IE630 Project Assignment 2

Mridul Choudhary, Viraj Joshi and Rutuja

1. Final Problem Statement

This project extends our initial traffic simulation of mixed vehicle and pedestrian movements at a busy urban intersection by incorporating emergency vehicle dynamics into the system. The core problem remains to evaluate the effectiveness of various traffic control strategies—fixed-time signals, synchronized “green wave” corridors, roundabout layouts, and adaptive smart systems—in optimizing intersection performance. The enhanced objective is to quantify not only traditional metrics such as average vehicle delay, pedestrian waiting times, and queue lengths but also emergency vehicle response times and priority passage effectiveness.

Scope and Boundaries

• **Geometric Scope:** A single four-legged intersection with crosswalks on each approach. Road segment lengths, lane counts, and turn pocket geometries mirror those of a typical urban arterial crossing.

• **Agent Types:** Regular vehicles (cars, buses, two-wheelers), pedestrians, and emergency vehicles (ambulance, fire truck, police cruiser).

• **Control Strategies:**

a. Fixed-time signals: Predefined cycle, phase splits, and offsets.
b. Green-wave synchronization: Coordinated offsets for platoon progression.
c. Roundabout control: Speed-calibrated entry and circulating flows.
d. Adaptive control: Real-time phase selection via vehicle detection algorithms, extended to support emergency preemption.

• **Emergency Integration**: Emergency vehicles enter the network according to a Poisson process, are granted immediate priority by preemptive signal control (all-red pause, dynamic phase insertion), and are tracked for clearance time through the intersection.

• **System Boundaries:**

a. Included: Intersection geometry, signal controllers, vehicle/pedestrian generators, data logging of delays, queue lengths, and emergency passage times.
b. Excluded: Network-wide coordination beyond the single intersection, weather effects, complex driver behaviors beyond car-following and gap acceptance, and pedestrian noncompliance events.

• Assumptions Added:

a. Emergency vehicles ignore queueing constraints but yield to collision-avoidance rules.
b. Signal preemption imposes a fixed all-red interval (3–5 s) for safety before granting green to emergency approaches.

2. Input Data Analysis

We will draw on five publicly available datasets to parameterize arrival rates, trajectories, and pedestrian flows:

1. **Vehicle Trajectory Dataset (GitHub: hvzzzz/Vehicle_Trajectory_Dataset)**
   a. Properties: High-frequency GPS trajectories, 100+ vehicles, 10 Hz sampling, includes lane-level positioning and speed.
   b. Advantages: Real-world, granular movement traces allow calibration of acceleration/deceleration profiles.
   c. Disadvantages: Limited spatial coverage, missing some turn maneuvers, and potential GPS noise.

2. **Urban Intersection Data (hdl.handle.net/20.500.11850/437802)**
   a. Properties: Sensor-based counts at signalized crossings, 15-min aggregation, includes directional splits.
   b. Advantages: Official government dataset, reliable counts for calibration of arrival distributions.
   c. Disadvantages: Low temporal resolution, aggregated counts may mask platoon effects.

3. **Traffic Prediction Dataset (Kaggle: Fedesoriano/traffic-prediction-dataset)**
   a. Properties: Multivariate time series of traffic speed, volume, and occupancy for 44 road segments, 5-min intervals.
   b. Advantages: Rich spatial granularity, supports demand forecasting and scenario generation.
   c. Disadvantages: Data gaps, complex preprocessing required, not strictly intersection-specific.

4. **Pedestrian In Traffic Dataset (Zenodo: 3653880)**
   a. Properties: Video-derived pedestrian counts and wait times at five crosswalks, 1-min resolution.
   b. Advantages: Direct measurement of pedestrian behavior, useful for validating crossing intervals.
   c. Disadvantages: Limited to peak hours, does not include lateral dispersion or group behavior.

5. **UCI Pedestrian Traffic Dataset (UCI ML Repository: dataset/536)**
    a. Properties: Sensor-based pedestrian counts, weather metadata, timestamps in 30-s intervals.
    b. Advantages: Includes exogenous factors (rain, temperature), high temporal resolution.
    c. Disadvantages: Pedestrian-only, requires integration with separate vehicle data sources.

