

RWR 4015

Traffic Simulation for Planning Applications

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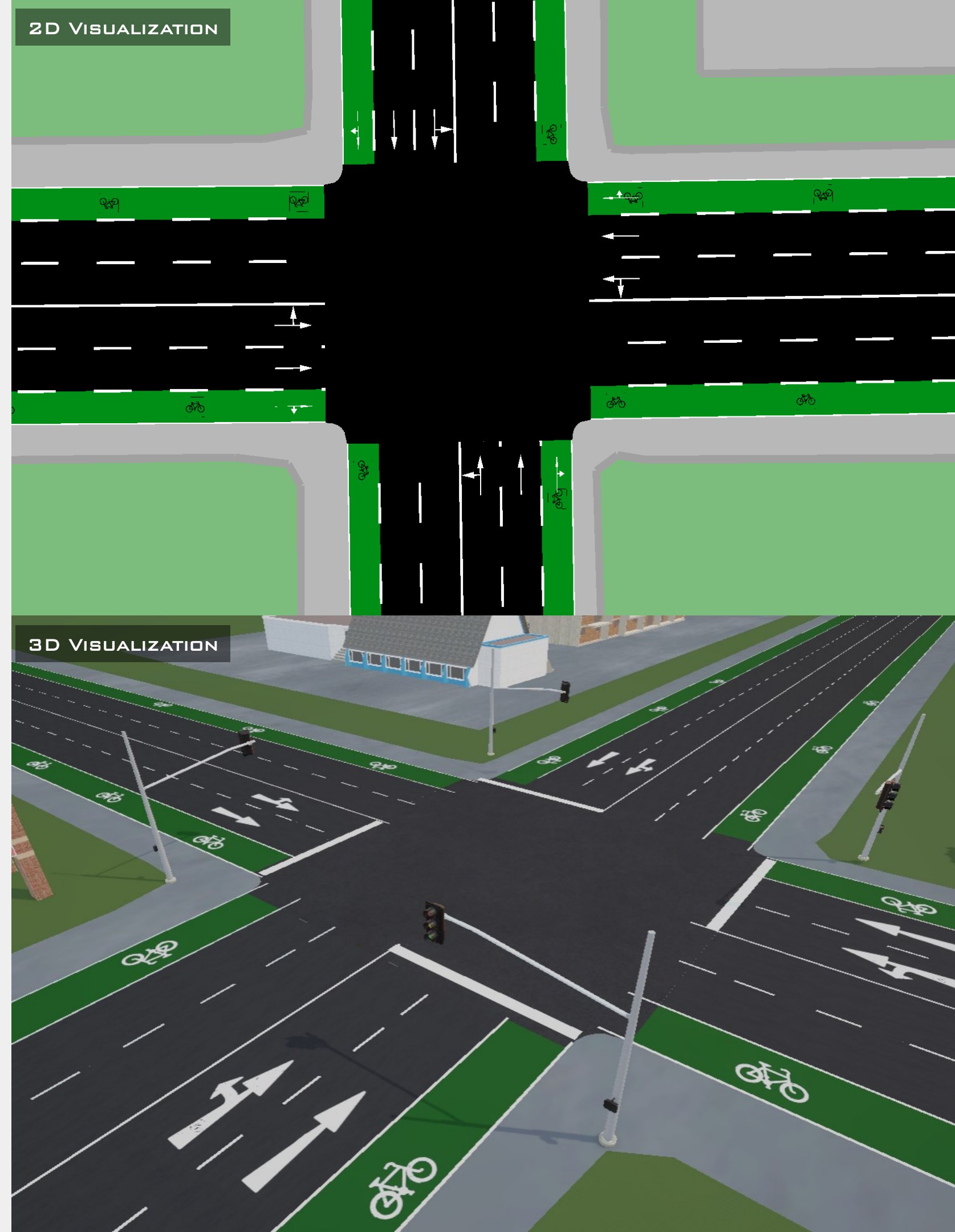
Week 6 | Hands-on:
Mixed Traffic Planning:
AVs and Human-Driven Vehicles

