Smart Emergency Traffic Control

Zakarya Boudraf (Matricola: 0522501649)

Information Visualization - Master's in Internet of Things - University of Salerno

Instructors: Prof. Lucia Cimmino, Prof. Andrea Francesco ABATE

Context & Motivation (The "Why")

- **The Problem:** Traditional "dumb" fixed-timer lights fail to adapt to real-time traffic chaos.
- **The Risk:** In medical emergencies, every second counts, gridlock equals mortality.
- **The Solution:** Moving to an AI agent that "sees" ambulances and clears paths intelligently.

Project Evolution & Objectives

Original Scope

Initially designed to manage a single isolated intersection using basic heuristics.

Challenge: Isolated nodes cannot simulate sophisticated network behaviors like coordinated flow.

Academic Guidance

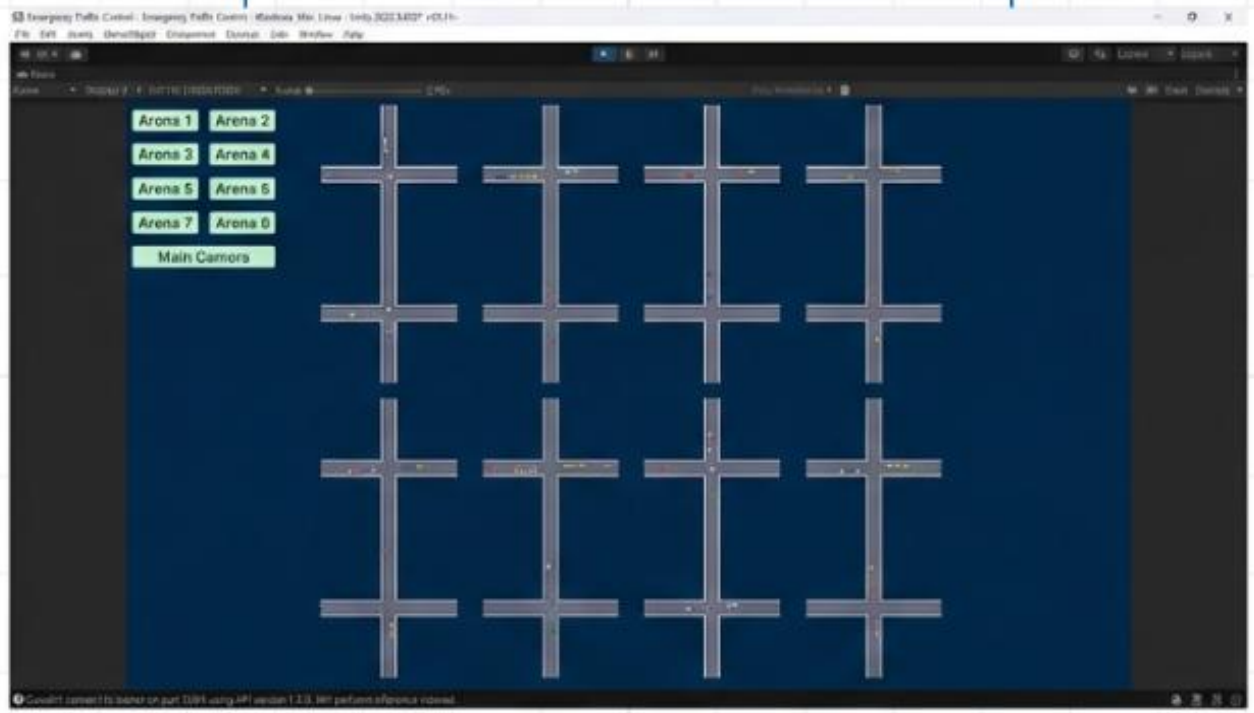
Prof. Cimmino recommended expanding to a **dual consecutive intersection** topology.

Goal: Force the agent to learn spatial-temporal coordination and predictive arrivals.

