SUMO User Conference 2018

Simulating Autonomous and Intermodal Transport Systems

Assessment of ACC and CACC systems using SUMO

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ACC/CACC Studies

1. *First Group*
   - Desired speeds or accelerations from ACC/CACC controllers are used as the actual speeds or accelerations in the simulation (ignores driveline dynamics, rolling and aerodynamic resistance).
2. *Second Group*
   - Applied a first-order lag between the controller command (i.e. the desired speed/acceleration) and the actual vehicle speed/acceleration to represent the driveline dynamics (the effects of external factors still cannot be captured).
3. *Third Group*
   - Vehicle dynamic model, which includes vehicle controller and both internal and external influential factors (consumes large computation time and it is barely feasible for the large-scale traffic simulations).
4. ***Fourth Group***
   - **Modeled the realized speeds/accelerations of ACC/CACC vehicles as the car-following response using data collected during field tests *(Milanes & Shladover, 2014; Xiao, Wang, & van Arem, 2017)*.**

Background

- Shladover, S., Su, D., & Lu, X. Y. (2012). Impacts of cooperative adaptive cruise control on freeway traffic flow. *Transportation Research Record: Journal of the Transportation Research Board*, (2324), 63-70.
- Milanés, V., & Shladover, S. E. (2014). Modeling cooperative and autonomous adaptive cruise control dynamic responses using experimental data. *Transportation Research Part C: Emerging Technologies*, *48*, 285-300.
- Milanés, V., Shladover, S. E., Spring, J., Nowakowski, C., Kawazoe, H., & Nakamura, M. (2014). Cooperative adaptive cruise control in real traffic situations. *IEEE Transactions on Intelligent Transportation Systems*, *15*(1), 296-305.
- Milanés, V., & Shladover, S. E. (2016). Handling cut-in vehicles in strings of cooperative adaptive cruise control vehicles. *Journal of Intelligent Transportation Systems*, *20*(2), 178-191.
- Xiao, L., Wang, M., & van Arem, B. (2017). Realistic car-following models for microscopic simulation of adaptive and cooperative adaptive cruise control vehicles. *Transportation Research Record: Journal of the Transportation Research Board*, (2623), 1-9.

ACC Control Algorithm

The control law in the ACC control algorithm is divided into three modes:

1. ***Speed Mode (Cruising Mode)***
   - Is designed for maintaining the pre-defined by the driver desired speed and is activated:
     - No preceding vehicles in the range covered by the sensors or preceding vehicles exist in a distance larger than a maximum threshold of 120 m
2. **Gap-closing *Mode***
   - Enables the transition from speed control mode to gap control mode and is triggered:
     - When the spacing to the preceding vehicle is smaller than 100 m
3. ***Gap Mode***
   - Is designed for maintaining a constant time gap between the controlled vehicle and its predecessor and is activated:
     - When the spacing to the preceding vehicle is smaller than 100 m , and
     - the gap and speed errors are concurrently smaller than 0.2 m and 0.1 m/s.

- If the spacing is between the maximum and minimum threshold, the controlled vehicle retains the previous control strategy to provide hysteresis in the control loop and perform a smooth transfer between the two strategies.

Speed Mode (ACC)

- The acceleration of **ACC** vehicles is modelled as:

$$\alpha_{sv}(t+1) = k_1(v_d - v_{sv}(t)) \qquad (1)$$

where,

$\alpha_{sv}(t+1)$: acceleration recommended by the ACC/CACC controller to the subject vehicle (m/s^2)

k_1: gain to determine the rate of speed error for acceleration ($k_1 = 0.4\ s^{-1}$ in this study)

v_d: desired speed (m/s)

$v_{sv}(t)$: current speed of the subject vehicle (m/s)

Gap Mode (ACC)

