

RWR 4015

# Traffic Simulation for Planning Applications

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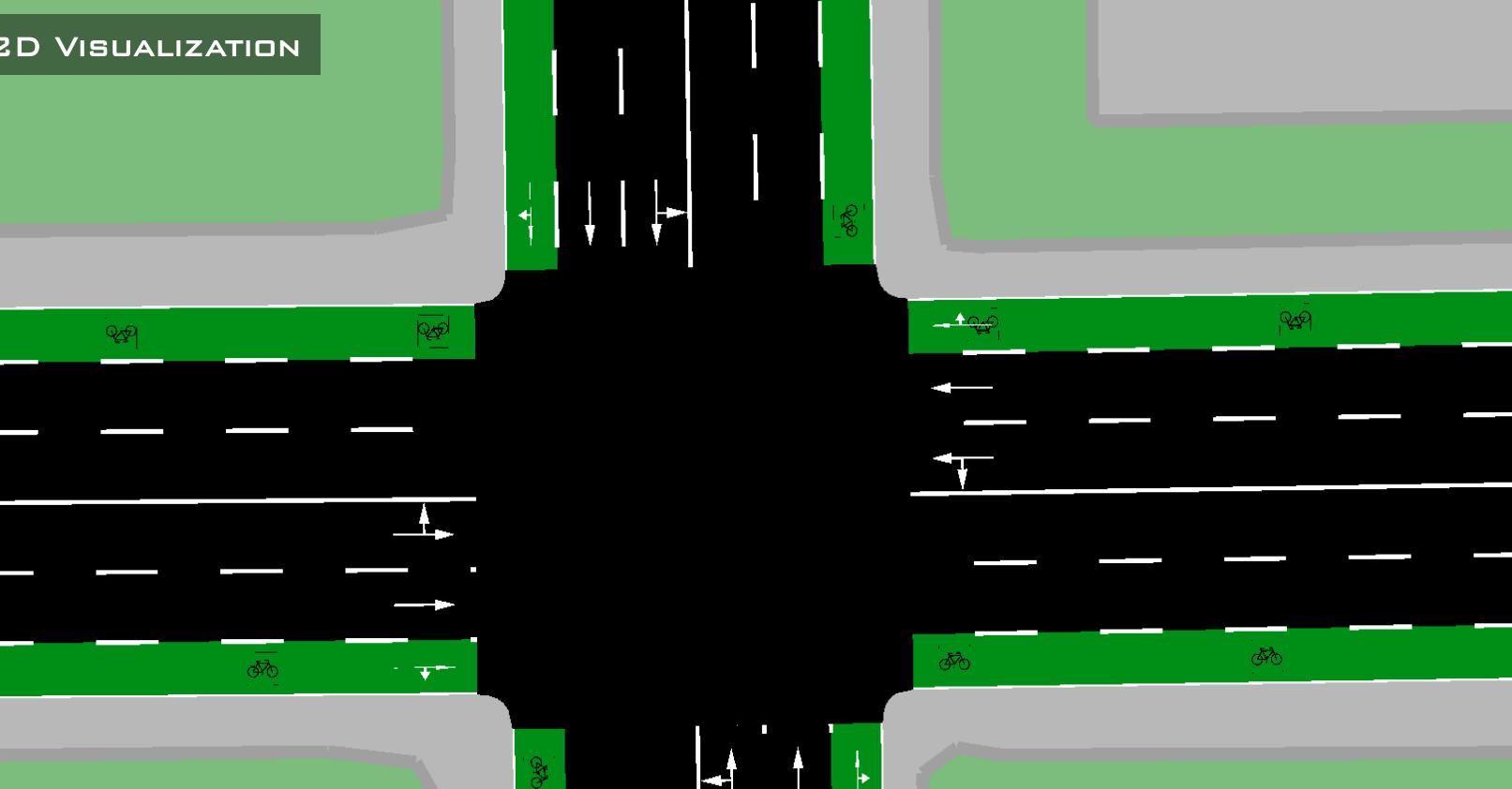
Week 6 | Hands-on:  
Mixed Traffic Planning:  
AVs and Human-Driven Vehicles