System Architecture

Engine: Unity 2022.3.62f2
+ ML-Agents 2.0.2

Algorithm: Proximal Policy Optimization (PPO)



Parallel Training Environment (8x Speed)

Architecture: 8 Simultaneous Arenas. This parallelization allows the agent to collect 8x the experience per second, stabilizing learning against stochastic traffic generation.

Implementation Challenges

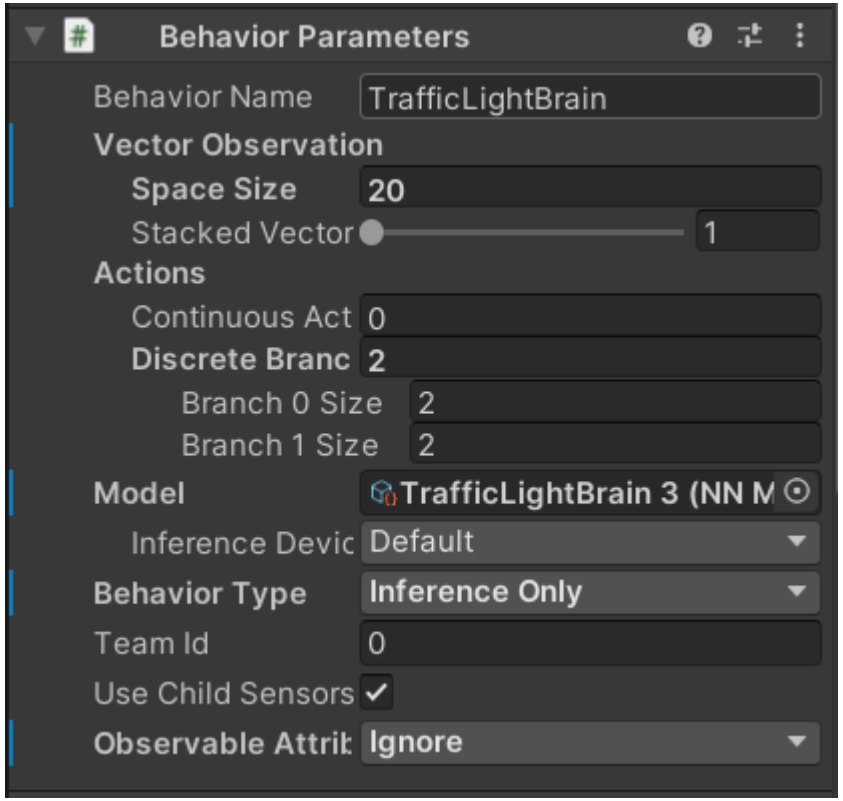
- **Dependency Conflicts:** High-friction versioning between protobuf, numpy, and tensorflow-intel.
- **Isolated Environments:** Required building custom Python virtual environments to bridge Unity C# and Python backends.
- **The Solution:** Strict version-alignment to stabilize the bridge between simulation and training.

Agent Perception (The "Eyes")

The agent "sees" through a **Vector of 20 observations**:

1. Intersection Data (16 obs): This is the raw sensor data, consisting of discrete counts of cars and ambulances waiting at each of the eight approaches across the two intersections

2. Internal State (4 obs): The agent possesses self-awareness of its own state, observing the current light phase



Safety Constraints

Multi-Discrete Control

The agent outputs simultaneous switch/hold actions for both intersections. However, neural networks can be erratic.

The Safety Layer: I implemented a hard-constraint in C# to enforce a minimumGreenTime. This prevents dangerous "flickering" and ensures realism.

```
if (action_I1 != i1_LightState) {
    if (timeSinceLastSwitchI1 >= minimumGreenTime) {
        i1_LightState = action_I1; // Allowed
    } else {
        // ACTION BLOCKED
    }
}
```

After some experimentation the timer was set to **2 seconds** as the sweet spot to prevent “flickering” while maintaining freedom to switch when necessary.

Reward (or Penalty) Engineering

$$R_{total} = R_{flow} + R_{emergency} + R_{coordination}$$

Efficiency

-0.001 Penalty per step for each waiting car.

Reason: To constantly flush queues.

Priority

+2.0 Reward for clearing an Ambulance.

