RWR 4015
Traffic Simulation for Planning Applications

Dr. Ahmad Mohammadi
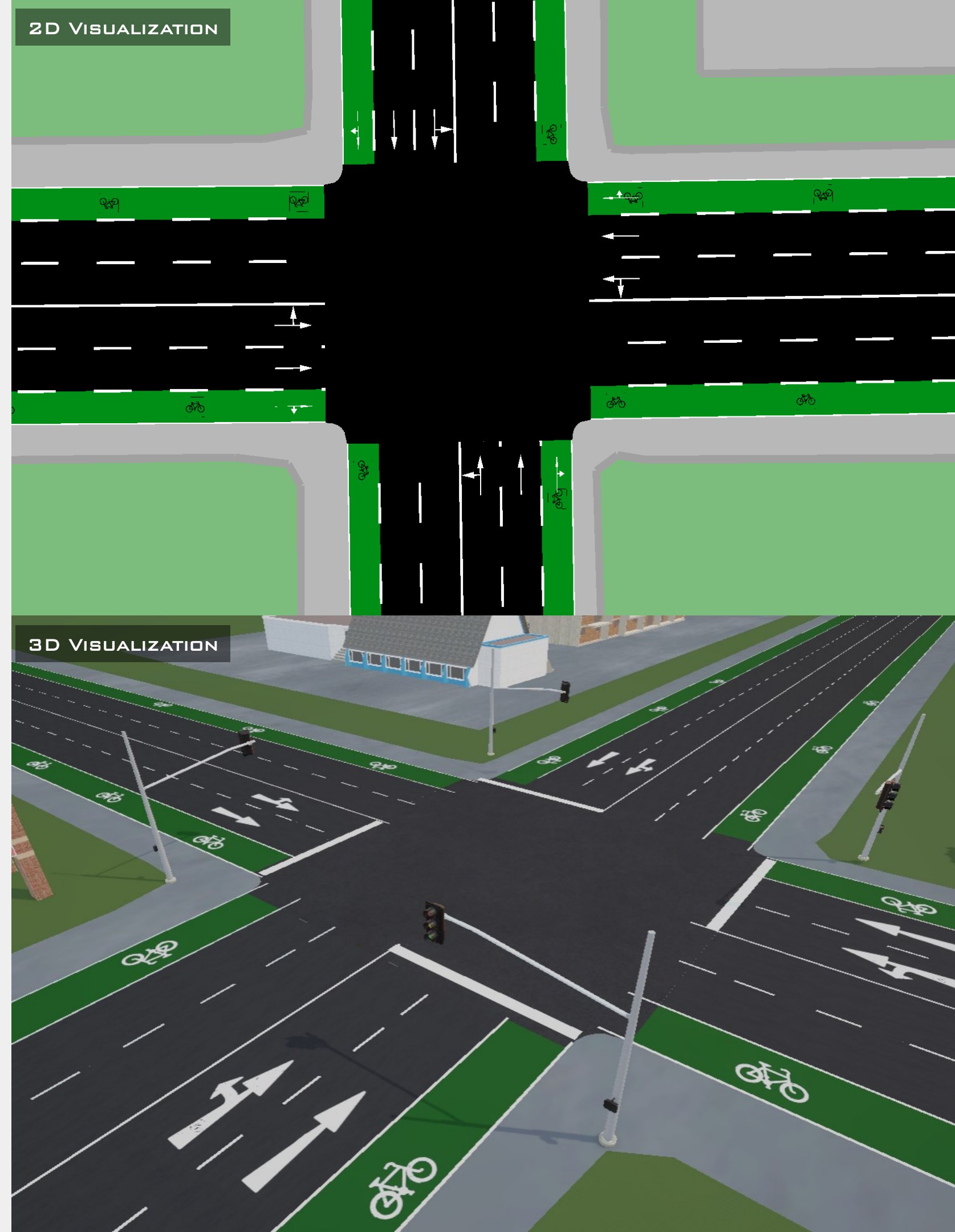
Week 6 | Hands-on:
Mixed Traffic Planning:
AVs and Human-Driven Vehicles

