

RWR 4015

Traffic Simulation for Planning Applications

Dr. Ahmad Mohammadi

Week 6 | Hands-on:
Mixed Traffic Planning:
AVs and Human-Driven Vehicles

Fall 2026

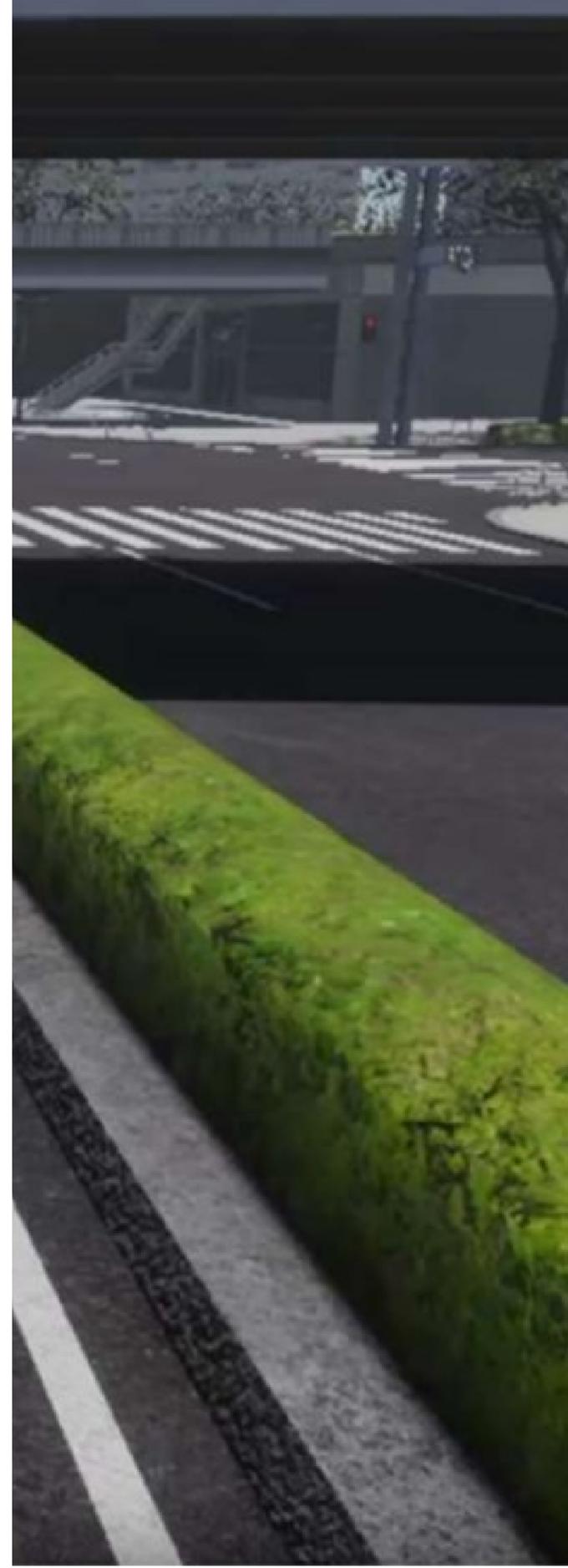
RoadwayVR





Agenda

- Develop Mixed Traffic Planning for AVs and Human-Driven Vehicles in Simulation
- Analyze Impacts of Different AV Penetration Rates on Traffic Performance

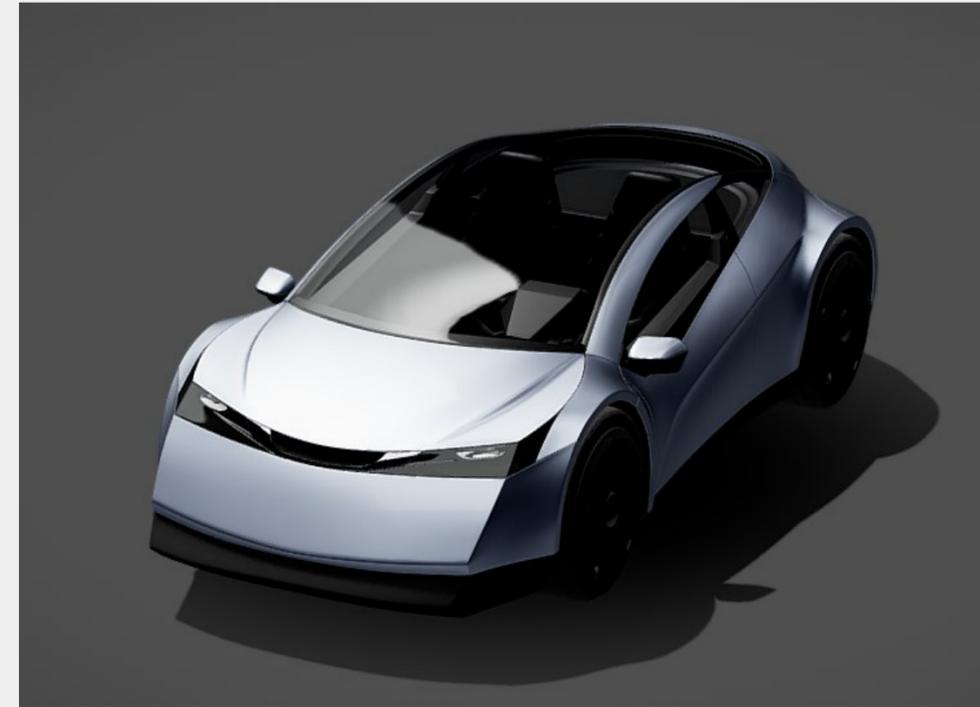
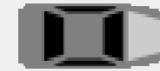