Fall 2026

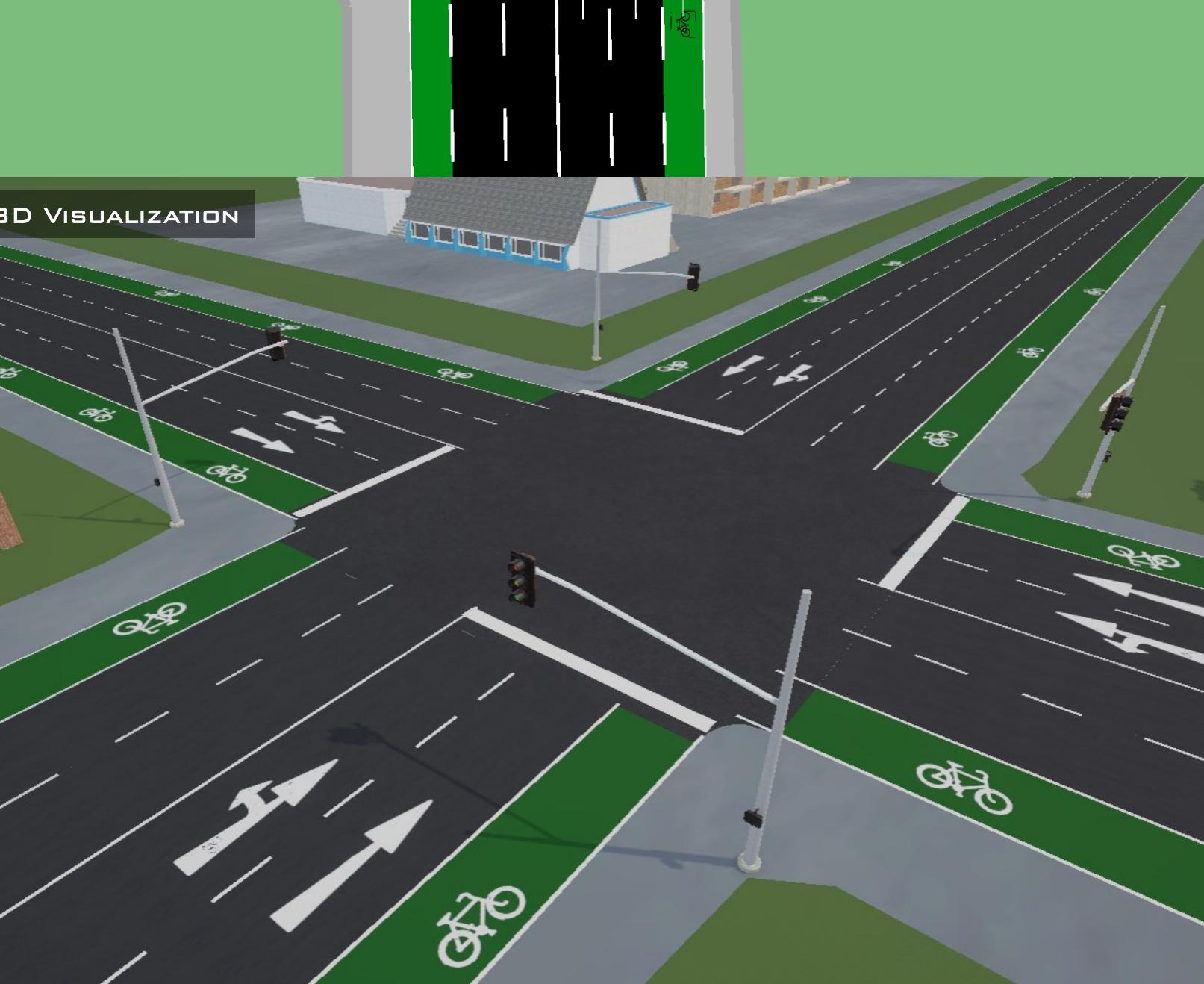
RoadwayVR



2D VISUALIZATION



3D VISUALIZATION



# Agenda

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

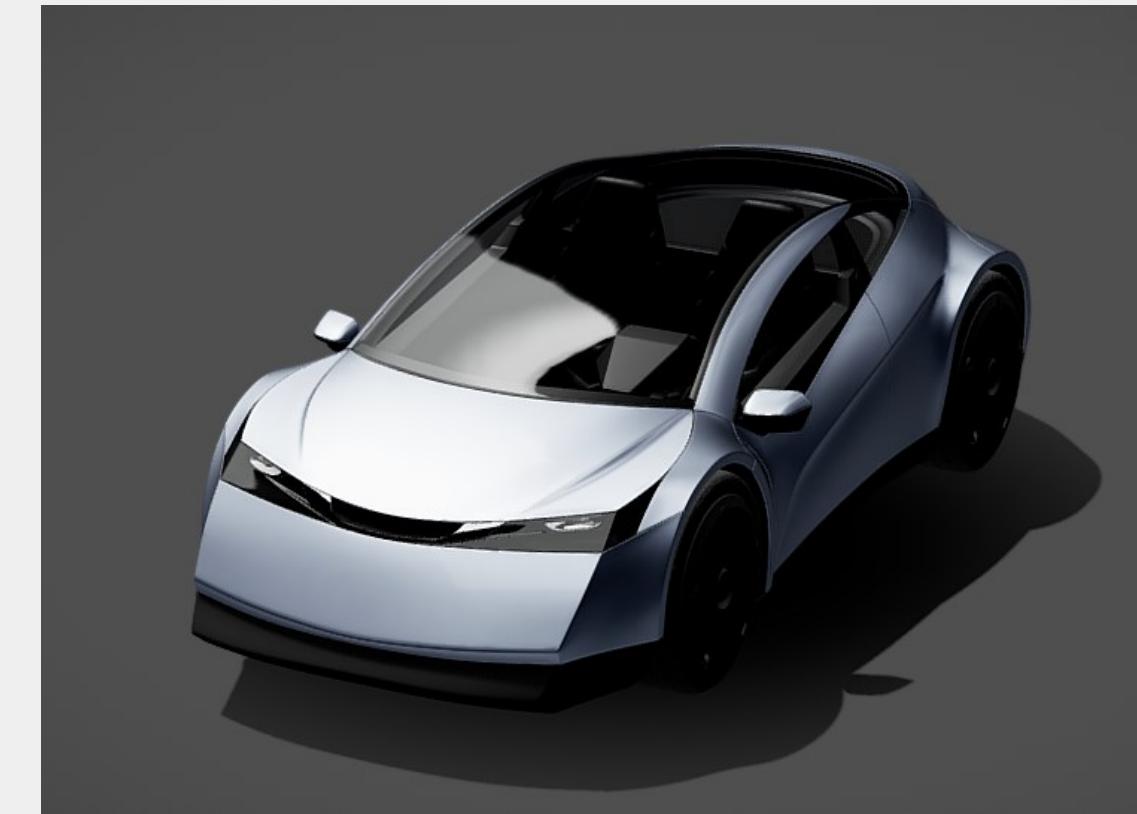