Fall 2026

RoadwayVR



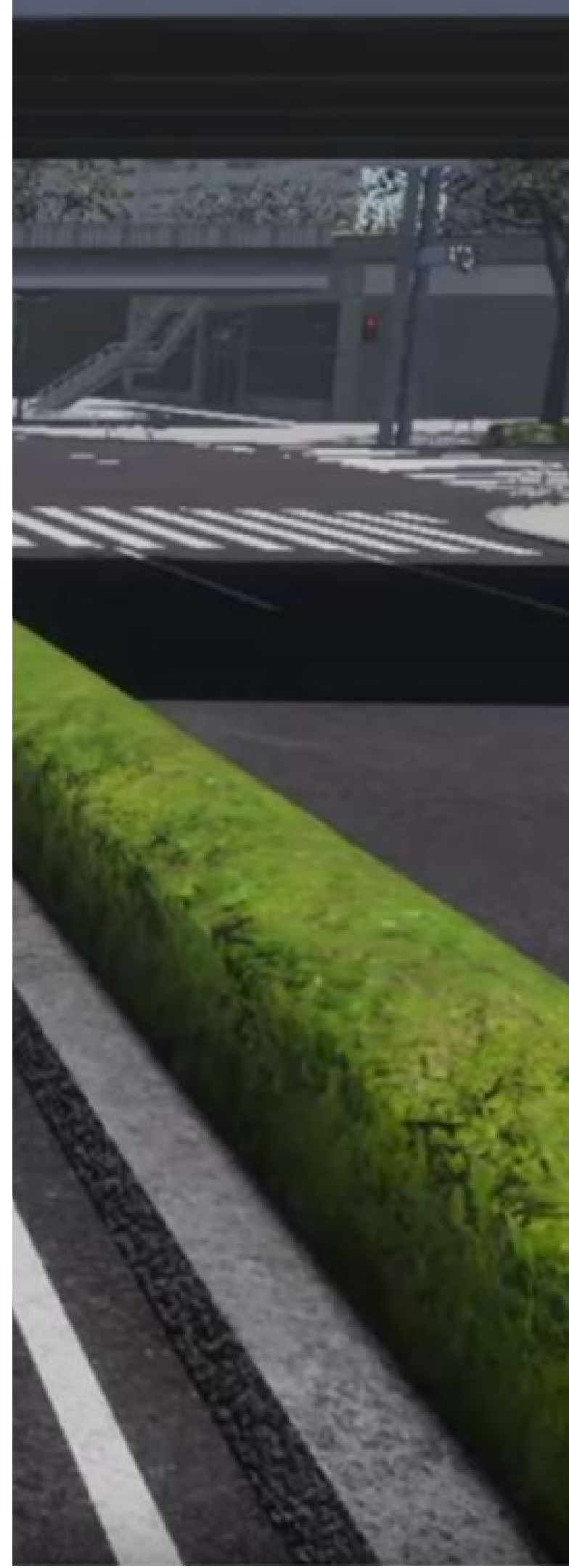
roadwayvr.github.io/TrafficSimulationforPlanningApplications