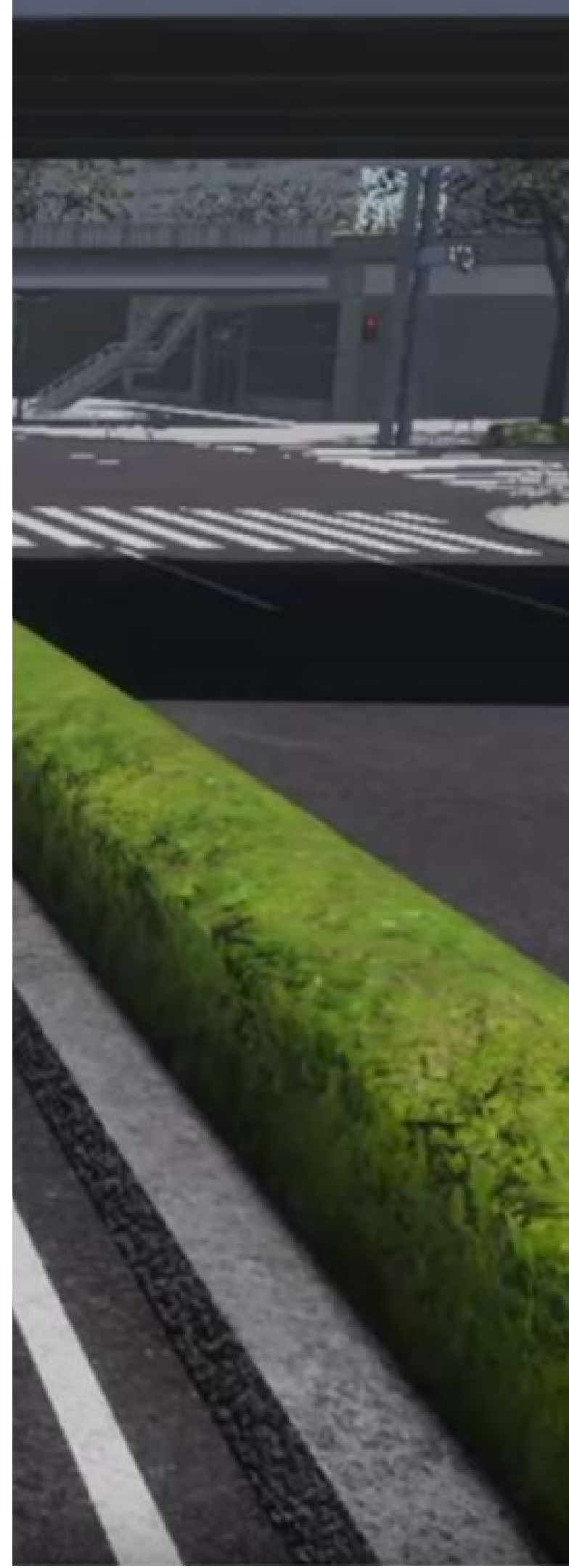**Fall 2026**

RoadwayVR

2D Visualization

3D Visualization

Agenda

- Develop Mixed Traffic Planning for AVs and