Human-Driven Vehicle vs Autonomous Vehicle

Human-Driven Vehicle (HDV)

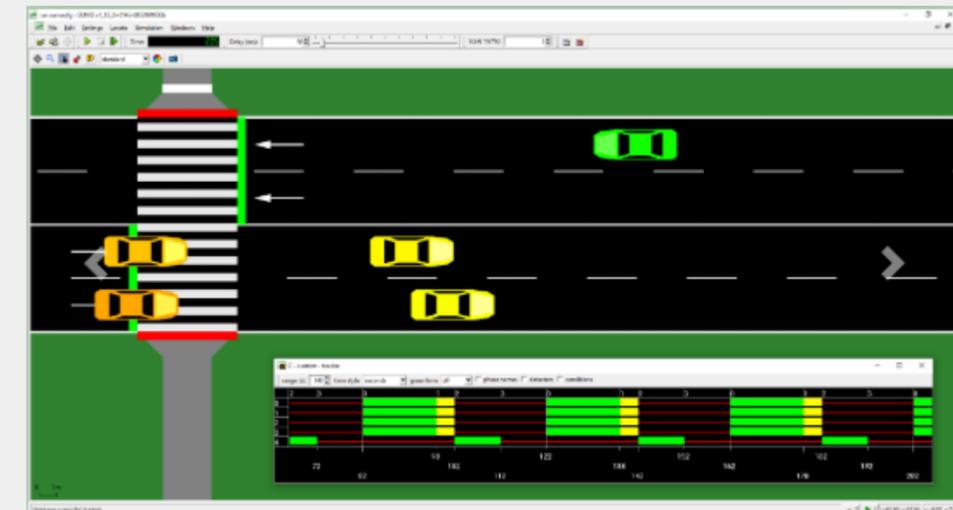
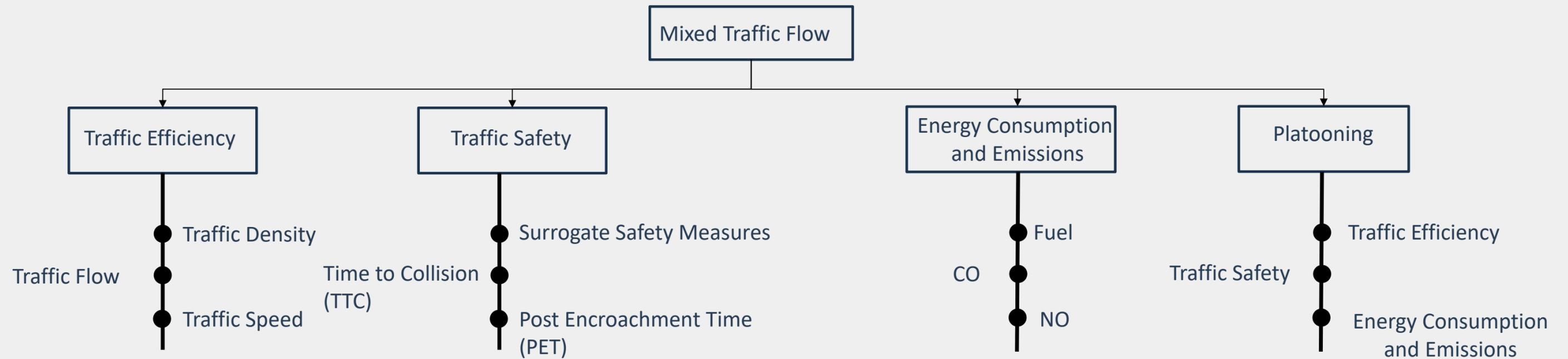


Autonomous Vehicle (AV)



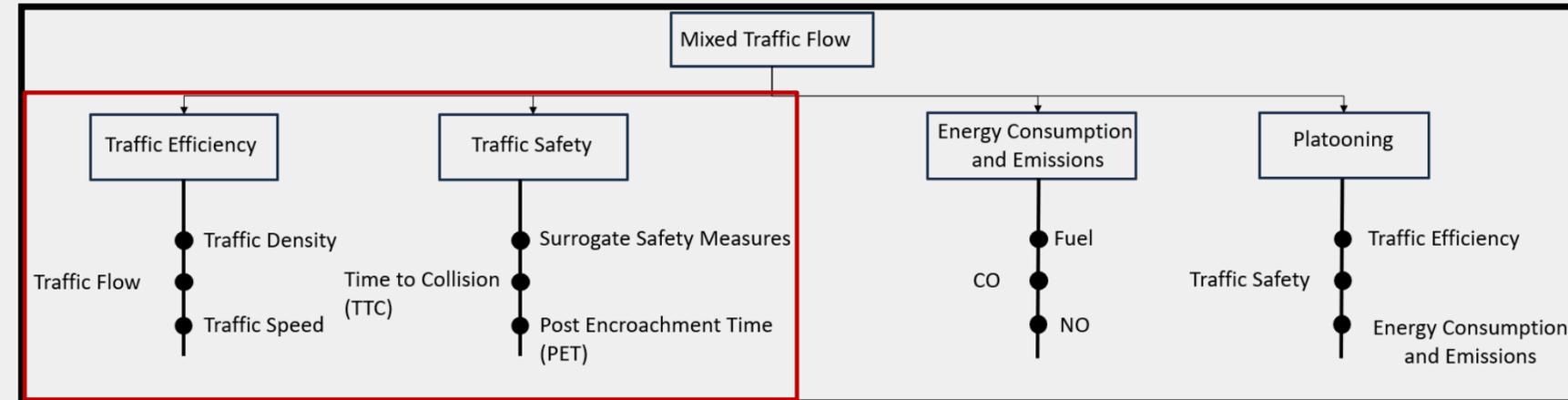
Develop Mixed Traffic Planning for AVs and HDV

□ A Microscopic Traffic Simulation Software



Develop Mixed Traffic Planning for AVs and HDV

□ **Goal:** The Impact of Connected and Automated Vehicles (CAVs) on traffic efficiency and safety at different penetration rate.



