TS ITE & ITS TN
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Cooperative Driving Automation Verification

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Driving Automation

Conventional vehicles

- Level 0: driver→ dynamics driving tasks;
- Level 1: driver assistant systems→ lateral or longitudinal;
- Level 2: driver assistant systems→ lateral & longitudinal.

Vehicles dedicated to automated driving systems

- Levels 3—5: automated driving systems→ dynamics driving tasks.

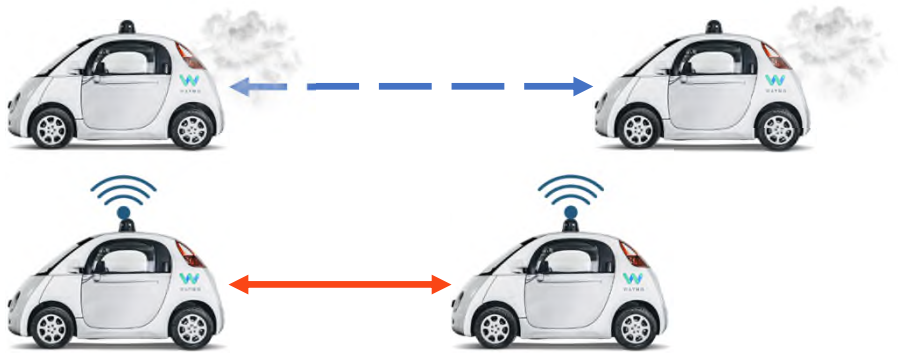
Cooperative Driving Automation

Vehicles equipped with cooperative automated driving systems

— Levels 3—5 driving automation,

— External communications.

- Classes
  - — Class A: sharing intent,
  - — Class B: sharing status,
  - — Class C: seeking agreement,
  - — Class D: prescriptive.
- Benefits
  - — Dynamic driving task performance,
  - — Safety,
  - — Traffic operations.



Conventional Simulation Tools

- **Vehicle dynamics simulation tools**
  - — E.g., CarMaker, CarSim;
  - — Mainly used for verification and validation purposes on a small scale;
  - — Can simulate longitudinal, lateral, and vertical dynamics;
  - — Compute-intensive but accurate.
- **Traffic microsimulation tools**
  - — E.g., Vissim, Aimsun;
  - — Mainly used for verification purposes on a large scale;
  - — Can simulate vehicle-following, lane-changing, and gap-acceptance behaviors;
  - — Compensate accuracy for simulation speed.