# Human-Driven Vehicle vs Autonomous Vehicle

**Human-Driven Vehicle (HDV)**

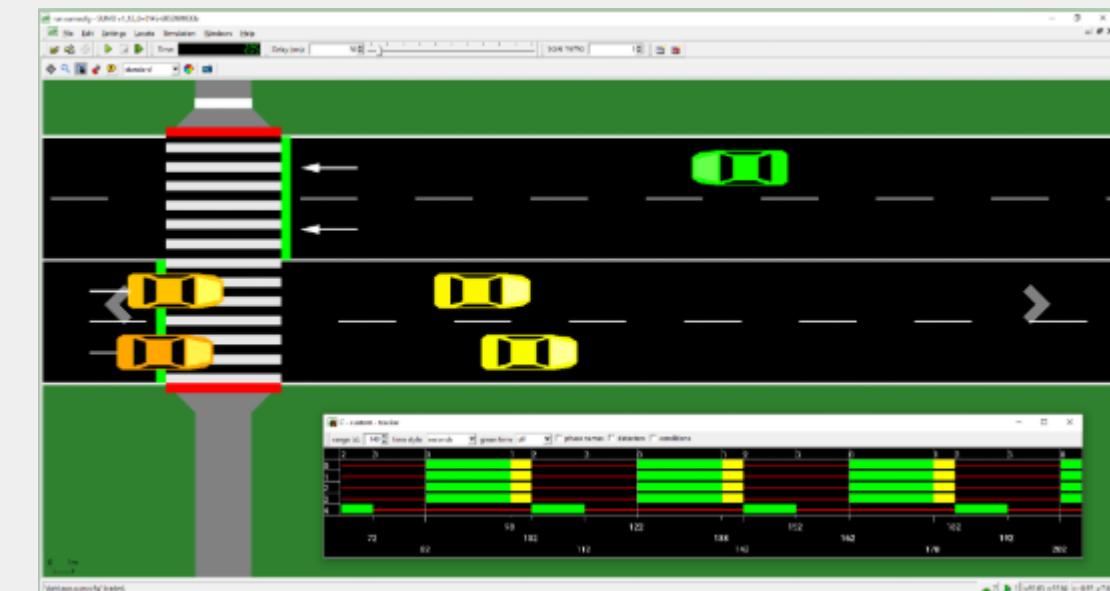
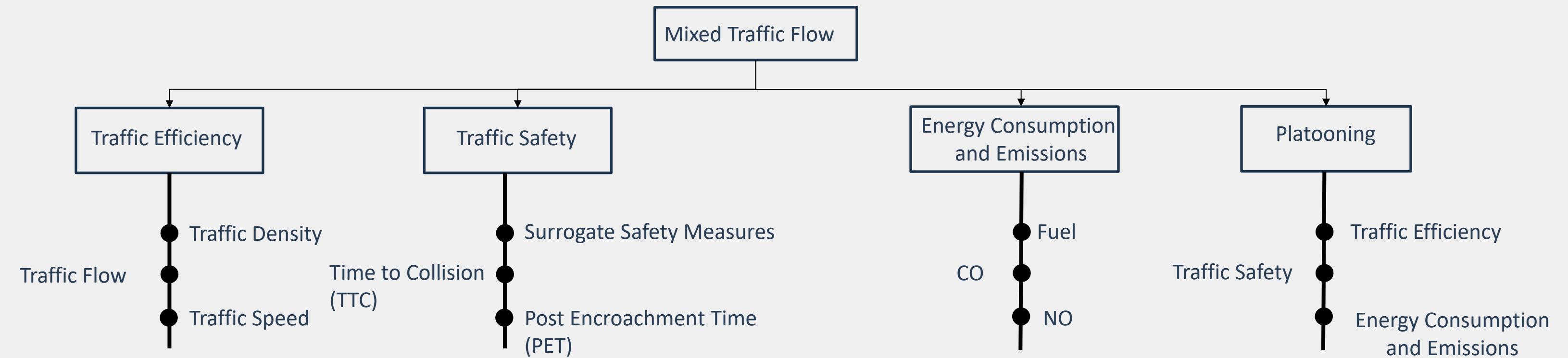


**Autonomous Vehicle (AV)**



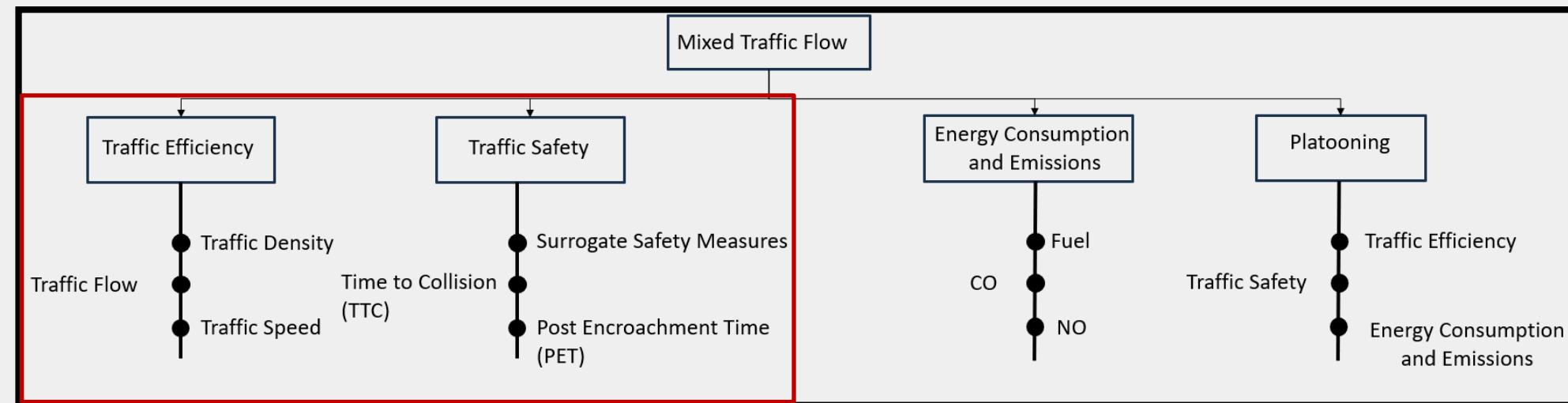
# Develop Mixed Traffic Planning for AVs and HDV