-2.0 Penalty if an Ambulance stops.

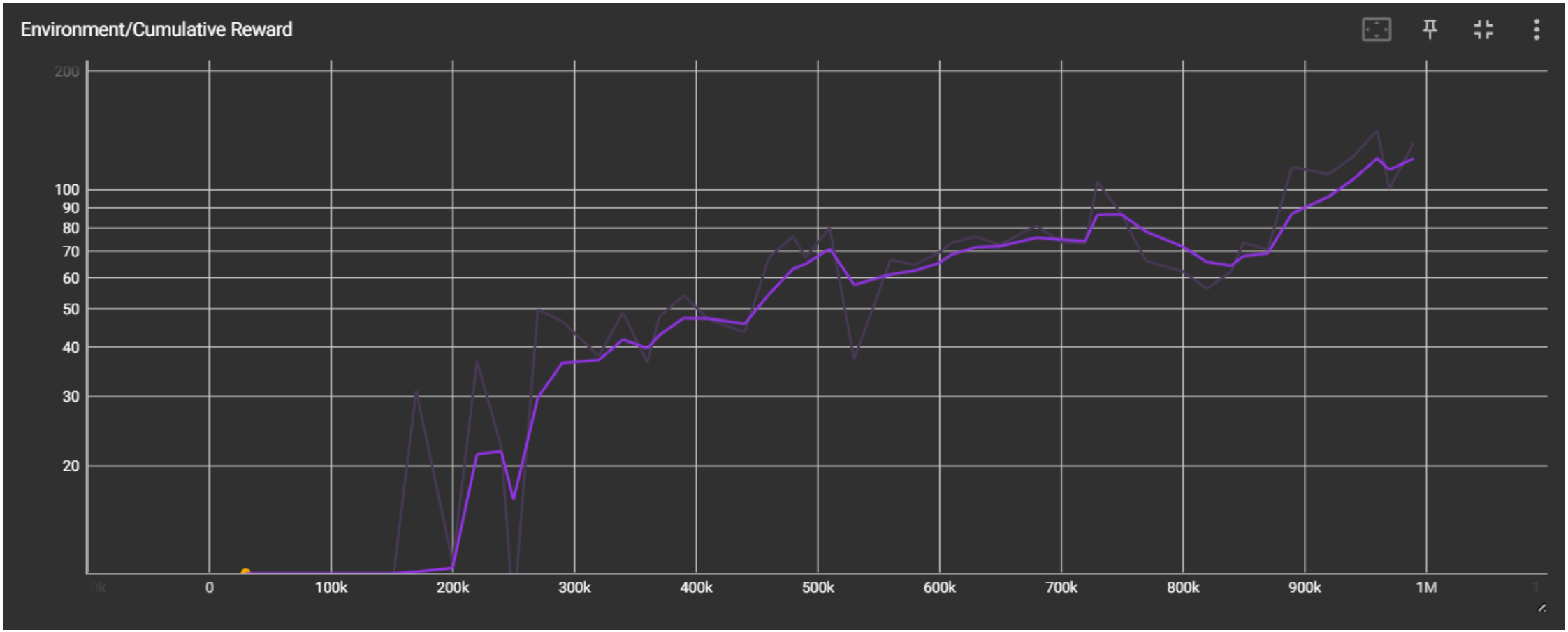
Result: The 'Green Wave' is learned.

Emergent Behavior

The agent learned that to secure the +2.0 at Intersection 2, it must open Intersection 1 early.

This is learned temporal planning.