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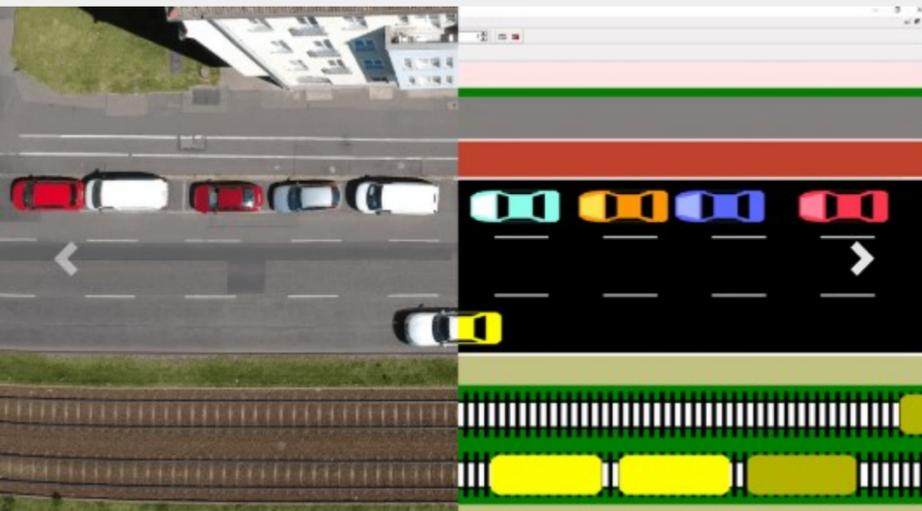
IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, VOL. 24, NO. 6, JUNE 2023

Can Connected Autonomous Vehicles Improve Mixed Traffic Safety Without Compromising Efficiency in Realistic Scenarios?

Mohit Garg^{ID} and Mélanie Bouroche^{ID}

Abstract—CAVs have the potential to improve traffic safety and efficiency in a fully connected environment, but they face additional challenges when they interact with human-driven vehicles in mixed-traffic scenarios due to the uncertainty in humans' driving behaviour. Another challenge is the unreliability of communication networks. Delays and packet losses in communication links due to dense traffic, communication interference, channel fading, etc. may jeopardize CAVs driving behaviour and negatively affect traffic safety and efficiency. While the impact of CAVs on traffic safety and efficiency at different

due to uncertainties in humans' driving behavior [3]. In contrast, CAVs have the potential to improve traffic safety and efficiency by controlling their driving behavior using onboard sensors information as well as information obtained from other vehicles and RSU-equipped infrastructure via V2X communication [4]. *Cooperative adaptive cruise control (CACC)* is a car-following control strategy employed in CAVs for their autonomous driving behavior in the longitudinal direction.



Develop Mixed Traffic Planning for AVs and HDV

□ Car Following Model for CAV

TABLE II
CAR-FOLLOWING MODEL PARAMETERS FOR SIMULATED CAVS

Parameter	Value
Speed deviation	0.05
Time headway	0.6 s
Minimum gap	1.5 m
Max acceleration	2.9 m s^{-2}
Deceleration	7.5 m s^{-2}
Emergency deceleration	9 m s^{-2}

Vehicle Type attributes

vClass	passenger	guiShape	passenger
id	DEFAULT_VEHTYPE	probability	1.00
color		personCapacity	4
length	5.00	containerCapacity	0
minGap	2.50	boardingDuration	0.50
maxSpeed	55.56	loadingDuration	90.00
desiredMaxSpeed	2777.78	latAlignment	center
speedFactor	normc(1.00, 0.10, .20, 2.00)	minGapLat	0.12
emissionClass	HBFA3/PC_G_EU4	maxSpeedLat	1.00
width	1.80	actionStepLength	0.00
height	1.50	carriageLength	-1.00
imgFile		locomotiveLength	-1.00
osgFile	car-normal-citrus.obj	carriageGap	1
laneChangeModel	default	Edit parameters	

Junction Model attributes

crossingGap	10	ignoreFoeProb	0.0
ignoreKeepClearTime	-1	ignoreFoeSpeed	0.0
driveAfterYellowTime	-1	sigmaMinor	0.0
driveAfterRedTime	-1	timegapMinor	1
driveRedSpeed	0.0	impatience	0.0

Lane Change Model attributes

strategic	1.0
cooperative	1.0
speedGain	1.0
keepRight	1.0
sublane	1.0
opposite	1.0
pushy	0.00
pushyGap	0.00
assertive	1.0
impatience	0.00
timeTolmpatience	infinity
accelLat	1.0
lookaheadLeft	2.0
speedGainRight	0.1
maxSpeedLatStanding	0.00
maxSpeedLatFactor	1.00
turnAlignDistance	0.00
overtakeRight	0.00
keepRightAcceptanceTime	-1
overtakeDeltaSpeedFactor	0.00