## □ 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.



6674

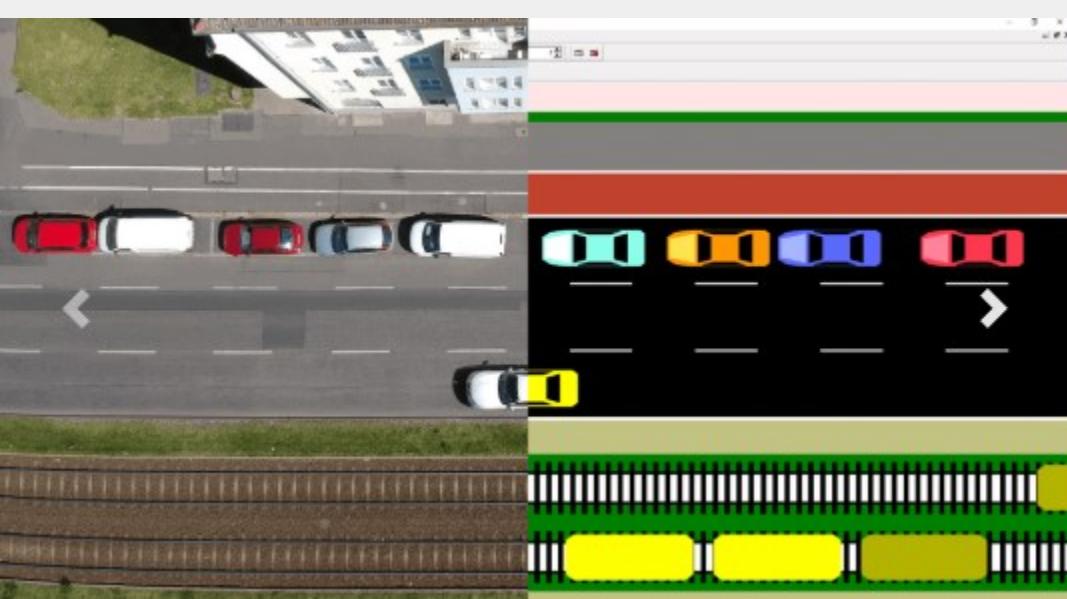
IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, VOL. 24, NO. 6, JUNE 2023

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

Mohit Garg<sup>ID</sup> and Mélanie Bouroche<sup>ID</sup>

**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	6
Time headway	0.6 s	4
Minimum gap	1.5 m	5
Max acceleration	$2.9 \text{ m s}^{-2}$	1
Deceleration	$7.5 \text{ m s}^{-2}$	2
Emergency deceleration	$9 \text{ m s}^{-2}$	3

Edit vType

Vehicle Type attributes		Lane Change Model attributes		Car Following Model attributes	
vClass		guiShape		Algorithm	CACC
passenger	DEFAULT_VEHTYPE	probability	1.00	1	accel 2.60
id		personCapacity	4	2	decel 4.50
color		containerCapacity	0	3	emergencyDecel 9.00
length	5.00	boardingDuration	0.50	4	tau 1.00speed
minGap	2.50	loadingDuration	90.00		
maxSpeed	55.56	latAlignment	center		
desiredMaxSpeed	2777.78	minGapLat	0.12		
speedFactor	normc(1.00,0.10,-0.20,2.00)	maxSpeedLat	1.00		
emissionClass	HBEFA3/PC_G_EU4	actionStepLength	0.00		
width	1.80	carriageLength	-1.00		
height	1.50	locomotiveLength	-1.00		
imgFile	car-normal-citrus.obj	carriageGap	1		
osgFile		impatience	0.00		
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		

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

Edit vType

Vehicle Type attributes			
vClass		guiShape	?
passenger		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	agent=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	

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

## □ Car Following Model for Normal Car

TABLE III  
CAR-FOLLOWING MODEL PARAMETERS FOR SIMULATED HDVs

Parameter	Value
Maximum acceleration $a$	$1.0 \text{ m s}^{-2}$ <span style="border: 1px solid red; border-radius: 50%; padding: 2px;">1</span>
Desired deceleration $b$	$2.0 \text{ m s}^{-2}$ <span style="border: 1px solid red; border-radius: 50%; padding: 2px;">2</span>
Time headway $T$	$1.5 \text{ s}$ <span style="border: 1px solid red; border-radius: 50%; padding: 2px;">4</span>
Free flow speed $v_f$	$33.3 \text{ m s}^{-1}$ <span style="border: 1px solid red; border-radius: 50%; padding: 2px;">3</span>
Minimum gap $s_0$	$2.0 \text{ m}$ <span style="border: 1px solid red; border-radius: 50%; padding: 2px;">5</span>
Imperfection $\sigma$	$0.5$ <span style="border: 1px solid red; border-radius: 50%; padding: 2px;">6</span>