Agenda

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

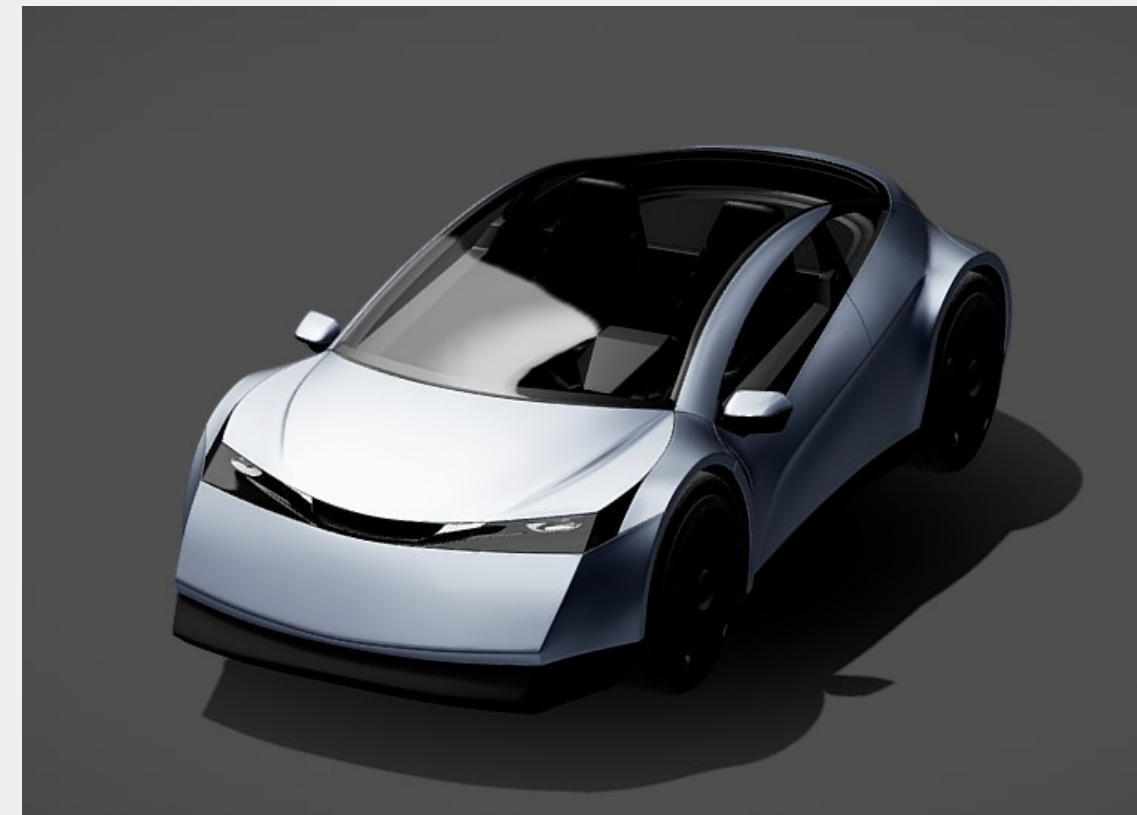


Human-Driven Vehicle vs Autonomous Vehicle

Human-Driven Vehicle (HDV)

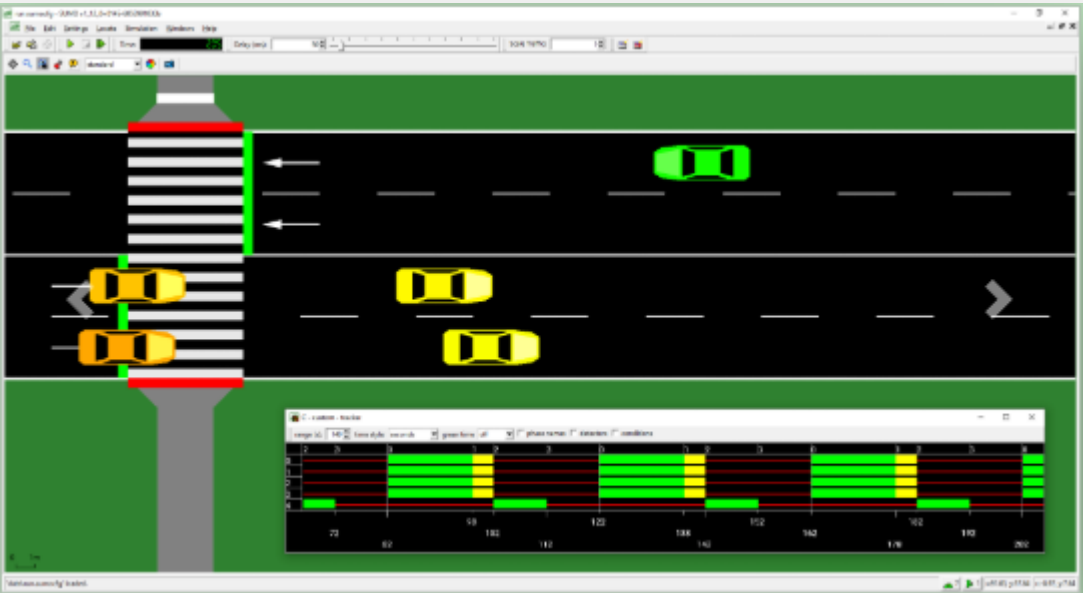
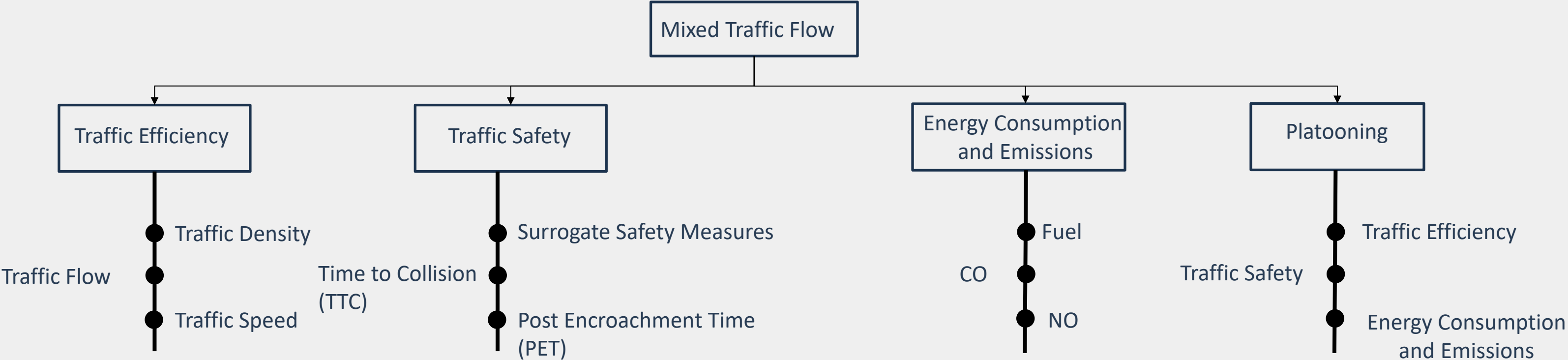