- The acceleration of **ACC** vehicles is modeled as:

$$\alpha_{sv}(t+1) = k_2 e_k + k_3(v_l(t) - v_{sv}(t)) \qquad (2)$$

where,

$\alpha_{sv}(t+1)$: acceleration recommended by the ACC controller to the subject vehicle (m/s^2)

k_2: gain on position difference between the preceding vehicle and the subject vehicle ($k_2 = 0.23\ s^{-2}$ in this study)

k_3: gain on speed difference between the preceding vehicle and the subject vehicle ($k_3 = 0.07\ s^{-1}$in this study)

$v_l(t)$: current speed of the preceding vehicle (m/s)

$v_{sv}(t)$: current speed of the subject vehicle (m/s)

e_k: the gap error, given as

$$e_k = d(t) - t_d v_{sv}(t) \qquad (3)$$

t_d: desired time gap of the ACC controller (s)

d(t): distance between the subject vehicle's front bumper and the preceding vehicle's rear bumper (m)

Gap-Closing Mode (*ACC*)

The gap-closing controller was derived by tuning the parameters of the existing gap controller *(Xiao, Wang, & van Arem, 2017)*.

More specifically:

- ACC car-following model: the control gains of Equation (2) are set as $k_2 = 0.04\ s^{-2}$ and $k_3 = 0.8\ s^{-1}$

CACC Control Algorithm

The control law in the CACC control algorithm is divided into three modes:

1. ***Speed Mode (Cruising Mode)***
   - Is designed for maintaining the pre-defined by the driver desired speed and is activated:
     - When the time gap to the preceding vehicle is longer than 2s.
2. **Gap-closing *Mode***
   - Enables the transition from speed control mode to gap control mode and is triggered:
     - When the time gap to the preceding vehicle is shorter than 1.5s
3. ***Gap Mode***
   - Is designed for maintaining a constant time gap between the controlled vehicle and its predecessor and is activated:
     - When the time gap to the preceding vehicle is shorter than 1.5s , and
     - the gap and speed errors are concurrently smaller than 0.2 m and 0.1 m/s.

- If the time gap is between the maximum and minimum threshold, the controlled vehicle retains the previous control strategy to provide hysteresis in the control loop and perform a smooth transfer between the two strategies.

Speed Mode (CACC)

- Speed controller for CACC vehicles is the same with ACC ones, since the additional information exchange between vehicles (V2V) and/or the infrastructure (V2I) through wireless communication does not influence the vehicle cruising mode.

$$\alpha_{sv}(t+1) = k_1(v_d - v_{sv}(t)) \qquad (1)$$

where,

$\alpha_{sv}(t+1)$: acceleration recommended by the ACC/CACC controller to the subject vehicle (m/s^2)

k_1: gain to determine the rate of speed error for acceleration ($k_1 = 0.4\ s^{-1}$ in this study)

v_d: desired speed (m/s)

$v_{sv}(t)$: current speed of the subject vehicle (m/s)

Gap Mode (CACC)

The velocity of **CACC** vehicles is modeled as

$$v_{sv}(t+1) = v_{sv}(t) + k_4 e_k + k_5 \dot{e}_k \qquad (4)$$

where,

v_{sv}: velocity recommended by the CACC controller to the subject vehicle (m/s)

k_4 and k_5: gains for adjusting the time gap between the subject vehicle and preceding vehicle ($k_4 = 0.45\ s^{-2}$ and $k_5 = 0.25\ s^{-1}$ in this study)

e_k: the gap error, given as

$$e_k = d(t) - t_d v_{sv}(t) \qquad (5)$$

t_d: desired time gap of the CACC controller (s)

- $\dot{e}_k$: the derivative of gap error, given as:

$$\dot{e}_k = v_l(t) - v_{sv}(t) - t_d \alpha_{sv}(t) \qquad (6)$$

Gap-Closing Mode (CACC)

The gap-closing controller was derived by tuning the parameters of the existing gap controller *(Xiao, Wang, & van Arem, 2017)*.