Edit vType

Vehicle Type attributes		Lane Change Model attributes		Car Following Model attributes	
vClass	<input checked="" type="button"/> passenger	guiShape	<input type="button"/>	strategic	1.0
id	t_0	default	<input type="button"/>	cooperative	1.0
color	<input type="button"/>	probability	1.00	speedGain	1.0
length	5.00	personCapacity	4	keepRight	1.0
minGap	2.50	containerCapacity	0	sublane	1.0
maxSpeed	55.56	boardingDuration	0.50	opposite	1.0
desiredMaxSpeed	2777.78	loadingDuration	90.00	pushy	0.00
speedFactor	normc(1.00,0.00)	latAlignment	center	pushyGap	0.00
emissionClass	HBEFA3/PC_G_EU4	minGapLat	0.12	assertive	1.0
width	1.80	maxSpeedLat	1.00	impatience	0.00
height	1.50	actionStepLength	0.00	timeTolImpatience	infinity
imgFile	<input type="button"/>	carriageLength	-1.00	accelLat	1.0
osgFile	car-normal-citrus.obj	locomotiveLength	-1.00	lookaheadLeft	2.0
laneChangeModel	default	carriageGap	1	speedGainRight	0.1
	<input type="button"/> Edit parameters	:=100 has.driverState.device=true		maxSpeedLatStanding	0.00
Junction Model attributes					
crossingGap	10	ignoreFoeProb	0.0	maxSpeedLatFactor	1.00
ignoreKeepClearTime	-1	ignoreFoeSpeed	0.0	turnAlignDistance	0.00
driveAfterYellowTime	-1	sigmaMinor	0.0	overtakeRight	0.00
driveAfterRedTime	-1	timegapMinor	1	keepRightAcceptanceTime	-1
driveRedSpeed	0.0	impatience	0.0	overtakeDeltaSpeedFactor	0.00

