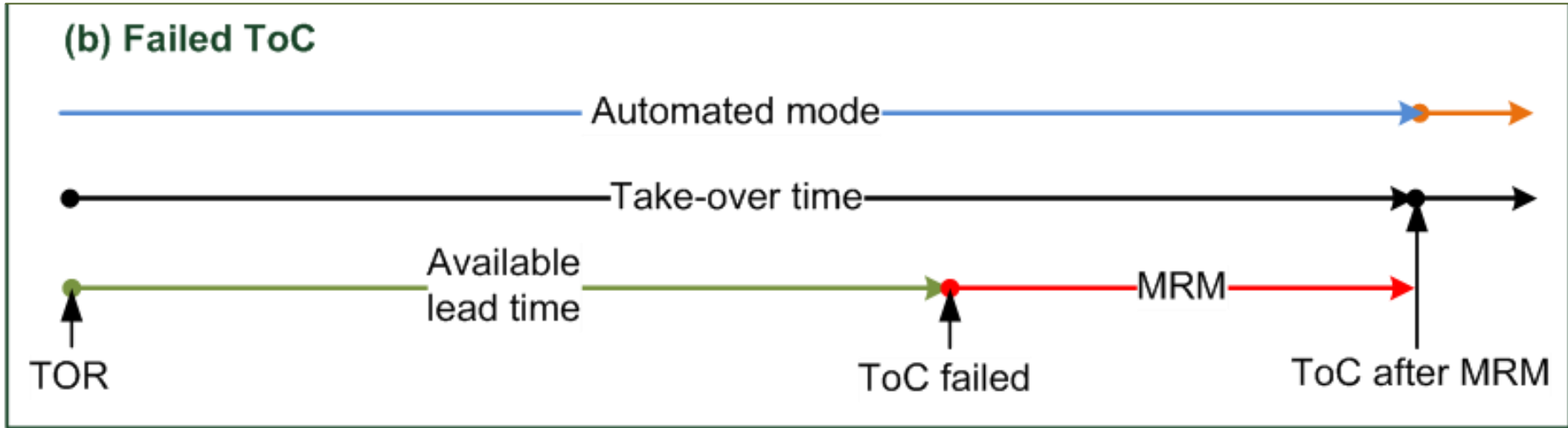


Erroneous CF Model:

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

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

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)

Model Integration 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)

Let's stay in touch

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