More specifically:

- ACC car-following model: the control gains of Equation (2) are set as $k_2 = 0.04\ s^{-2}$ and $k_3 = 0.8\ s^{-1}$

Highway Scenario

Network

- Single-lane straight freeway with speed limit of 100 km/h
- 6.5 km

Simulation Parameters

- Simulation length: 1 h
- Simulation step 0.1 s
- The flow data are recorded at intervals of 50 s

Vehicle Parameters

- Vehicle length 4.7 m
- Desired time gap for manually driving: t_d=1.64 s - Krauss model
- Desired time gaps for ACC vehicles: 31.1% at 1.6 s, 18.5% at 1.4 s, 50.4% at 1.1 s
- Desired time gaps for CACC vehicles: 31.1% at 1.1 s, 18.5% at 0.9 s, 50.4% at 0.7 s
- Using a speed deviation, provided by SUMO through the attributes *speedFactor* and *speedDev*, the maximum speed is randomly selected for each vehicle, so that vehicles are not identical.

Parameter	Value			Description
	Manual	ACC	CACC	
accel	2.0	2.0	2.0	Acceleration capability of vehicles (in m/s^2).
decel	2.0	2.0	2.0	Deceleration capability of vehicles (in m/s^2
emergencyDecel	2.0	2.0	2.0	Maximal physically possible deceleration for the vehicle (in m/s^2)
sigma	0.5	-	-	Driver imperfection (between 0 and 1)
minGap	2.0	-	-	Minimum desired net distance to the leading vehicle (in m)
maxSpeed	27.78	27.78	27.78	Vehicle's maximum velocity (in m/s)
speedFactor	1.0	1.0	1.0	Vehicle's expected multiplicator for lane speed limits
speedDev	0.1	0.1	0.1	Deviation of the speedFactor
actionStepLength	0.7	0.1	0.1	Reaction time (in sec)

Simulation scenarios were defined to represent diverse combinations of manually driven, ACC and CACC vehicles so that the effects of changes in market penetration of each kind of vehicle could be determined.

Highway Scenario – Results (1)

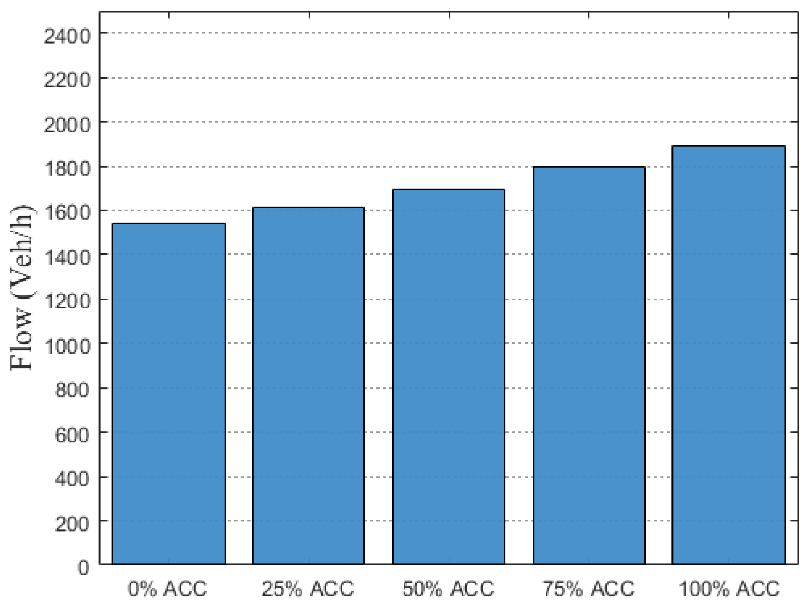


Figure 1: Traffic flow as function of changes in ACC market penetration relative to manually driven vehicles