Human-Driven Vehicles in Simulation

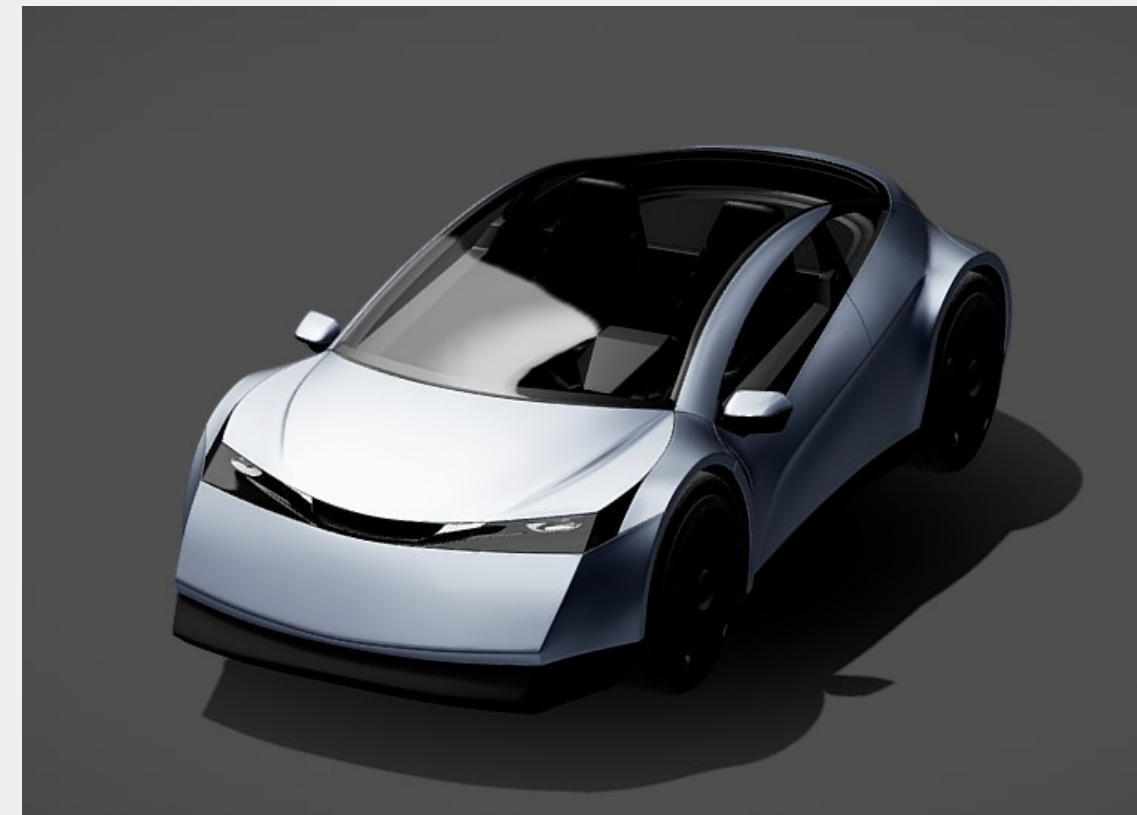- Analyze Impacts of Different AV Penetration Rates on Traffic Performance