Car Following Model attributes

Algorithm	CACC
accel	2.60
decel	4.50
emergencyDecel	9.00
tau	1.00speed
collisionMinGapFactor	

Some attributes wasn't implemented yet

Accept Cancel Reset

Develop Mixed Traffic Planning for AVs and HDV

- Lane Changing Model for CAVs: LC 2013 → cooperative 1

Vehicle Type attributes

vClass	passenger	guiShape	default
id	t_0	probability	1.00
color		personCapacity	4
length	5.00	containerCapacity	0
minGap	2.50	boardingDuration	0.50
maxSpeed	55.56	loadingDuration	90.00
desiredMaxSpeed	2777.78	latAlignment	center
speedFactor	normc(1.00,0.00)	minGapLat	0.12
emissionClass	HBFA3/PC_G_EU4	maxSpeedLat	1.00
width	1.80	actionStepLength	0.00
height	1.50	carriageLength	-1.00
imgFile		locomotiveLength	-1.00
osgFile	car-normal-citrus.obj	carriageGap	1
laneChangeModel	LC2013	Edit parameters	ent=2 has.driverState.device=true

Lane Change Model attributes

strategic	1.0
cooperative	1
speedGain	1.0
keepRight	1.0
sublane	1.0
opposite	1.0
pushy	0.00
pushyGap	0.00
assertive	1.0
impatience	0.00
timeToImpatience	infinity
accelLat	1.0
lookaheadLeft	2.0
speedGainRight	0.1
maxSpeedLatStanding	0.00
maxSpeedLatFactor	1.00
turnAlignDistance	0.00
overtakeRight	0.00
keepRightAcceptanceTime	-1
overtakeDeltaSpeedFactor	0.00

Car Following Model attributes

Algorithm	CACC
accel	2.60
decel	4.50
emergencyDecel	9.00
tau	1.00
collisionMinGapFactor	

Some attributes wasn't implemented yet

Accept Cancel Reset

Develop Mixed Traffic Planning for AVs and HDV

□ Car Following Model for Normal Car

TABLE III
CAR-FOLLOWING MODEL PARAMETERS FOR SIMULATED HDVS

Parameter	Value
Maximum acceleration a	1.0 m s^{-2}
Desired deceleration b	2.0 m s^{-2}
Time headway T	1.5 s
Free flow speed v_f	33.3 m s^{-1}
Minimum gap s_0	2.0 m
Imperfection σ	0.5

Edit vType
✕

Vehicle Type attributes

vClass	passenger	guiShape	default
id	t_0	probability	1.00
color		personCapacity	4
length	5.00	containerCapacity	0
minGap	2.50	boardingDuration	0.50
maxSpeed	55.56	loadingDuration	90.00
desiredMaxSpeed	2777.78	latAlignment	center
speedFactor	normc(1.00,0.00)	minGapLat	0.12
emissionClass	HBEFA3/PC_G_EU4	maxSpeedLat	1.00
width	1.80	actionStepLength	0.00
height	1.50	carriageLength	-1.00
imgFile		locomotiveLength	-1.00
osgFile	car-normal-citrus.obj	carriageGap	1
laneChangeModel	default	Edit parameters	:=100 has.driverState.device=true

Lane Change Model attributes

strategic	1.0
cooperative	1.0
speedGain	1.0
keepRight	1.0
sublane	1.0
opposite	1.0
pushy	0.00
pushyGap	0.00
assertive	1.0
impatience	0.00
timeToImpatience	infinity
accelLat	1.0
lookaheadLeft	2.0
speedGainRight	0.1
maxSpeedLatStanding	0.00
maxSpeedLatFactor	1.00
turnAlignDistance	0.00
overtakeRight	0.00
keepRightAcceptanceTime	-1
overtakeDeltaSpeedFactor	0.00

Car Following Model attributes

Algorithm	IDM
1 accel	2.60
2 decel	4.50
4 emergencyDecel	9.00
tau	1.00
collisionMinGapFactor	
6 delta	
stepping	

Junction Model attributes

crossingGap	10	ignoreFoeProb	0.0
ignoreKeepClearTime	-1	ignoreFoeSpeed	0.0
driveAfterYellowTime	-1	sigmaMinor	0.0
driveAfterRedTime	-1	timegapMinor	1
driveRedSpeed	0.0	impatience	0.0

✓ Accept ✗ Cancel ↺ Reset

Device in SUMO

- ❑ Vehicle devices are used to model and configure different aspects such as output (device.fcd) or behavior (device.rerouting). Two Examples

Taxi

Customer Stops

Taxis will stop to pick-up and drop-off customers. The 'actType' attribute of a stop indicates the purpose ('pickup' / 'dropOff')

```
<vType id="taxi" vClass="taxi">
  <param key="has.taxi.device" value="true"/>
  <param key="device.taxi.pickupDuration" value="0"/>
  <param key="device.taxi.dropOffDuration" value="60"/>
  <param key="device.taxi.parking" value="false"/>
</vType>
```

- duration for pick-up stop can be configured with vType/vehicle param "device.taxi.pickupDuration" (default "0")
- duration for drop-off stop can be configured with vType/vehicle param "device.taxi.dropOffDuration" (default "60")

By default, vehicle stops will have attribute `parking="true"` which means that the taxi will not block a driving lane. This can