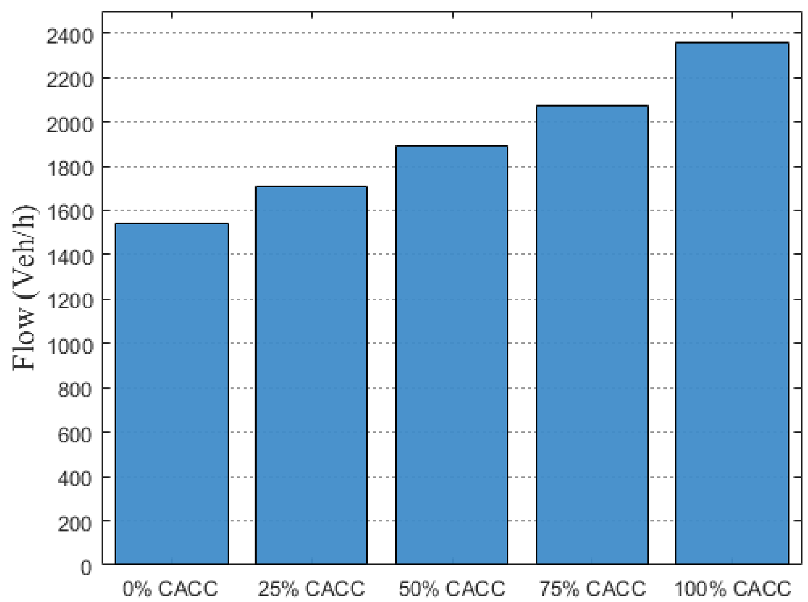


Figure 2: Traffic flow as function of changes in CACC market penetration relative to manually driven vehicles

Highway Scenario – Results (2)