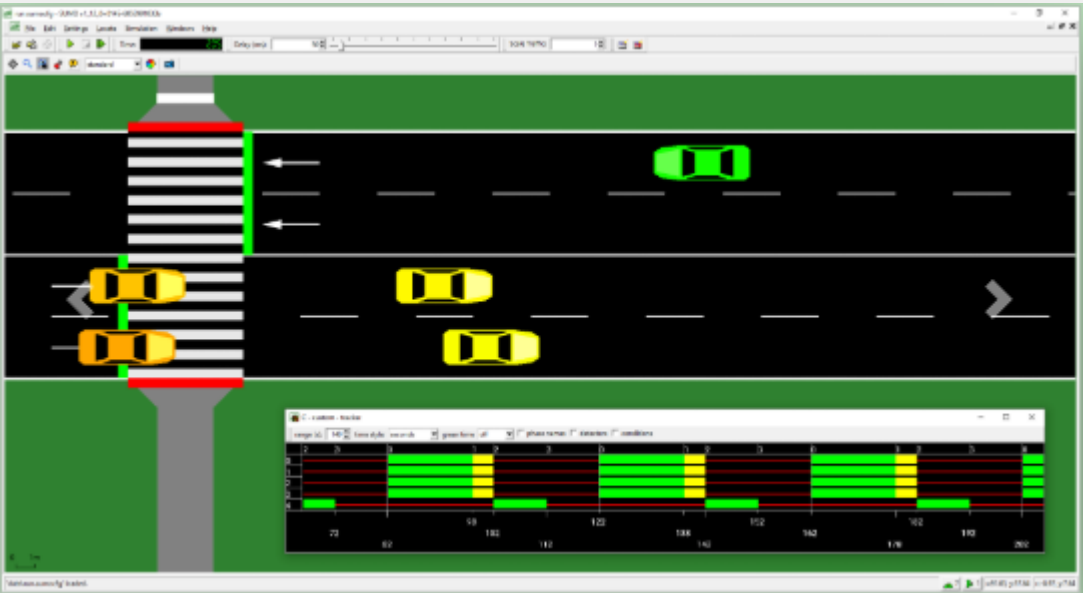# Human-Driven Vehicle vs Autonomous Vehicle
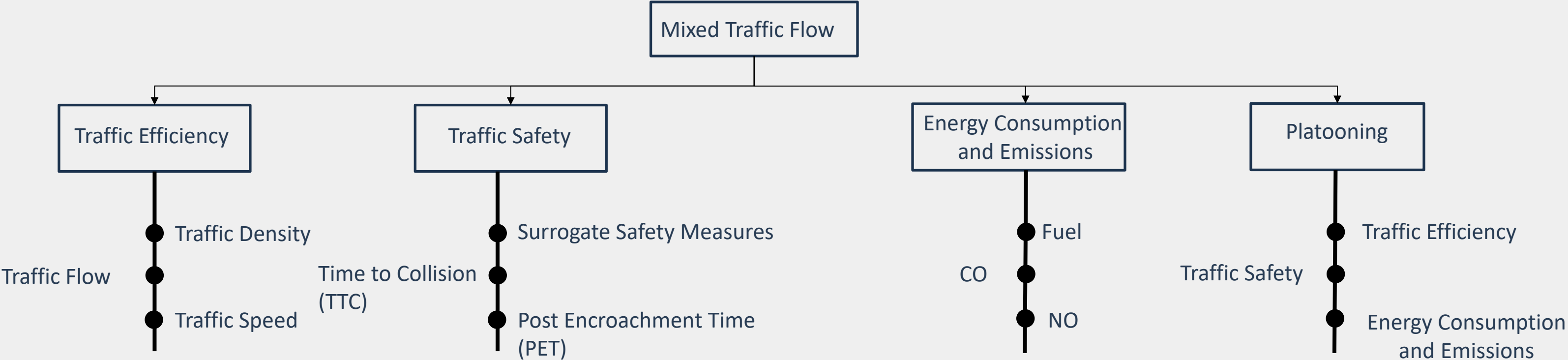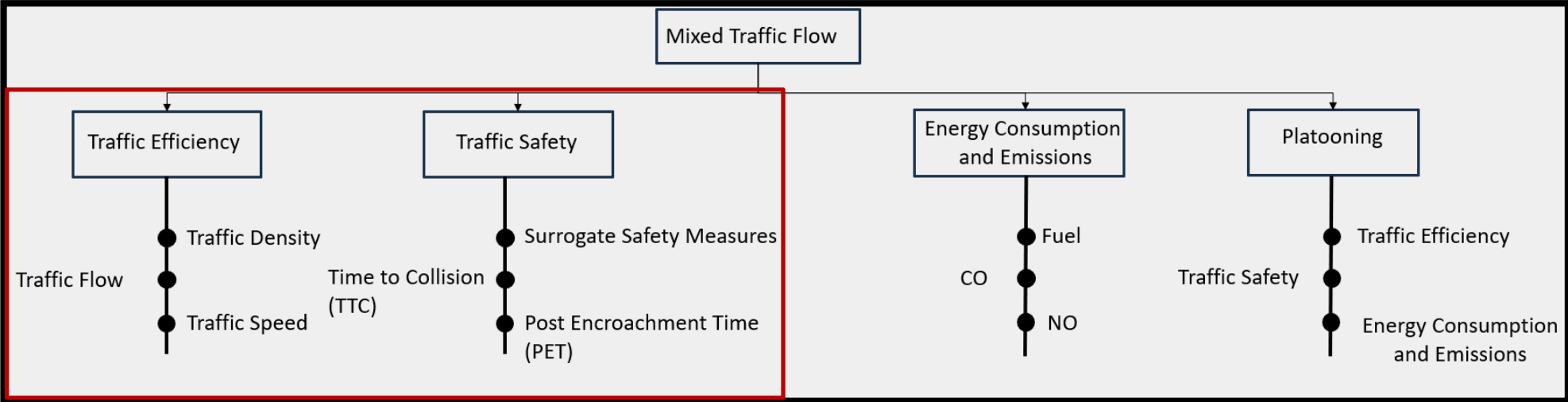
Human-Driven Vehicle (HDV)