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>
```



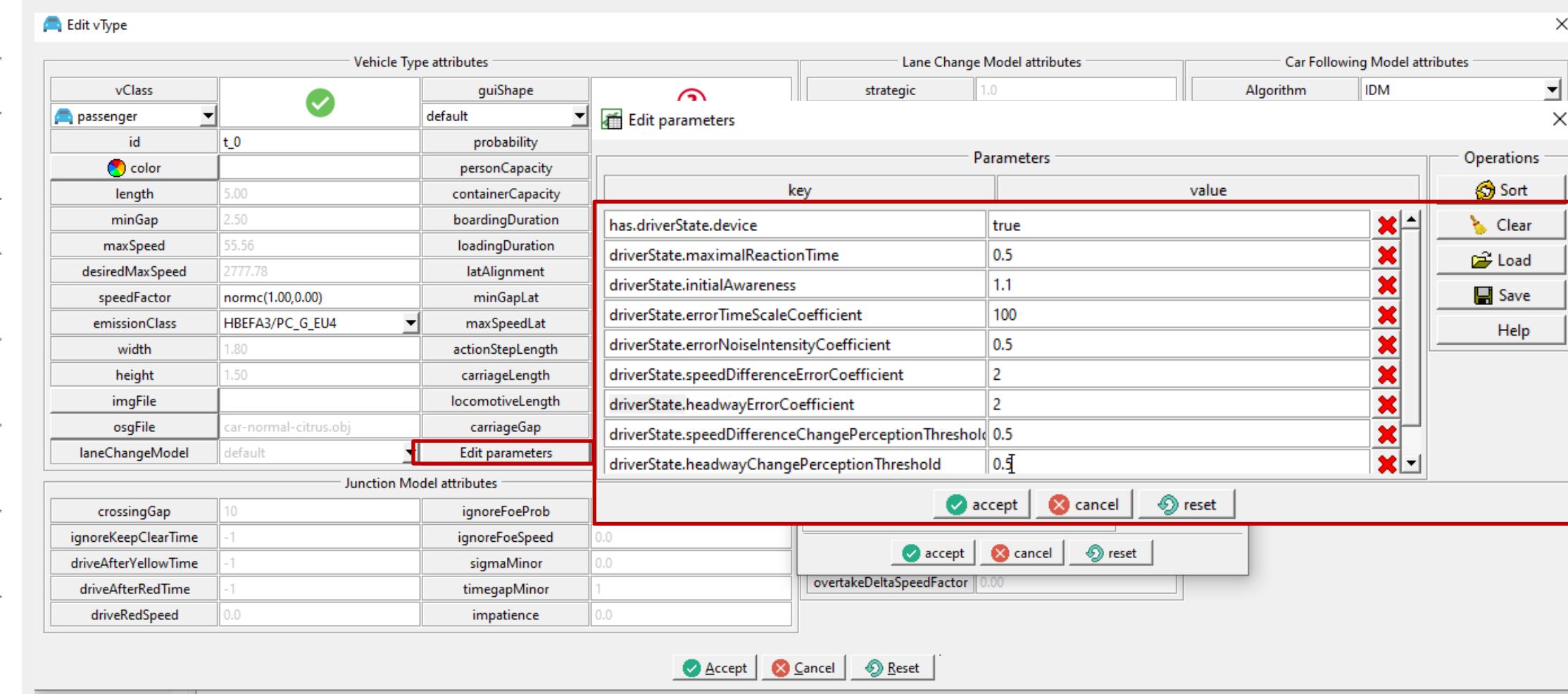
# Device in SUMO

□ **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





# 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
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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="http://openstreetmap.de/xsd/routes.xsd">
    <!-- 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="IDM">
            <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>