Quantitative Results (Training)

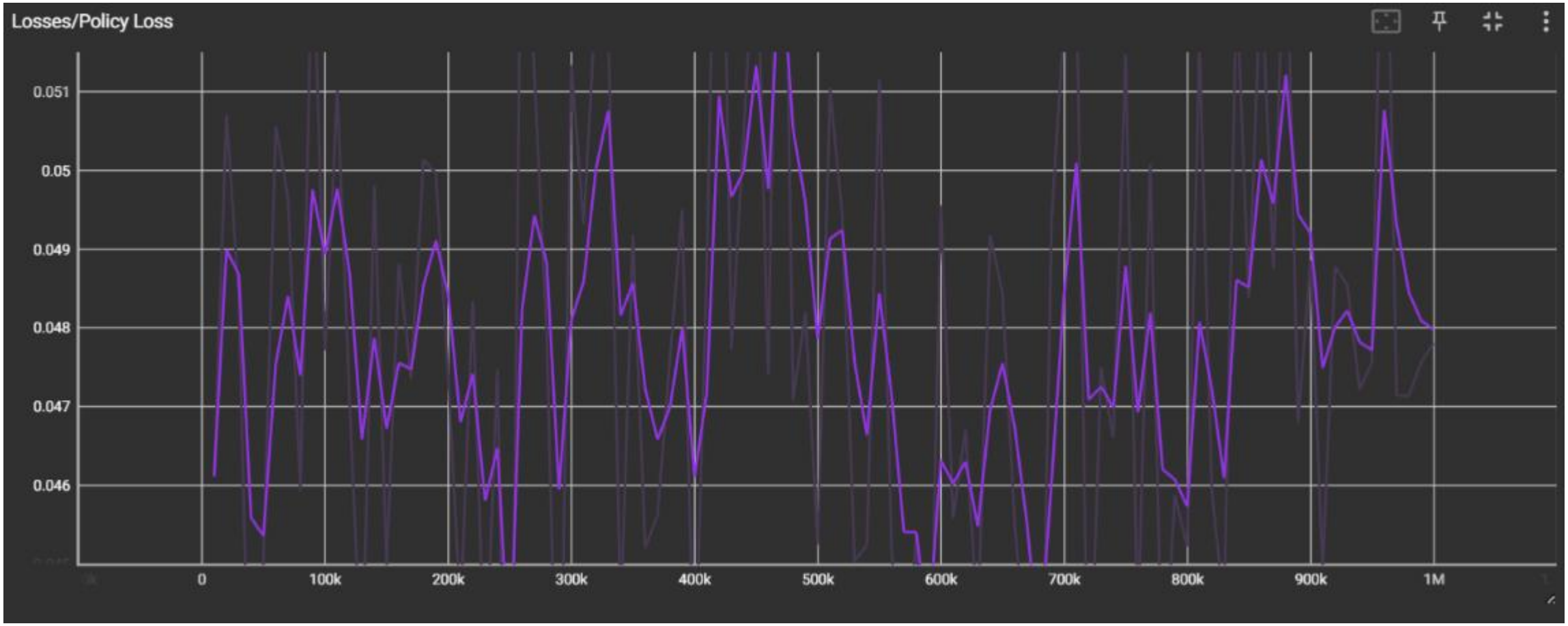


Mean Reward: ~140

Convergence: 700k

Policy Loss: ~0.005

Quantitative Results (Training)