Autonomous Vehicle (AV)

Develop Mixed Traffic Planning for AVs and HDV

❑ **A Microscopic Traffic Simulation Software**

```
                          ┌─────────────────────┐
                          │  Mixed Traffic Flow │
                          └─────────────────────┘
```

| Traffic Efficiency | Traffic Safety | Energy Consumption and Emissions | Platooning |

- Traffic Density
- Traffic Flow
- Traffic Speed

- Surrogate Safety Measures
- Time to Collision (TTC)
- Post Encroachment Time (PET)

- Fuel
- CO
- NO

- Traffic Efficiency
- Traffic Safety
- Energy Consumption and Emissions

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.

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

Mohit Garg and Mélanie Bouroche

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 m s^{-2}	①
Deceleration	7.5 m s^{-2}	②
Emergency deceleration	9 m s^{-2}	③

Develop Mixed Traffic Planning for AVs and HDV

❑ **Lane Changing Model for CAVs:** LC 2013 → cooperative 1

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

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' / 'dropOf...

```xml
<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 ca...

SSM

```xml
<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>
```

https://sumo.dlr.de/docs/Definition_of_Vehicles%2C_Vehicle_Types%2C_and_Routes.html#devices

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.

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Parameter	Description	Value
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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**

```xml
<routes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocatio
    <!-- VTypes -->
    <vType id="CAV" minGap="1.50" speedFactor="normc(1.00,0.05)" guiShape="passenger" colo
    <vType id="HDV" minGap="2.00" maxSpeed="33.30" guiShape="passenger" carFollowModel="ID
        <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>
```
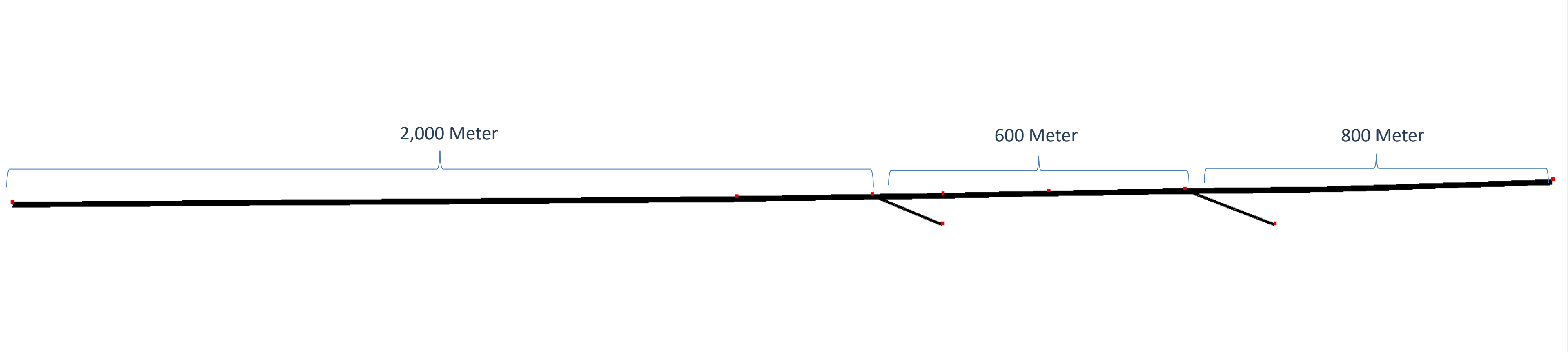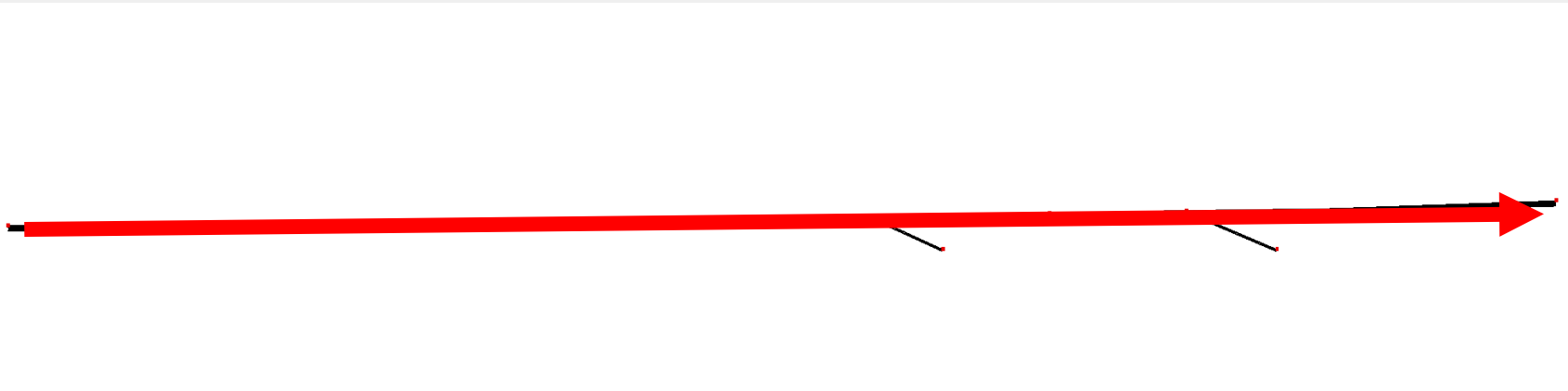
Develop Mixed Traffic Planning for AVs and HDV

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

Develop Mixed Traffic Planning for AVs and HDV

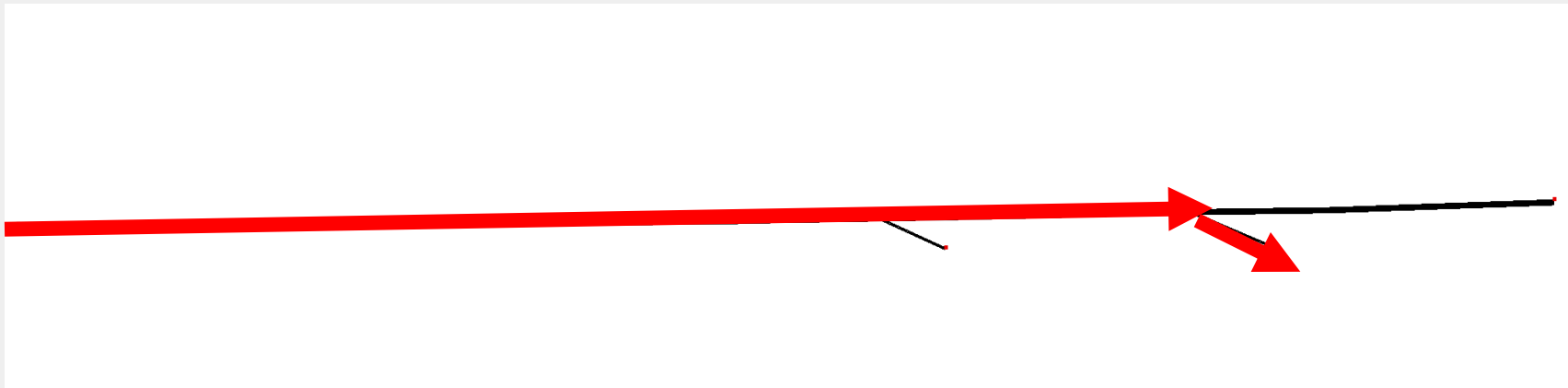❑**Create A Network**

Analyze Impacts of Different AV Penetration Rates
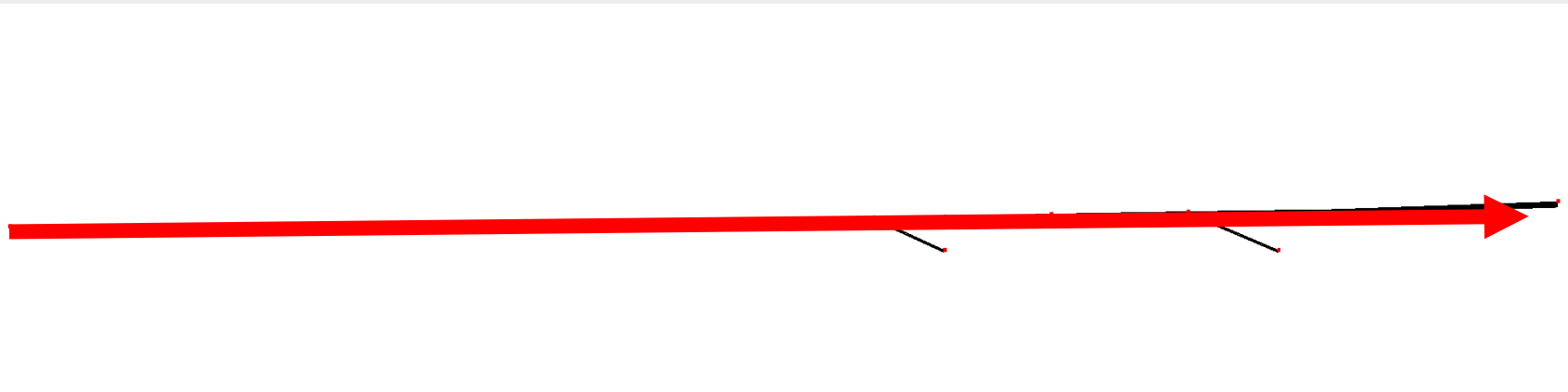