SSM

```
<routes>
  ...
  <vehicle id="v0" route="route0" depart="0">
    <param key="has.ssm.device" value="true"/>
    <param key="device.ssm.measures" value="TTC DRAC PET BR SGAP TGAP PPET MDRAC"/>
    <param key="device.ssm.thresholds" value="3.0 3.0 2.0 0.0 0.2 0.5 2.0 3.4"/>
    <param key="device.ssm.range" value="50.0" />
    <param key="device.ssm.mdrac.prt" value="1.0" />
    <param key="device.ssm.extratime" value="5.0" />
    <param key="device.ssm.file" value="ssm_v0.xml" />
    <param key="device.ssm.trajectories" value="false" />
    <param key="device.ssm.geo" value="false" />
    <param key="device.ssm.write-positions" value="false" />
    <param key="device.ssm.write-lane-positions" value="false" />
    <param key="device.ssm.filter-edges.input-file" value="input_list.txt" />
    <param key="device.ssm.exclude-conflict-types" value="" />
  </vehicle>
  ...
</routes>
```

Device in SUMO



□ **Driver State:** Induce imperfection into car-following and lane change models.

TABLE IV
DRIVER STATE DEVICE PARAMETERS FOR
SIMULATING DRIVER'S IMPERFECTION

Parameter	Description	Value
actionStepLength	Driver reaction time in executing the decision logic	0.5 s
initialAwareness	Driver awareness	1.1
errorTimeScaleCoefficient	Time scale constant of the perception error process	100
errorNoiseIntensityCoefficient	Noise intensity constant of the perception error process	0.5
speedDifferenceErrorCoefficient	Scaling coefficient for the relative speed difference error	2
headwayErrorCoefficient	Scaling coefficient for the relative distance difference error	2
speedDifferenceChangePerceptionThreshold	Threshold value for the perception of changes in the speed difference	0.5
headwayChangePerceptionThreshold	Threshold value for the perception of changes in the distance difference	0.5

The screenshot shows the 'Edit vType' window in SUMO, specifically the 'Parameters' section for a vehicle type. The 'has.driverState.device' parameter is set to 'true'. Other parameters listed include 'driverState.maximalReactionTime' (0.5), 'driverState.initialAwareness' (1.1), 'driverState.errorTimeScaleCoefficient' (100), 'driverState.errorNoiseIntensityCoefficient' (0.5), 'driverState.speedDifferenceErrorCoefficient' (2), 'driverState.headwayErrorCoefficient' (2), 'driverState.speedDifferenceChangePerceptionThreshold' (0.5), and 'driverState.headwayChangePerceptionThreshold' (0.5). The interface also shows 'Vehicle Type attributes', 'Lane Change Model attributes', and 'Junction Model attributes'.

Device in SUMO



□ **Driver State:** Induce imperfection into car-following and lane change models.

TABLE IV
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speedDifferenceErrorCoefficient	Scaling coefficient for the relative speed difference error	2
headwayErrorCoefficient	Scaling coefficient for the relative distance difference error	2
speedDifferenceChangePerceptionThreshold	Threshold value for the perception of changes in the speed difference	0.5
headwayChangePerceptionThreshold	Threshold value for the perception of changes in the distance difference	0.5

```
has.driverState.device → true
driverState.maximalReactionTime → 0.5
driverState.initialAwareness → 1.1
driverState.errorTimeScaleCoefficient → 100
driverState.errorNoiseIntensityCoefficient → 0.5
driverState.speedDifferenceErrorCoefficient → 2
driverState.headwayErrorCoefficient → 2
driverState.speedDifferenceChangePerceptionThreshold → 0.5
driverState.headwayChangePerceptionThreshold → 0.5
```



Device in SUMO

□ Check Route File

```
<routes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="
<!-- VTypes -->
<vType id="CAV" minGap="1.50" speedFactor="normc(1.00,0.05)" guiShape="passenger" color="red"
<vType id="HDV" minGap="2.00" maxSpeed="33.30" guiShape="passenger" carFollowModel="IDP"
  <param key="driverState.errorNoiseIntensityCoefficient" value="0.5"/>
  <param key="driverState.errorTimeScaleCoefficient" value="100"/>
  <param key="driverState.headwayChangePerceptionThreshold" value="0.5"/>
  <param key="driverState.headwayErrorCoefficient" value="2"/>
  <param key="driverState.initialAwareness" value="1.1"/>
  <param key="driverState.maximalReactionTime" value="0.5"/>
  <param key="driverState.speedDifferenceChangePerceptionThreshold" value="0.5"/>
  <param key="driverState.speedDifferenceErrorCoefficient" value="2"/>
  <param key="has.driverState.device" value="true"/>
</vType>
</routes>
```

Develop Mixed Traffic Planning for AVs and HDV

- Lane Changing Model for Normal Car: LC 2013 → cooperative 1 to 0.5

Edit vType

Vehicle Type attributes			
vClass	passenger	guiShape	default
id	t_0	probability	1.00
color		personCapacity	4
length	5.00	containerCapacity	0
minGap	2.50	boardingDuration	0.50
maxSpeed	55.56	loadingDuration	90.00
desiredMaxSpeed	2777.78	latAlignment	center
speedFactor	normc(1.00,0.00)	minGapLat	0.12
emissionClass	HBEFA3/PC_G_EU4	maxSpeedLat	1.00
width	1.80	actionStepLength	0.00
height	1.50	carriageLength	-1.00
imgFile		locomotiveLength	-1.00
osgFile	car-normal-citrus.obj	carriageGap	1
laneChangeModel	LC2013	Edit parameters	ent=2 has.driverState.device=true