Vissim and CarMaker co-simulation

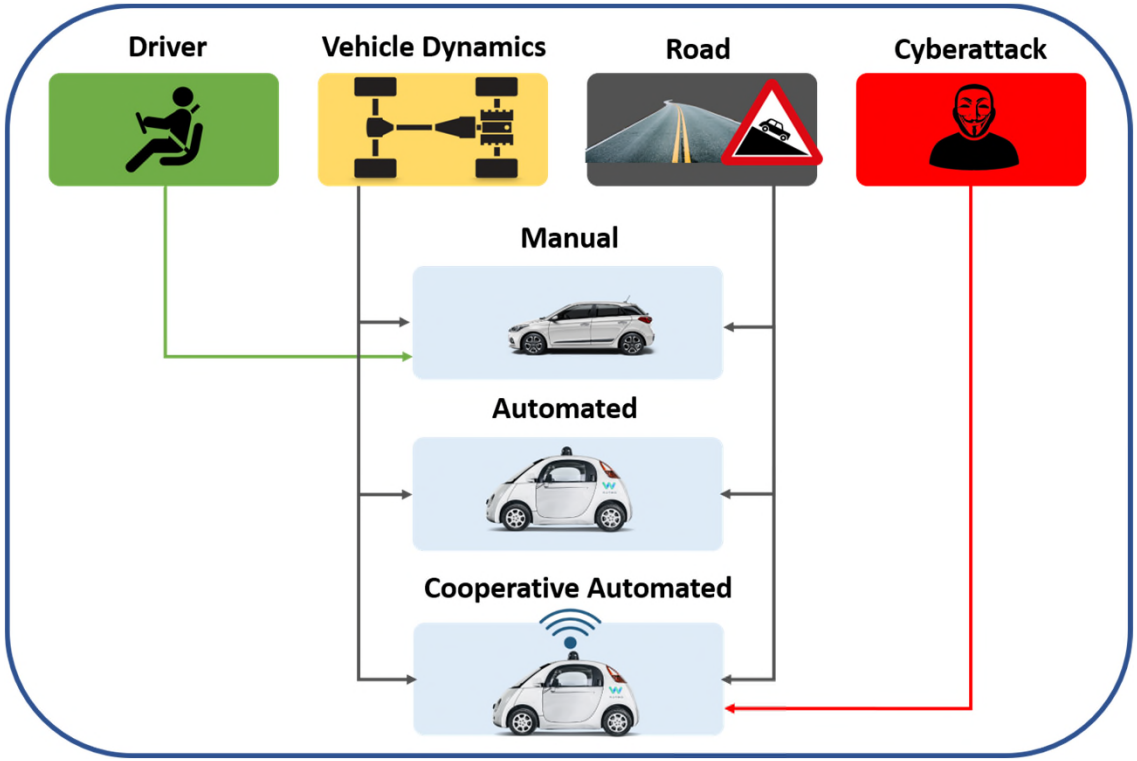
Problem Statement

- Verification scale,
- Verification resolution,
- Vehicle powertrain,
- Maximum acceleration & maximum deceleration,
  — sensitive to vehicle model, grade, pavement conditions, and traffic conditions.
- Longitudinal control variables,
  — sensitive to driver characteristics, vehicle model, grade, pavement conditions, operating mode, malicious fault magnitude, and traffic conditions.
- Contested environments.

Contested Environments

- Noise, natural fault, malicious fault;
- Minor faults may lead to malfunction or even failure if not responded promptly;
- A single cyberattack can cost an average OEM $1.6 billion a year;
- From 2010 to 2021, 367 cyberattacks on connected vehicles have been reported;
- Common cyberattacks on connected vehicles
  - — Spoofing
  - — Data falsification
  - — Replay
  - — Denial-of-service

Our Proposed Simulation Tool



Modules (I)

- **Driver**
  - — 10 driver types,
  - — speed multiplier, acceleration multiplier, deceleration multiplier, % included in traffic.
- **Vehicle**
  - — 14 vehicle model,
  - — torque map, drag coefficient, width, height, weight, wheelbase length, wheel radius, differential gear ratio, drive axle slippage, drivetrain, efficiency, transmission gear ratio, shift up speeds, shift down speeds, % included in traffic,
  - — vehicle generation,
  - — reference speed profiles,
  - — vehicle dynamics.

Modules (II)

- **Road**
  - — any desired freeway segment,
  - — grade, road adhesion coefficient, free-flow speed.
- **Cyberattack**
  - — 3 malicious fault magnitudes,
  - — % injected on traffic.
- **Operating mode**
  - — manual, automated, cooperative automated,
  - — % included in traffic.

Longitudinal Movement

- **Manual mode**
  - — Improved intelligent driver model.
- **Automated mode**
  - — when a vehicle dedicated to automated driving systems approaches a vehicle, or a vehicle equipped with cooperative automated driving systems approaches a vehicle not equipped with cooperative automated driving systems;
  - — similar to ACC.
- **Cooperative automated mode**
  - — when a vehicle equipped with cooperative automated driving systems approaches another vehicle equipped with cooperative automated driving systems;
  - — similar to CACC.

Max. Acceleration (Normal)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - passenger cars := 1.6 × trucks.
- Sensitive to speed.

Max. Deceleration (Normal)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - passenger cars := 1.2 × trucks.
- Sensitive to speed.

Min. Safe Distance Gap (Normal)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - — trucks := 2.6 × passenger cars.
- Sensitive to speed.
  - — high speeds := 5.4 × low speeds.

Min. Safe Time Gap (Normal)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - — ***high speeds***: trucks := 2.4 × passenger cars.
- Sensitive to speed.
  - — high speeds := 1.9 × low speeds.

Acceleration Error (Contested)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - ***high speeds***: passenger cars := 1.1 × trucks;
  - ***low speeds***: passenger cars := 1.2 × trucks.
- Not sensitive to speed;
- Sensitive to fault magnitude.
  - 3 ft/s^2 := 4.0 × 1 ft/s^2;
  - 5 ft/s^2 := 6.1 × 1 ft/s^2.

Distance Gap Error (Contested)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - — ***low speeds***: passenger cars := 1.1 × trucks;
- Sensitive to speed;
- Sensitive to fault magnitude.
  - — 3 ft/s^2 := 2.6 × 1 ft/s^2;
  - — 5 ft/s^2 := 3.8 × 1 ft/s^2.

Time Gap Error (Contested)

- Sensitive to vehicle model;
- Sensitive to vehicle classification;
  - ***high speeds***: passenger cars := 2.7 × trucks;
  - ***low speeds***: passenger cars := 1.2 × trucks.
- Sensitive to speed;
  - low speeds := 1.4 × high speeds.
- Sensitive to fault magnitude.
  - 3 ft/s^2 & 5 ft/s^2 := 1.7 × 1 ft/s^2.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