Mean Reward: ~140

Convergence: 700k

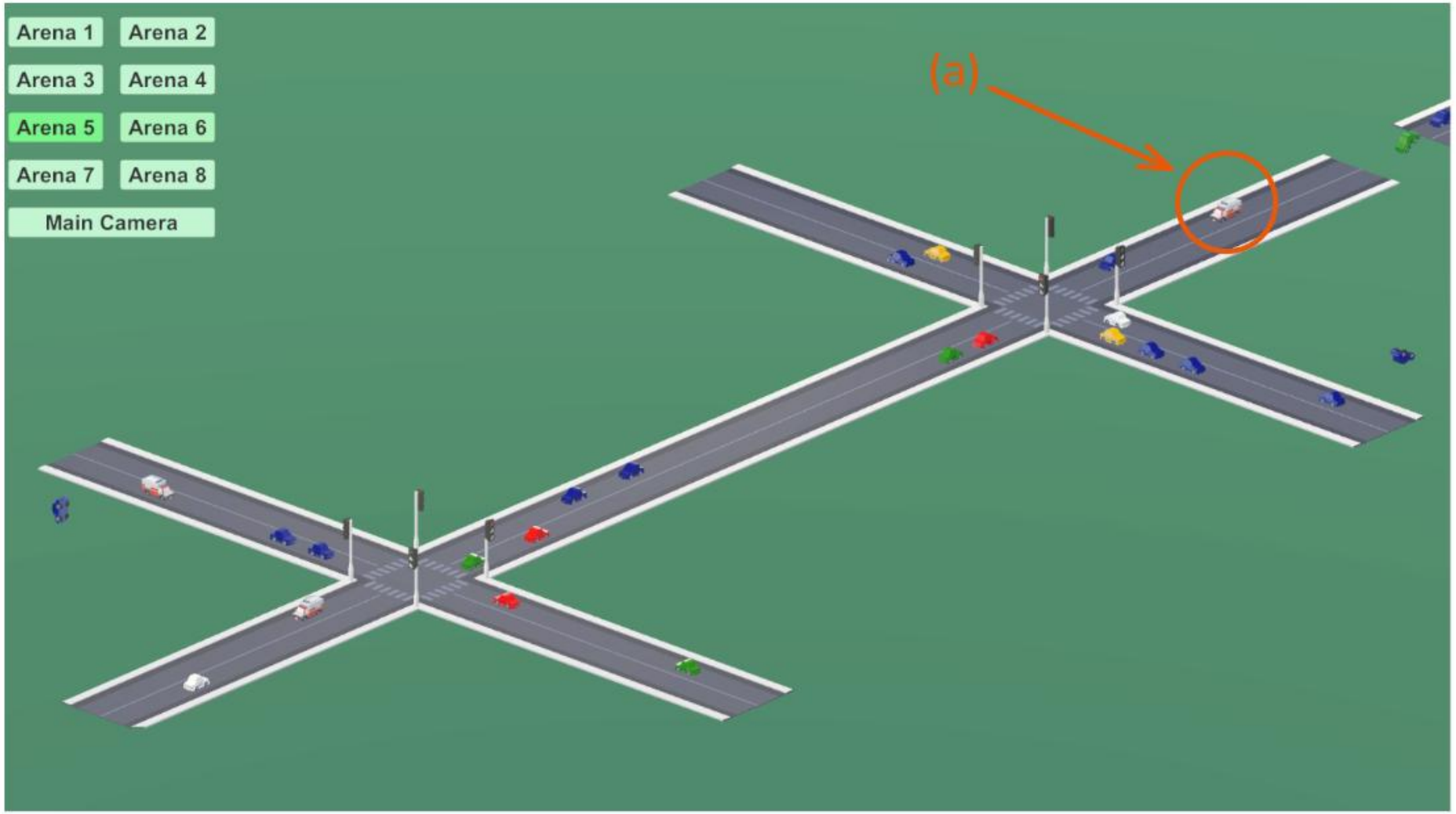
Policy Loss: ~0.005

The "Green Wave" Result

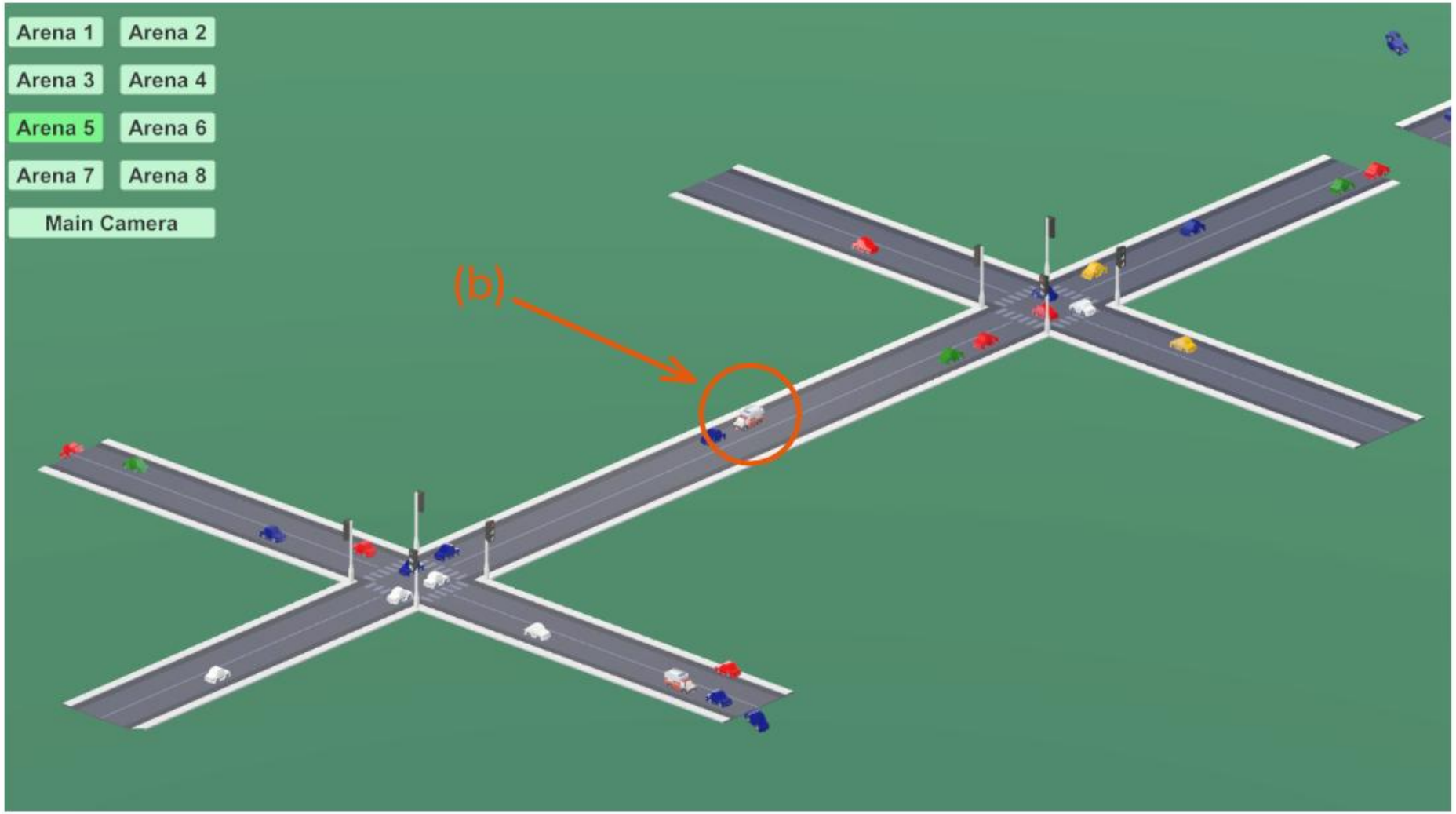
Ambulance stops were reduced from **85% (Fixed Timer)** to **<5% (AI-Powered)**.

The agent anticipates arrival across the bridge, turning Node 2 green before arrival.