Lane Change Model attributes	
strategic	1.0
cooperative	0.5
speedGain	1.0
keepRight	1.0
sublane	1.0
opposite	1.0
pushy	0.00
pushyGap	0.00
assertive	1.0
impatience	0.00
timeToImpatience	infinity
accelLat	1.0
lookaheadLeft	2.0
speedGainRight	0.1
maxSpeedLatStanding	0.00
maxSpeedLatFactor	1.00
turnAlignDistance	0.00
overtakeRight	0.00
keepRightAcceptanceTime	-1
overtakeDeltaSpeedFactor	0.00

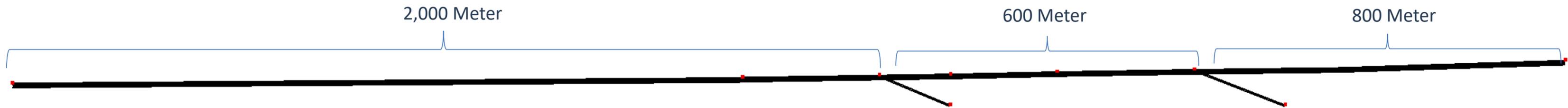
Car Following Model attributes	
Algorithm	IDM
accel	2.60
decel	4.50
emergencyDecel	9.00
tau	1.00
collisionMinGapFactor	
delta	
stepping	

Junction Model attributes			
crossingGap	10	ignoreFoeProb	0.0
ignoreKeepClearTime	-1	ignoreFoeSpeed	0.0
driveAfterYellowTime	-1	sigmaMinor	0.0
driveAfterRedTime	-1	timegapMinor	1
driveRedSpeed	0.0	impatience	0.0