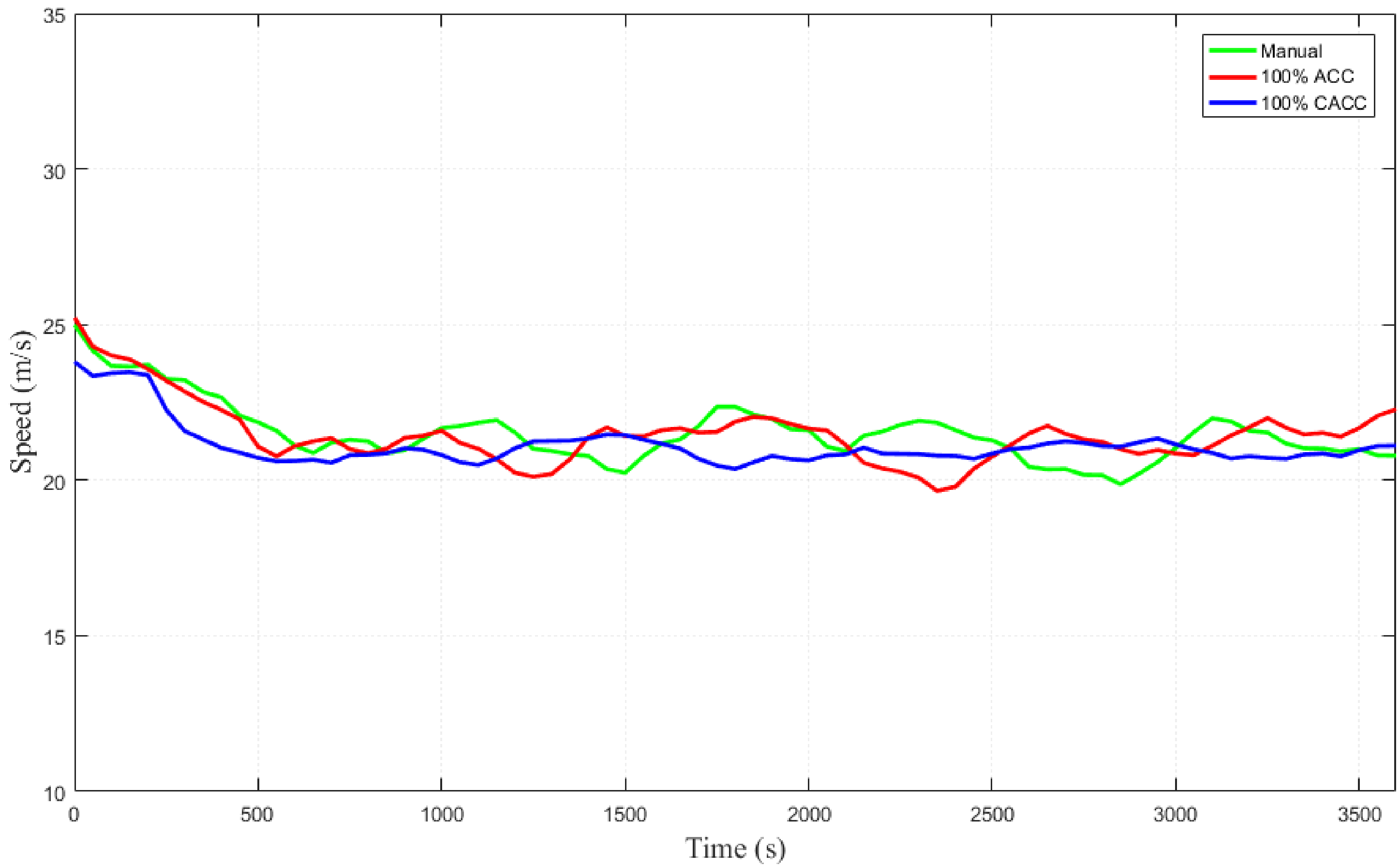


Figure 3: Speed fluctuations for manual, 100% ACC and 100% CACC vehicles

Ring-Road Scenario

Network

- Single-lane ring-road with speed limit of 120 km/h and 4 km long

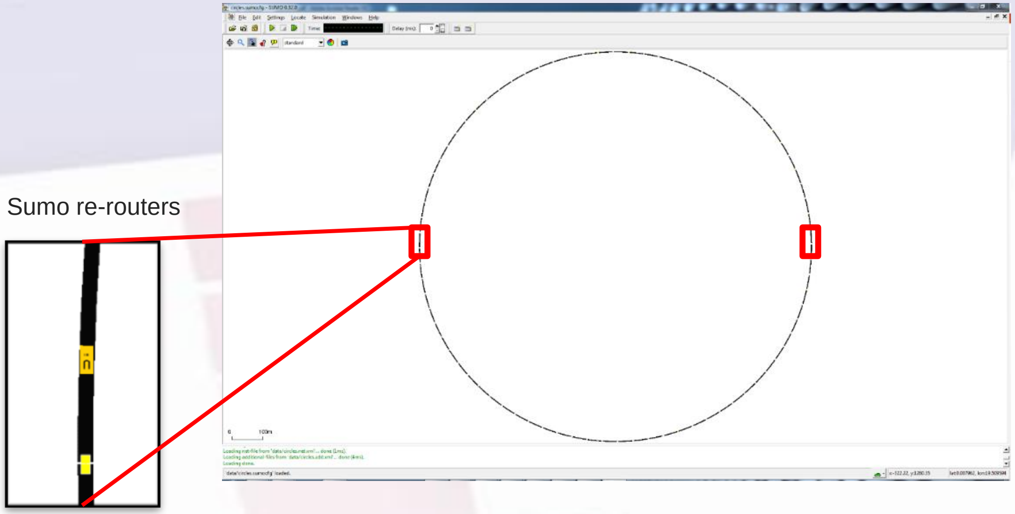
Simulation Parameters

- Simulation length: 4000 sec
- Warm up period: 1500 sec
- Simulation step 0.1 s
- Detectors were placed every 50 m and aggregated flow measurements were collected every 20 s.

Vehicle Parameters

- 200 identical vehicles
- Vehicle length 5.0 m
- Manually driven vehicles: IDM model
- Desired time gap t_d=1.5 s
- Acceleration 1 m/s^2

Once the traffic became almost uniform at time 2000 s, a perturbation was applied, through the deceleration of a vehicle for 60 s and its subsequent acceleration.



Simulation scenarios were defined to test the stability of the ACC system compared to manually driving.