3. Modeling

We will implement the simulation in AnyLogic via agent-based and discrete-event hybrid modeling.

Key components:

• Entities and Resources:

a. Agents: VehicleAgent (regular, emergency subclass), PedestrianAgent.
b. Resources: RoadSegmentResource (capacity, length), SignalController (statechart with phases), CrosswalkResource.

• Events and Interactions:

a. ArrivalEvent: Generates agents per Poisson/Empirical distribution.
b. SignalChangeEvent: Triggers phase transitions; supports emergency preemption insertion.
c. CrosswalkEvent: Allows pedestrians to traverse during walk intervals.
d. ClearanceCheck: Monitors emergency agent location and logs passage time.

• Pseudo-code:

```
initializeSimulation() {
  loadParameters(); // arrival rates, signal timings
  scheduleArrival(VehicleAgent, regularRate);
  scheduleArrival(VehicleAgent, emergencyRate);
  scheduleArrival(PedestrianAgent, pedestrianRate);
  scheduleRecurring(signalCycle, SignalChangeEvent);
}

on ArrivalEvent(agentType) {
  Agent a = createAgent(agentType);
  if (agentType == emergency) priorityQueue.add(a);
  mainRoad.enter(a);
}

on SignalChangeEvent() {
  if (!priorityQueue.isEmpty()) {
```

```
    preemptToEmergencyPhase();
  } else {
    advanceToNextPhase();
  }
  logSignalState();
}

on AgentEnterSegment(a, segment) {
  if (a is VehicleAgent) followCarFollowingModel(a);
  if (a is PedestrianAgent) walkAtConstantSpeed(a);
}
```

• AnyLogic Code Snippet (Main Agent):

```
// In Main.agent startup code
addPopulation("vehicles", 1000, VehicleAgent.class);
addPopulation("pedestrians", 500, PedestrianAgent.class);
// Emergency generator
new Event() {
  public void execute() {
    VehicleAgent ev = add_vehicle();
    ev.setEmergency(true);
    schedule(Exp(emergencyRate), this);
  }
}.execute();
```

4. Output Data Analysis

• Key Output Variables:

a. Average Vehicle Delay: Time spent waiting at all approaches.
b. Queue Length: Max and average vehicles per lane.
c. Pedestrian Waiting Time: Delay before the walk phase begins.
d. Emergency Response Time: Interval from network entry to intersection exit.
e. Throughput: Vehicles/pedestrians served per cycle.

• Analysis Methodology:

a. Scenario Comparison: Statistical comparison (ANOVA) of control strategies across metrics.
b. Sensitivity Analysis: Vary arrival rates, emergency rates, and preemption delays to test robustness.
c. Visualizations: Time-series plots of queue evolution, boxplots of delay distributions.

5. Experimental Use Cases

We plan to test the following scenarios:

• **Baseline Fixed-Time vs. Adaptive Control:**

a. What-if: Compare delays and throughput under current signal plan and adaptive algorithm.
b. Hypothesis: Adaptive control reduces average delay by ≥15% under peak demand.

• **Emergency Preemption Impact:**

a. What-if: Introduce emergency vehicle frequency of 2 per hour; measure system-wide delays.
b. Hypothesis: Preemption improves response time to <45 s but increases regular vehicle delay by ≤10%.

• **Green-Wave Corridor Coordination:**

a. What-if: Synchronize two adjacent intersections (in appendix) for platoon progression.
b. Hypothesis: Throughput increases by 20% with minimal pedestrian impact.

• **Roundabout vs. Signalized Control:**

a. What-if: Replace signalized intersection with single-lane roundabout logic.
b. Hypothesis: Roundabout yields lower vehicular delay off-peak but higher pedestrian delay.

• **Pedestrian Demand Surge:**

a. What-if: Double pedestrian arrival during school dismissal; measure pedestrian waiting and safety.
b. Hypothesis: Current crosswalk timing insufficient; requires extension of walk phase by ≥ 5 s.