Accept Cancel Reset

Develop Mixed Traffic Planning for AVs and HDV

Create A Network

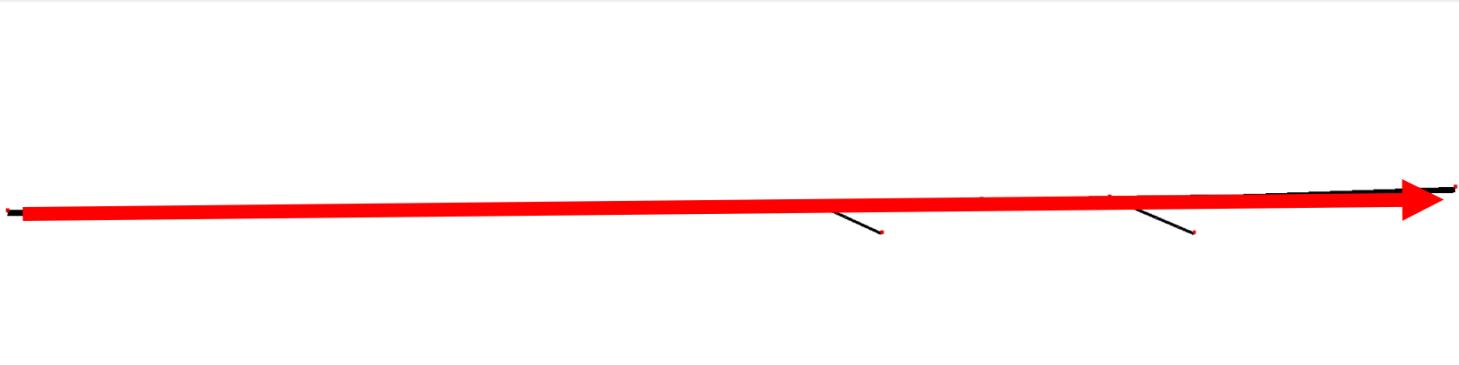


Analyze Impacts of Different AV Penetration Rates

Add Traffic Volume

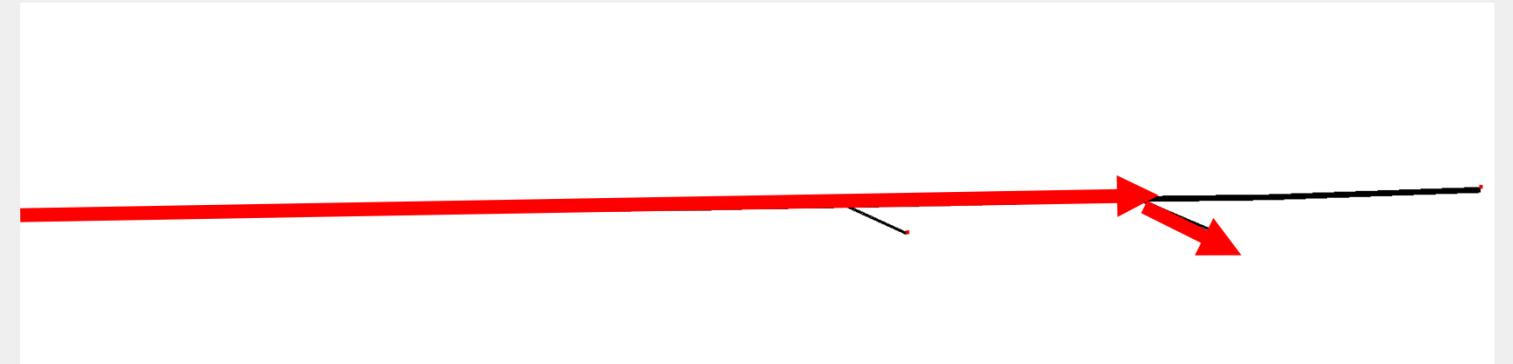
F_0: 1800

Vehicle Type: CAVs



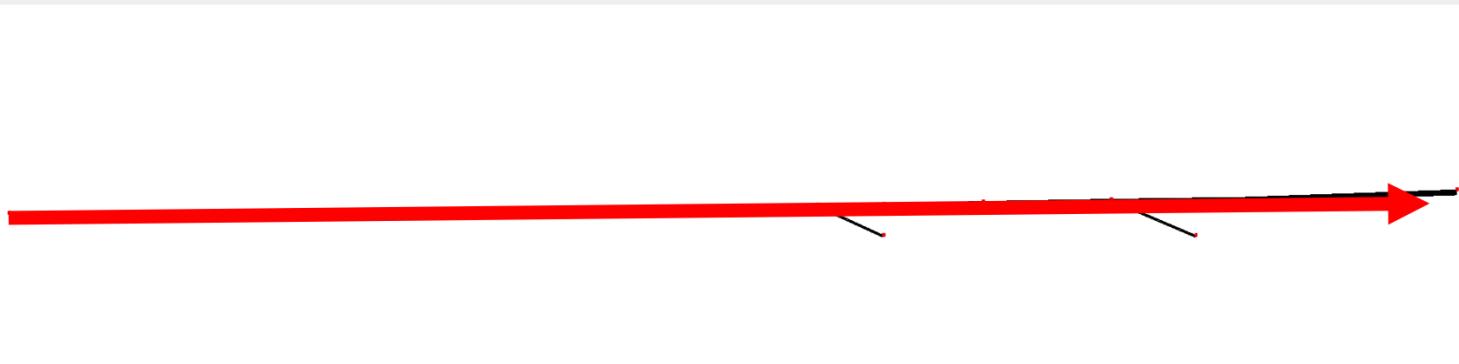
F_1: 500

Vehicle Type: CAVs



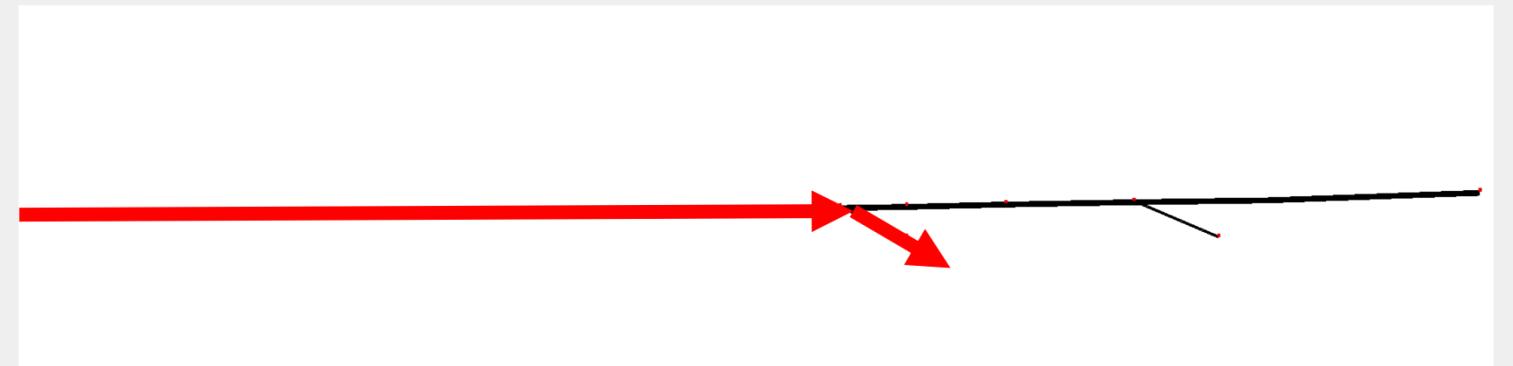
F_2: 1800

Vehicle Type: Normal



F_3: 500

Vehicle Type: Normal



Analyze Impacts of Different AV Penetration Rates

□ Result

Penetration rate: 100 % (CAVs) - 0 %(Normal)



Travel Time: 260



Penetration rate: 50 %(CAVs) - 50 %(Normal)



Travel Time: 314



Penetration rate: 0 %(CAVs) - 100 %(Normal)