Autonomous Vehicle (AV)



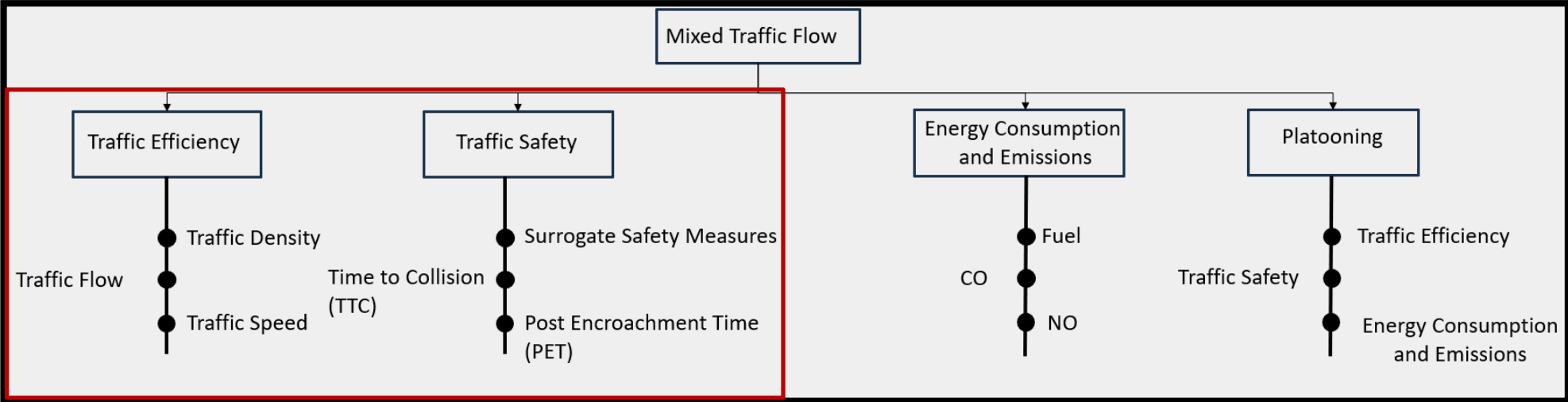
Develop Mixed Traffic Planning for AVs and HDV

❑ 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.



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^{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 |

Edit vType

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(1.00,0.10,0.20,2.00) | 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 |
| 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 | 1.00speed |
| 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

Edit vType

Vehicle Type attributes

| | | | |
|-----------------|---------------------------------|-------------------|-----------------------------------|
| vClass | <div><div>passenger</div></div> | guiShape | <div><div>default</div></div> |
| 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 |

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 |
| 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} | 1 |
| Desired deceleration b | 2.0 m s^{-2} | 2 |
| Time headway T | 1.5 s | 4 |
| Free flow speed v_f | 33.3 m s^{-1} | 3 |
| Minimum gap s_0 | 2.0 m | 5 |
| Imperfection σ | 0.5 | 6 |

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 |

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 |
| 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 | |

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' dialog box in SUMO. The 'Vehicle Type attributes' tab is active, showing a 'passenger' vehicle. The 'Lane Change Model attributes' and 'Car Following Model attributes' tabs are also visible. The 'Parameters' section is expanded, showing a list of parameters and their values. The 'Driver State' parameters are highlighted with a red box, including '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), and 'driverState.headwayChangePerceptionThreshold' (0.5). The 'Operations' section on the right includes buttons for 'Sort', 'Clear', 'Load', 'Save', and 'Help'. The 'Accept', 'Cancel', and 'Reset' buttons are at the bottom.

| key | value |
|--|-------|
| 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

❑ **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 |

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 | <div>passenger</div> | guiShape | <div>default</div> |
| 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 |

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 | 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 | |