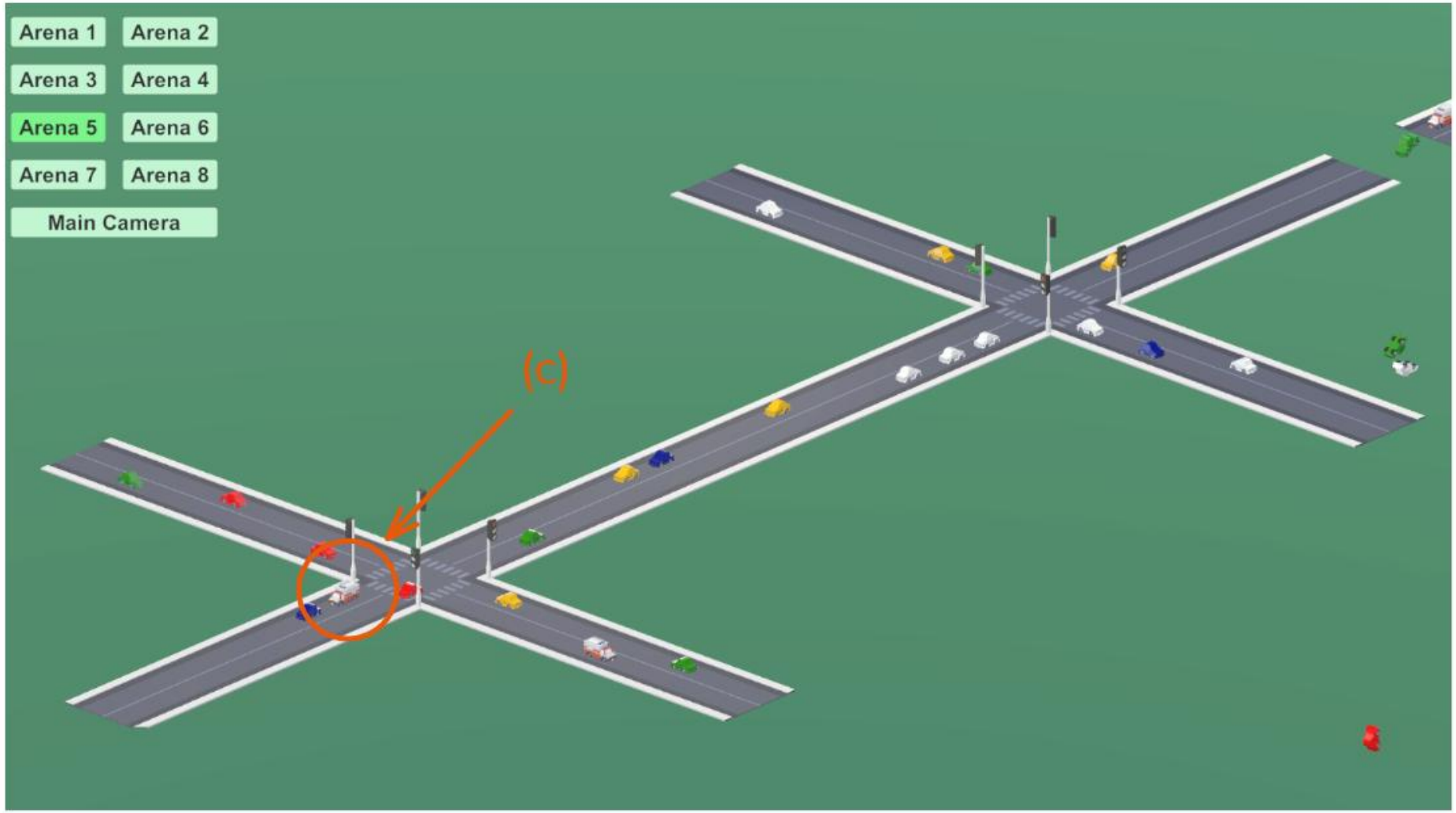
The Green Wave



The Green Wave



The Green Wave



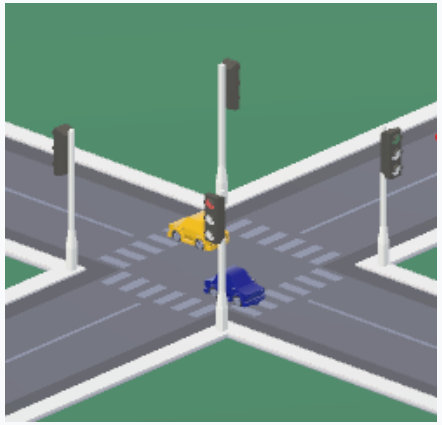
Interactive Visualization Features

Camera Switcher

Toggle between **Strategic Top-down View** and **Close-up Intersection View** for detailed analysis.

Traffic Light Visuals

In the close-up intersecion view the traffic lights switch in real time which allows inspection of model behavior



Conclusion & Future Work

This project serves as proof that **reinforcement learning** allows for transforming a static infrastructure into a dynamic, city-scale cognitive network capable of real-time, multi-objective optimization.

- **Complexity:** Adding yellow lights as well as car turns will be imperative for implementation in real life settings.
- **Scalability:** Ready for deployment across large arterial corridors.

Thank You! | Questions?