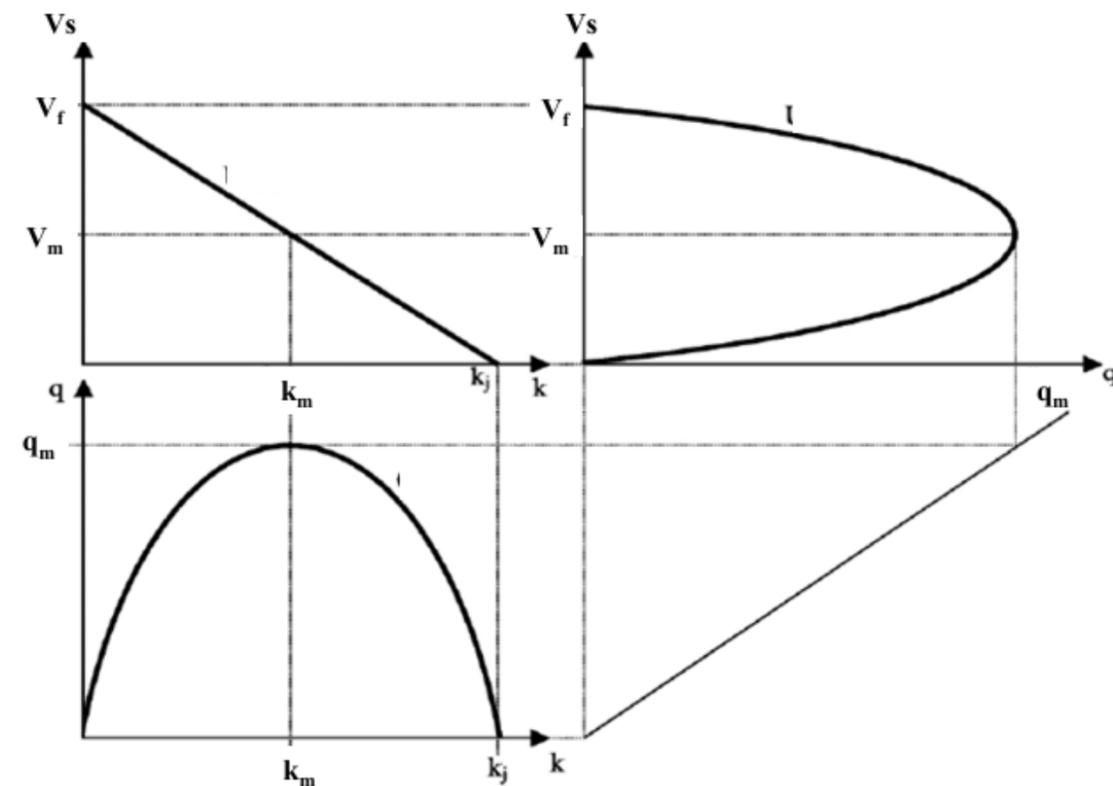
Travel Time:

Analyze Impacts of Different AV Penetration Rates

Normal

Speed(v_s)-Flow(q)-Density(k) Relationship

□ Greenshield's Model (1934):



9

Mixed Traffic

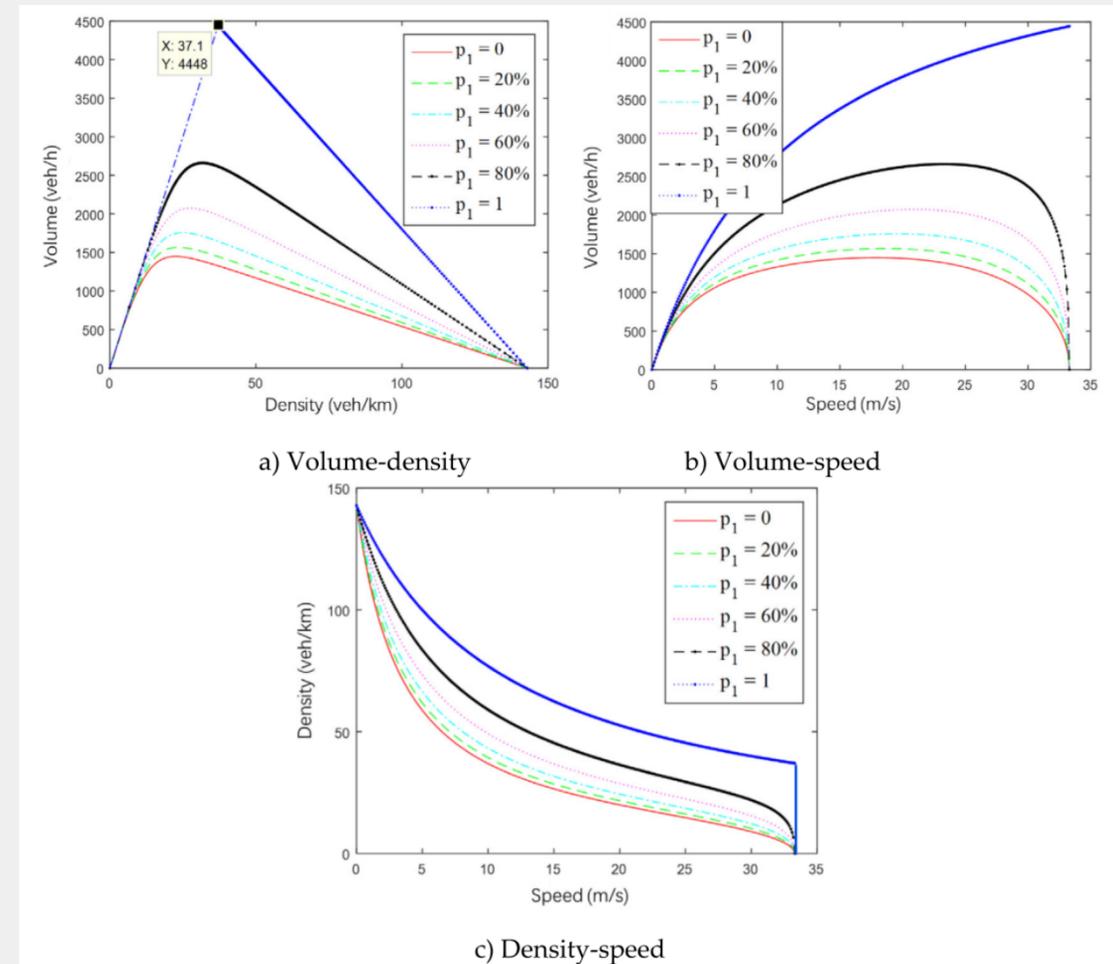


Fig. 2. Fundamental diagram of $\theta = 0$ with different p_1 .