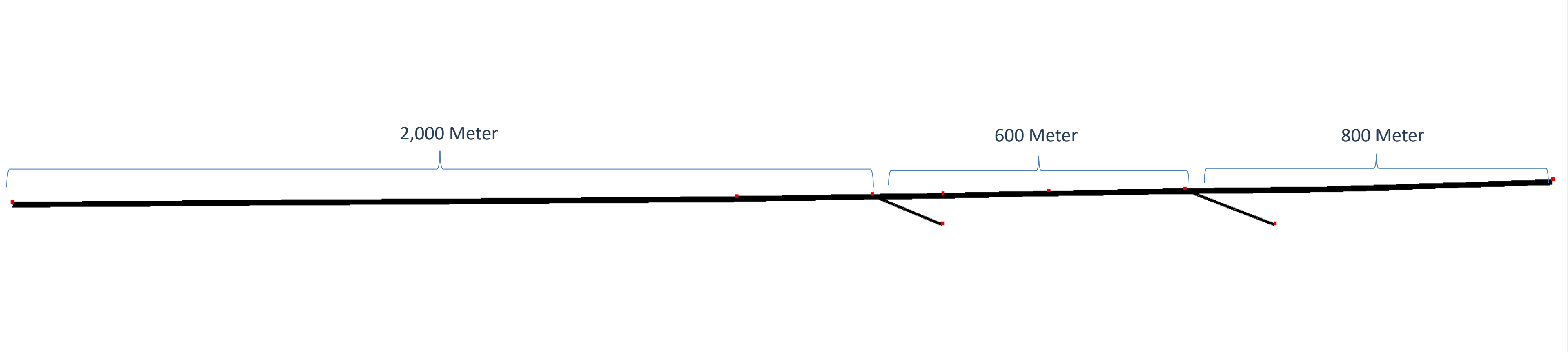
Accept

Cancel

Reset

Develop Mixed Traffic Planning for AVs and HDV

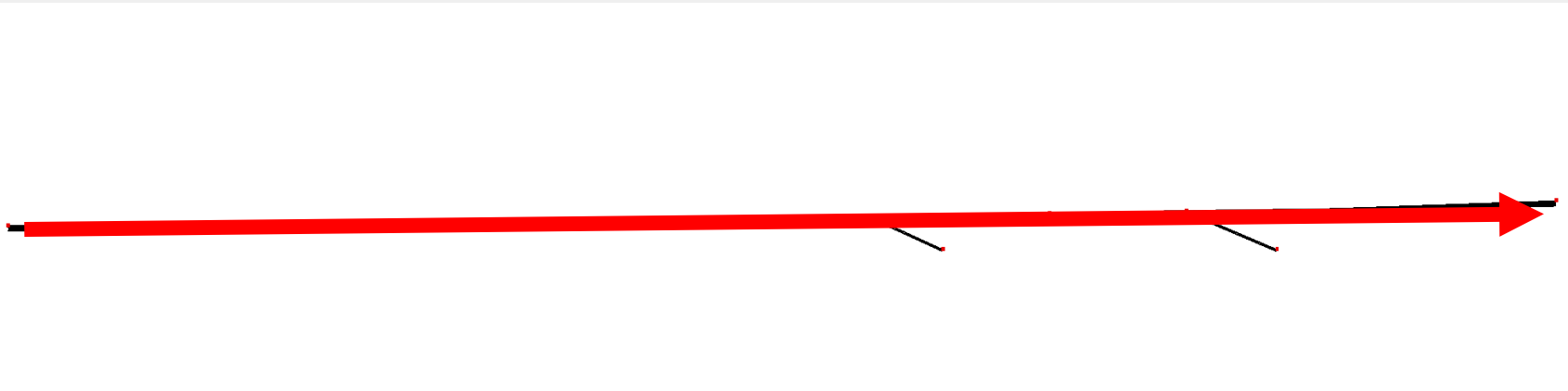
☐ Create A Network



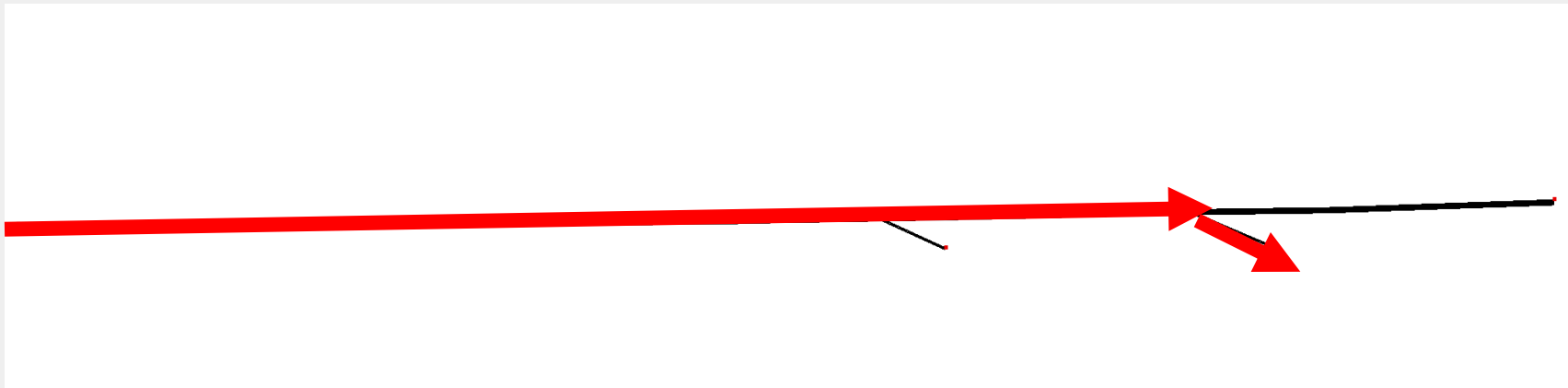
Analyze Impacts of Different AV Penetration Rates