❏ **Add Traffic Volume**

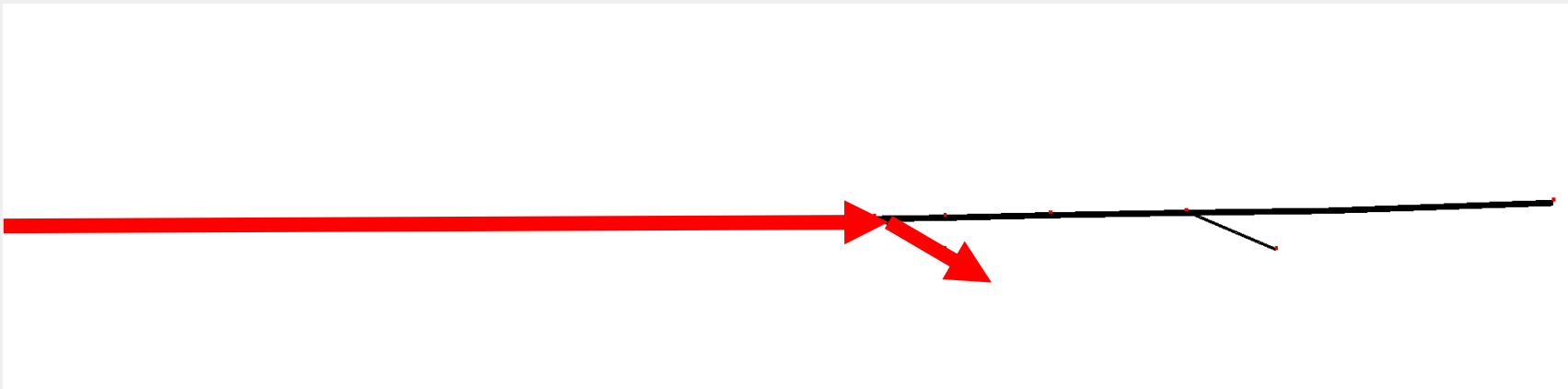F_0: 1800   Vehicle Type: CAVs

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

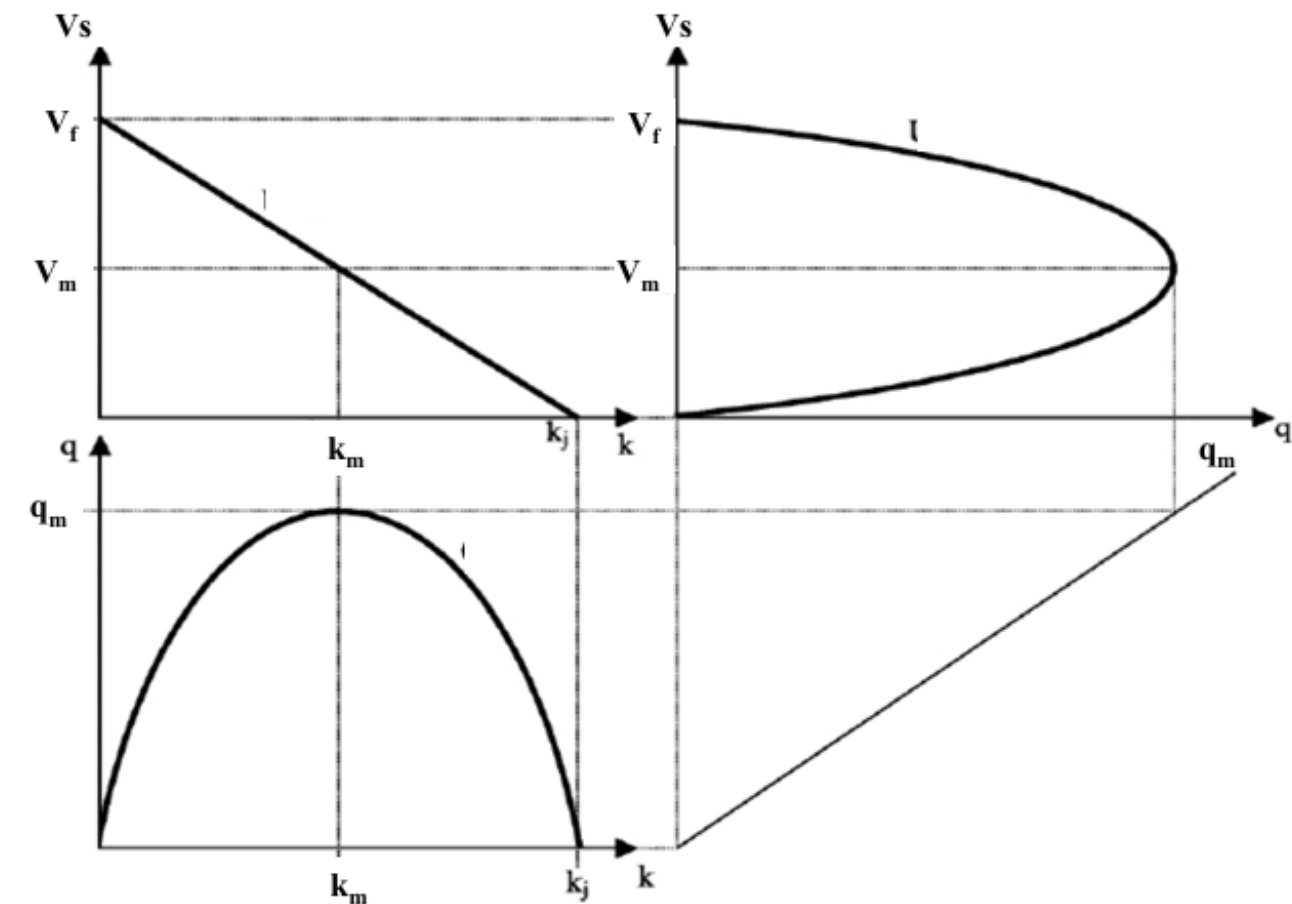Penetration rate: 0 %(CAVs) – 100 %(Normal)

Travel Time:

Analyze Impacts of Different AV Penetration Rates

Normal
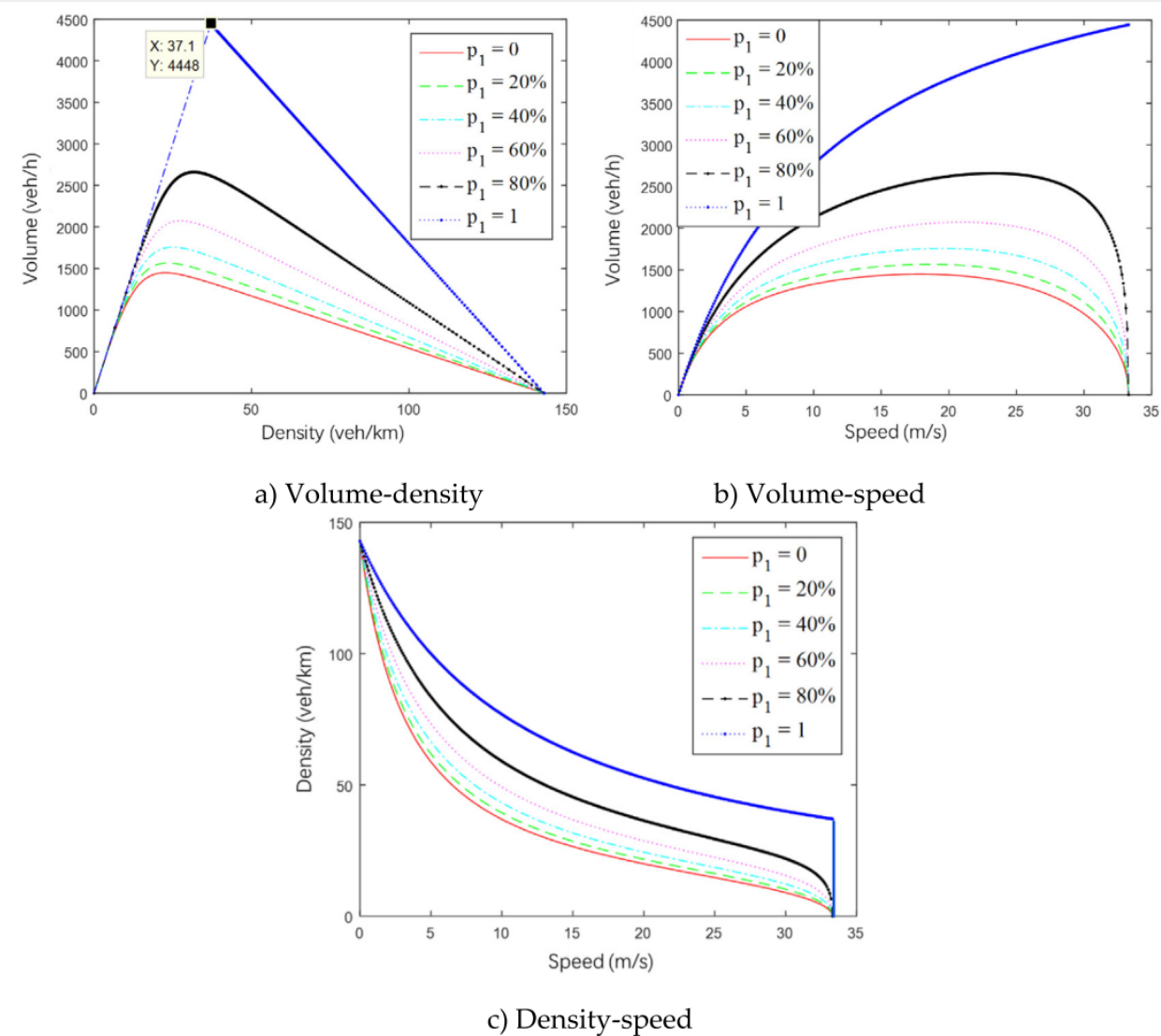

Mixed Traffic

a) Volume-density

b) Volume-speed

c) Density-speed

Fig. 2. Fundamental diagram of **O** = 0 with different **p_1**.

Li, R., Sun, S., Wu, Y., Hao, H., Wen, X., & Yao, Z. (2023). Fundamental diagram of mixed traffic flow considering time lags, platooning intensity, and the degradation of connected automated vehicles. *Physica A: Statistical Mechanics and its Applications*, *627*, 129130.