    </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		guiShape	
passenger		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	

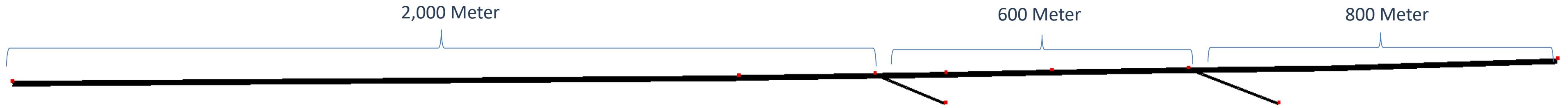
Junction Model attributes

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

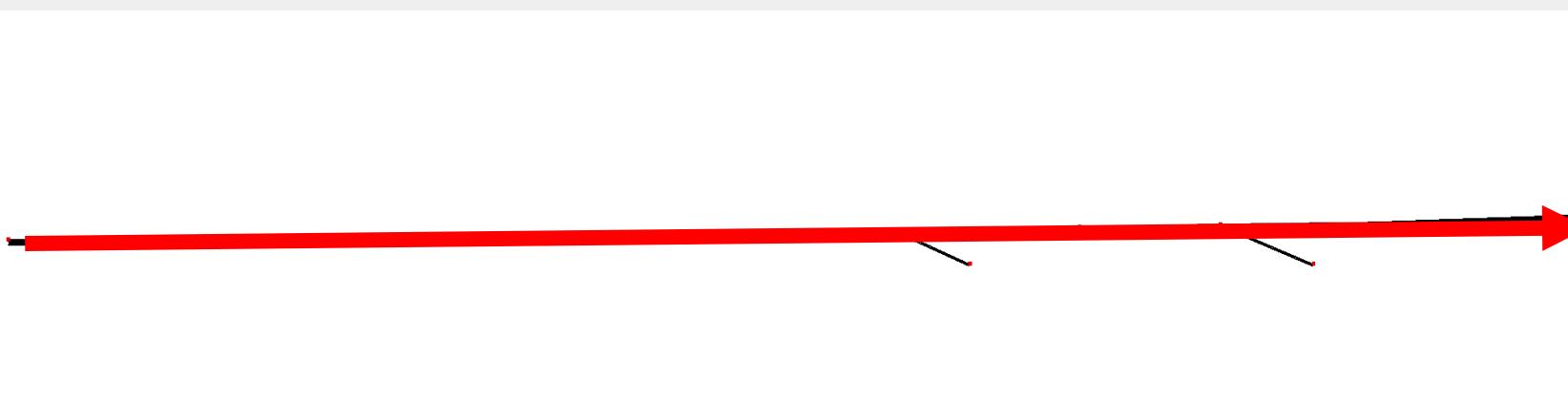
## Create A Network



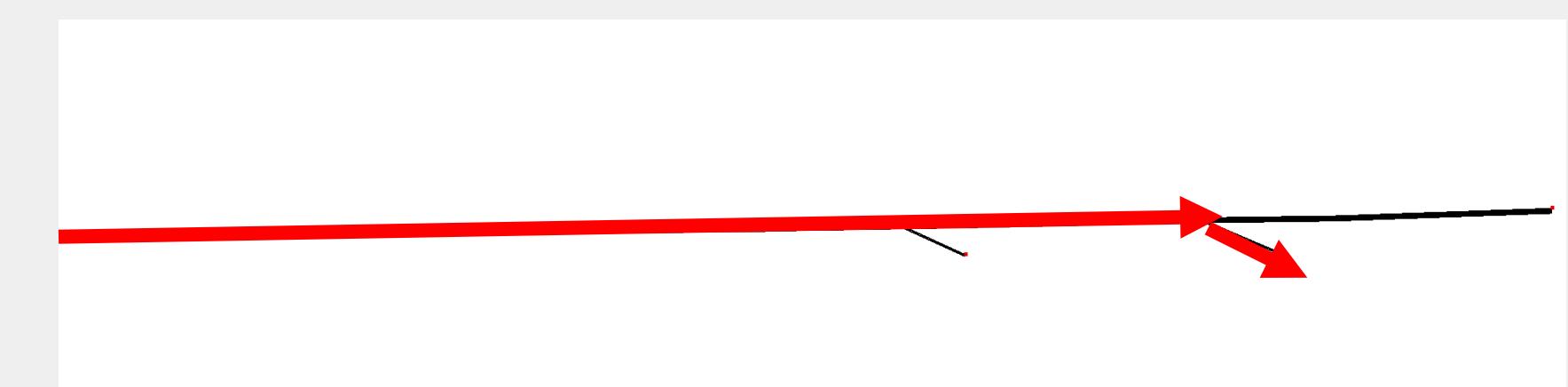
# Analyze Impacts of Different AV Penetration Rates

## Add Traffic Volume

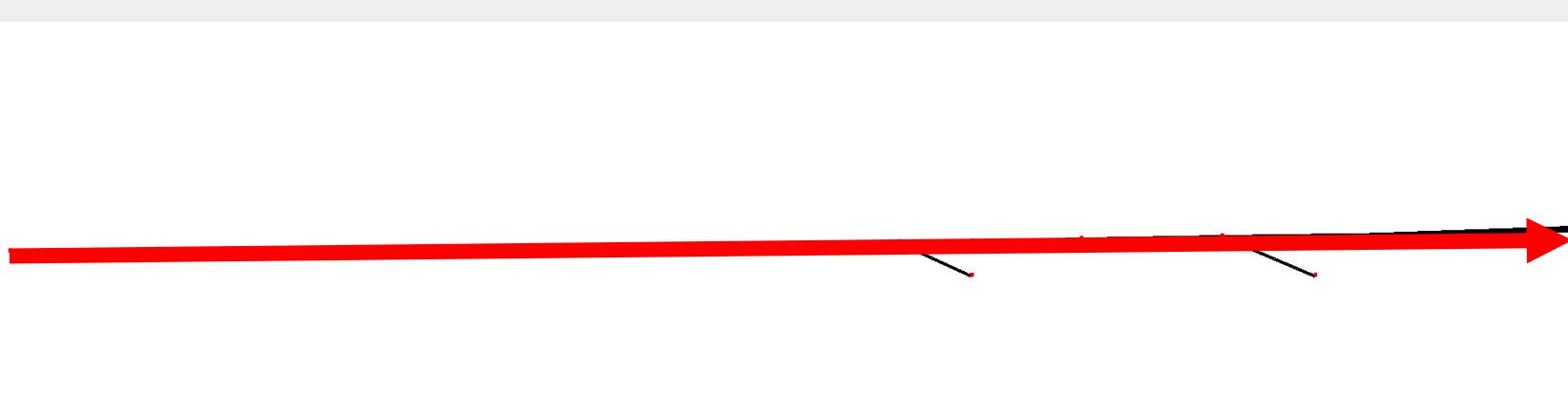
F\_0: 1800      Vehicle Type: CAVs



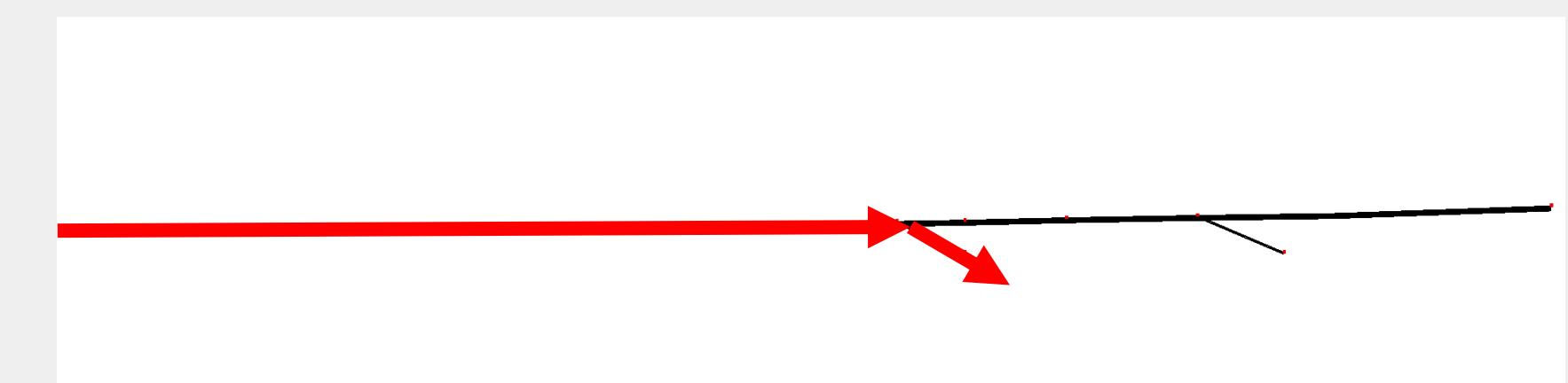
F\_1: 500      Vehicle Type: CAVs