☐ Add Traffic Volume

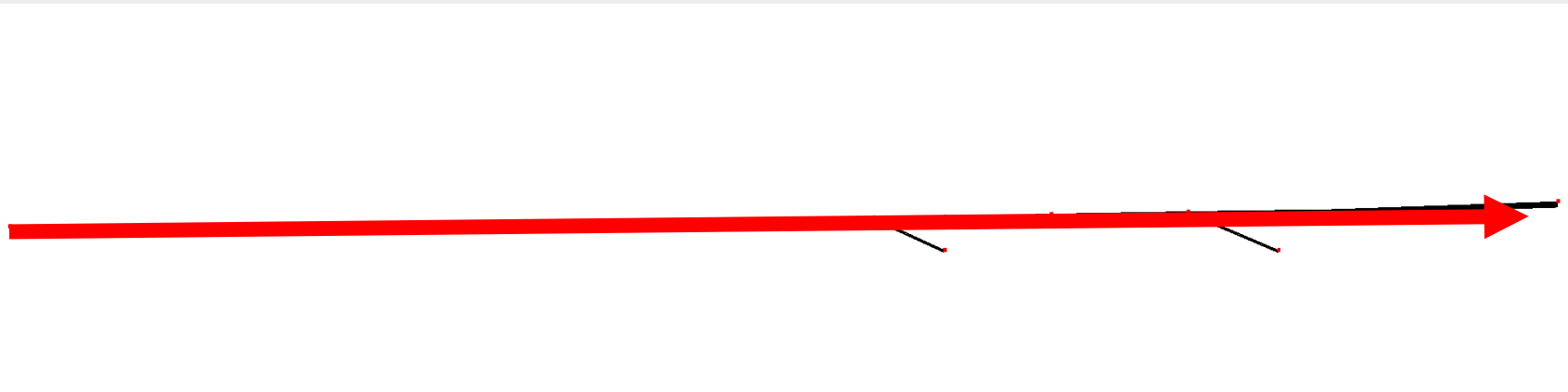
F_0: 1800 Vehicle Type: CAVs



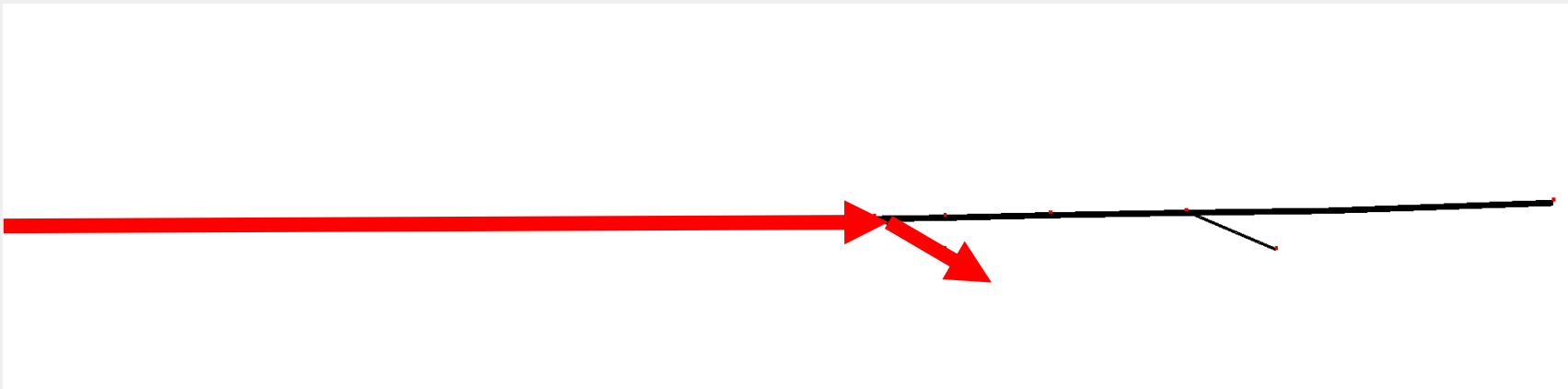
F_1: 500 Vehicle Type: CAVs



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:

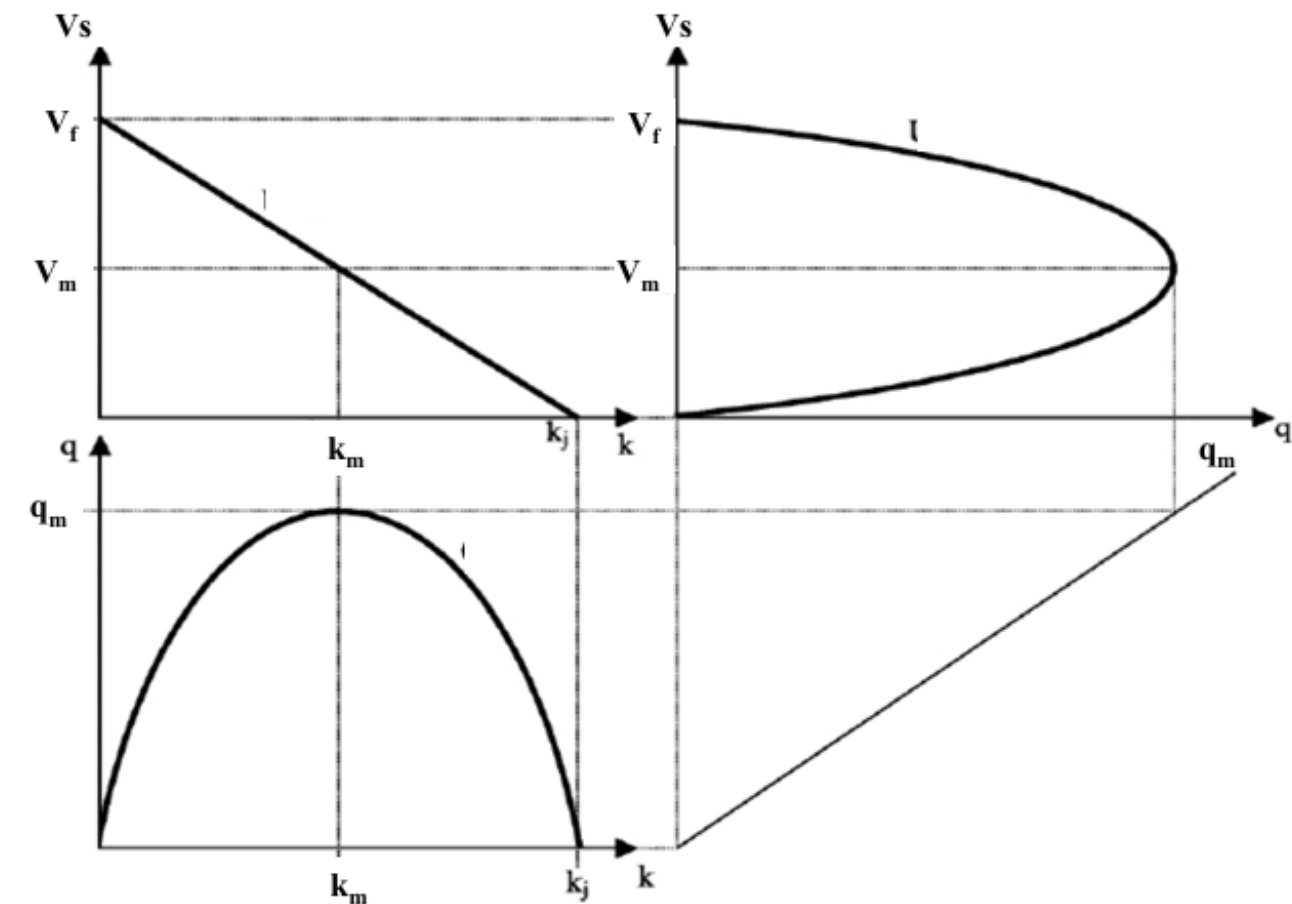


Analyze Impacts of Different AV Penetration Rates

Normal

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

□ Greenshield's Model (1934):