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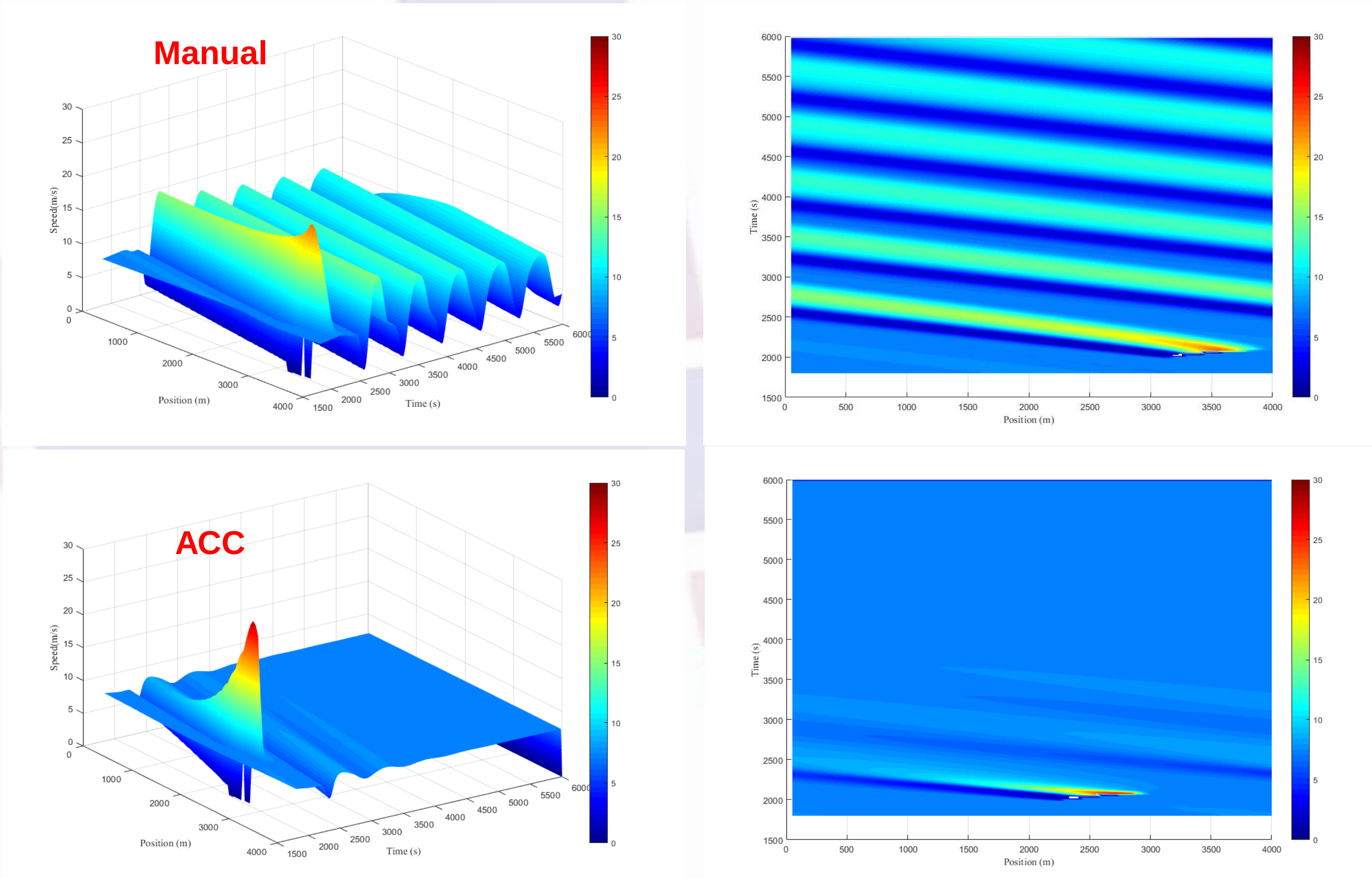
Ring-Road Scenario – Results (1)



Conclusions

- ACC and CACC systems have the potential to increase throughput even at low market penetration rates.

- ACC vehicles can enhance the stability of traffic flow by eliminating stop-and-waves.

Future Work

- Conduct sensitivity analysis with respect to controller gains.

- Examine the effects of CACC on the stability of traffic flow.

- Integrate and compare other ACC and CACC controllers in SUMO.

Questions? & Answers…

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