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)



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



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

Travel Time: 260



Travel Time: 314



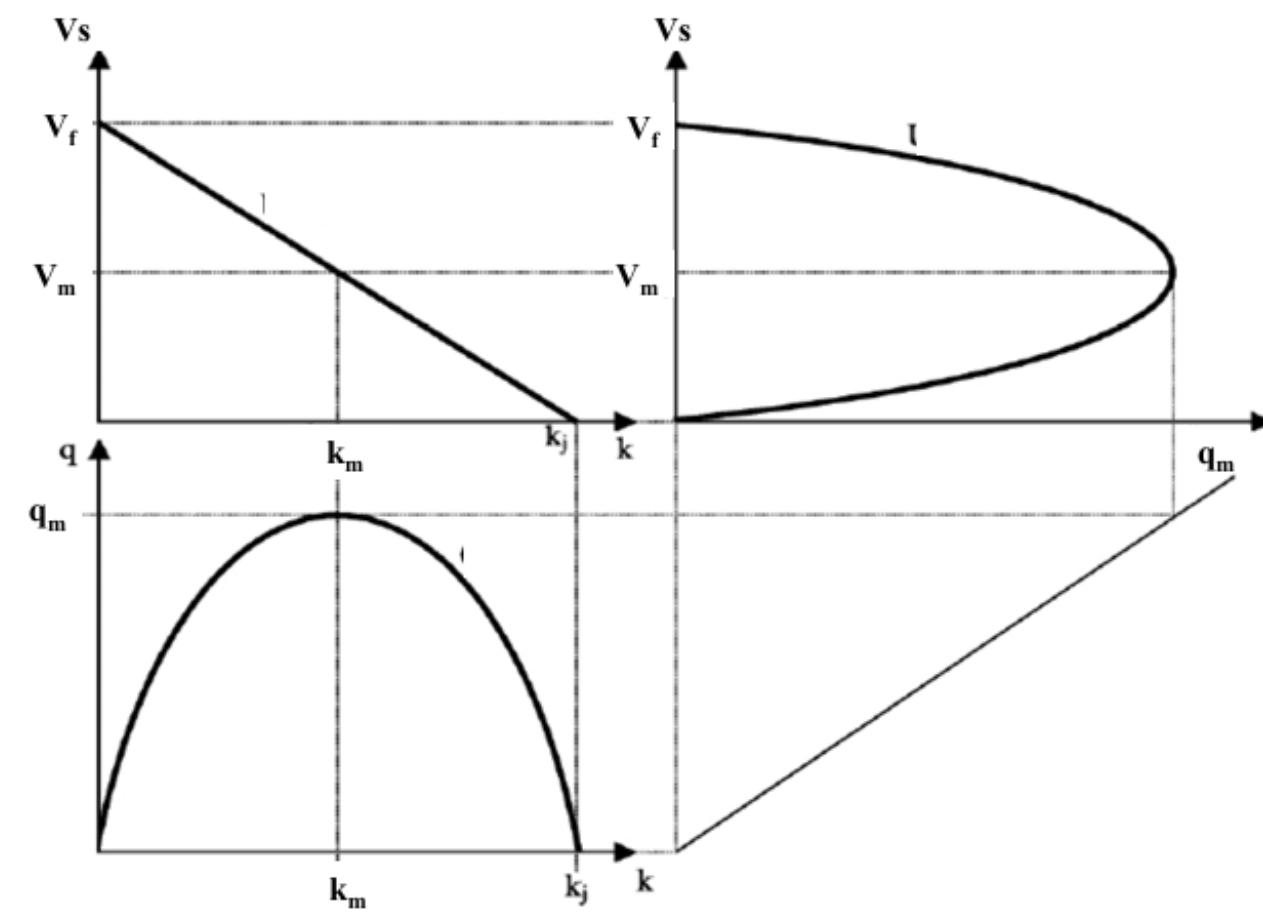
Travel Time:

# Analyze Impacts of Different AV Penetration Rates

Normal

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

□ Greenshield's Model (1934):



Mixed Traffic

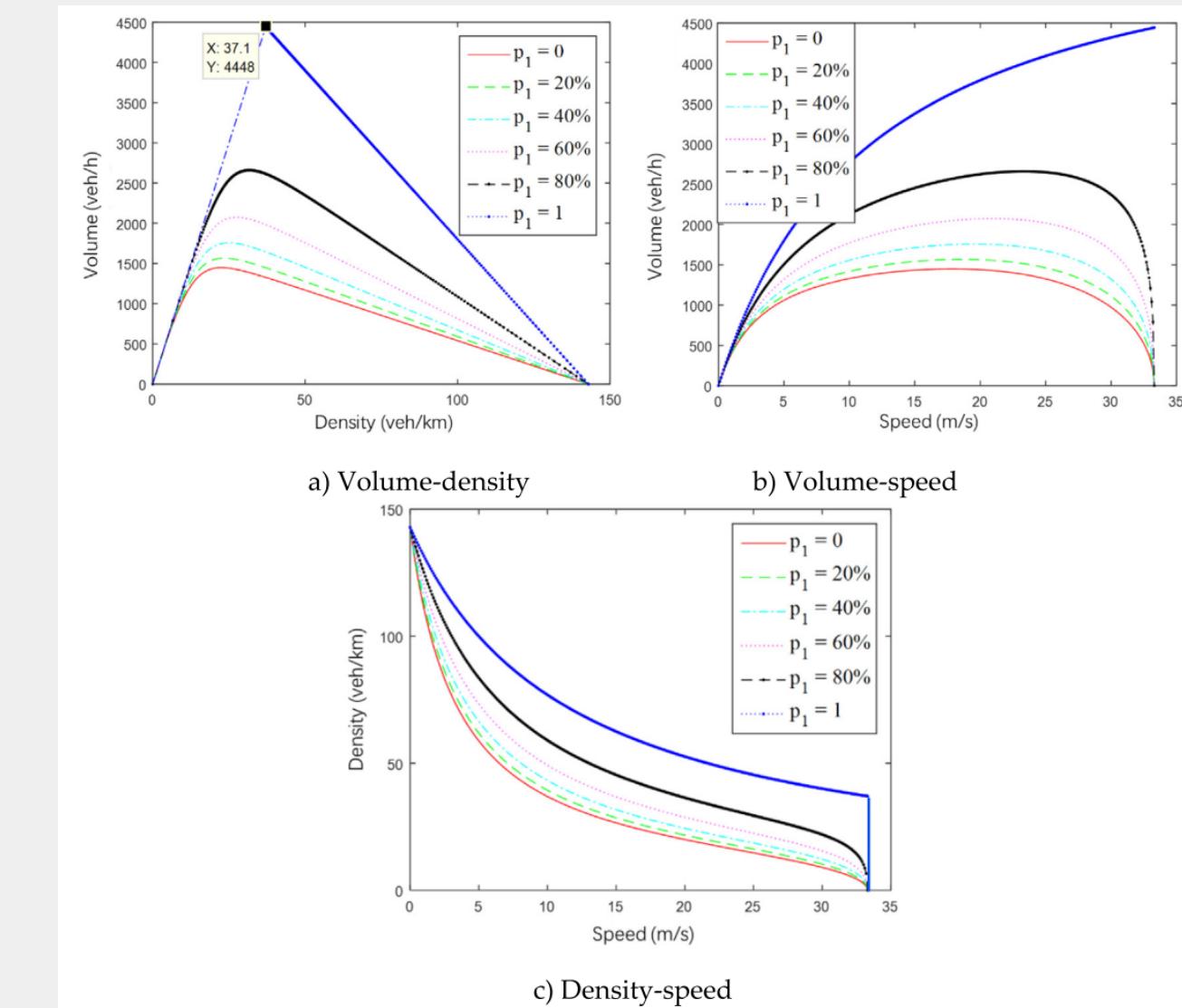


Fig. 2. Fundamental diagram of  $\sigma = 0$  with different  $p_1$ .