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Mixed Traffic

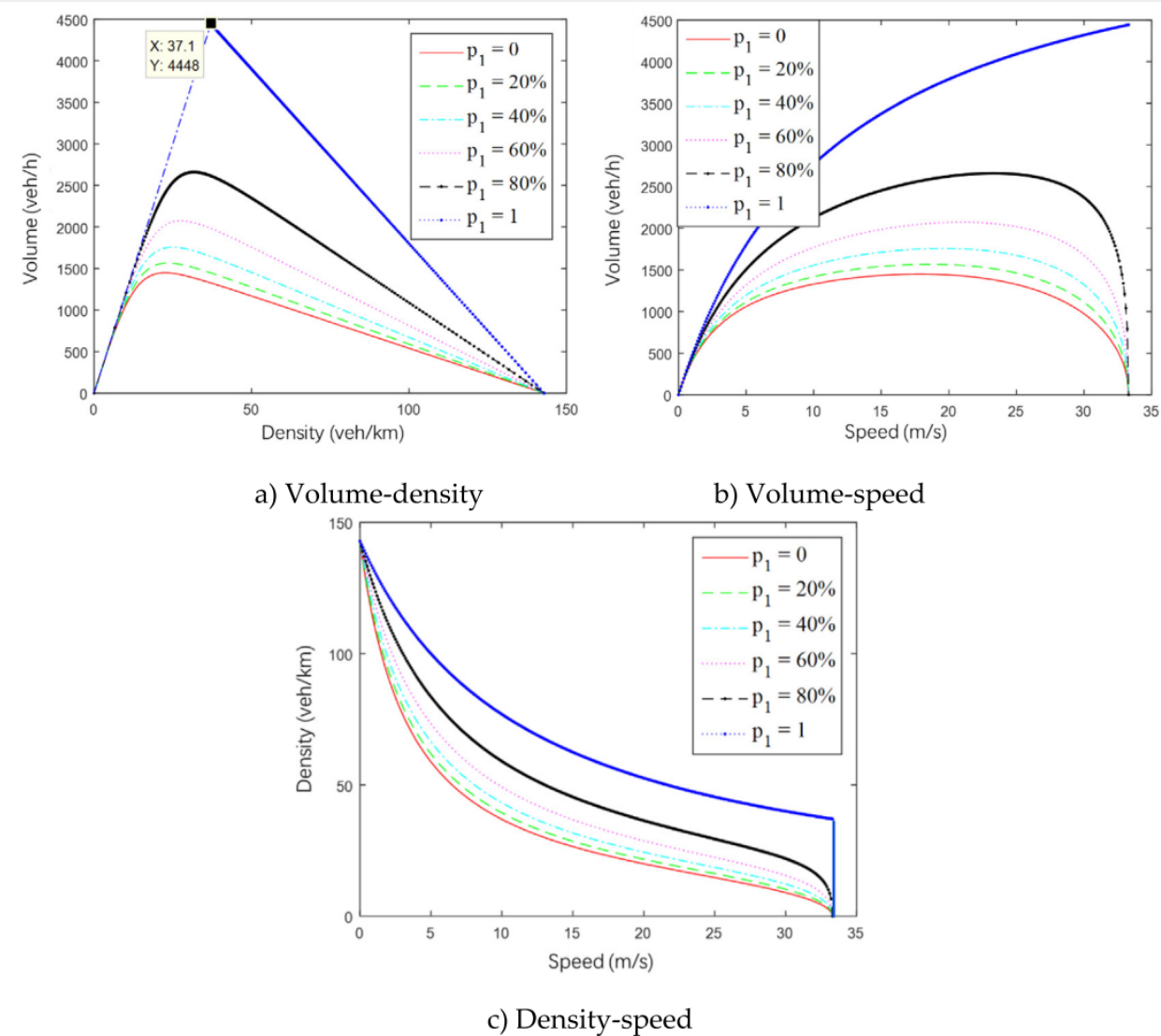


Fig. 2. Fundamental diagram of $\theta = 0$ with different p_1 .