A Simulation Study on Adaptive Traffic Light Control

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1. **Problem Description**

This project focuses on evaluating and optimizing traffic light control strategies at a busy four-way intersection to improve traffic flow efficiency and reduce vehicle congestion. Two algorithms will be compared:

1. **Fixed-time Traffic Light Control:** A static algorithm with predetermined green light durations for each direction, independent of real-time traffic conditions.
2. **Adaptive Traffic Light Control:** A dynamic algorithm that adjusts green light durations based on the number of vehicles in each queue, with a minimum service time to prevent starvation.

The simulation models an intersection with two lanes of traffic in each direction (north, south, east, and west). Traffic rules include:

* Vehicles can only proceed when their lane's light is green.
* Left turns require the corresponding lane to be clear and must wait for a green light.
* Right turns are not allowed on red.
* There are no left-turn-specific signals; the intersection operates solely with red and green lights.

Traffic flow is modeled using a **Poisson arrival process** to simulate realistic vehicle arrival patterns, representing varying traffic densities throughout the day. Scenarios will include high-traffic periods, such as rush hours, and low-traffic periods, such as late evenings, to evaluate the algorithms under different conditions.

The project aims to address the following questions:

1. How does the adaptive traffic light system compare to the fixed-time system in terms of reducing average vehicle waiting time?
2. Can an adaptive system significantly improve throughput and queue management during peak and non-peak hours?

By studying these algorithms, this simulation provides insights into improving traffic light control strategies to alleviate congestion and enhance intersection efficiency.

**2. Methodology**

**Queueing Model**

The simulation is based on an M/M/8 multi-class, multi-server queuing model to represent the traffic flow through an intersection. The key characteristics of the model are:

1. **Poisson Arrival Process**:
   * Vehicle arrivals are modeled using a Poisson process, meaning inter-arrival times follow an exponential distribution. This assumption is well-suited for traffic modeling as it realistically captures random vehicle arrivals under varying traffic conditions, such as during rush hours or low-traffic periods.
2. **Exponential Service Times**:
   * The service time (i.e., the time it takes for a vehicle to clear the intersection) is modeled with an exponential distribution. This assumption simplifies the model while accommodating the natural variability in vehicle crossing times.
3. **8 Servers**:
   * Each lane at the intersection functions as a server. Specifically:
     + There are 2 lanes per direction for 4 approaches (north, south, east, and west), resulting in 8 servers in total.
   * Each server processes vehicles independently, but traffic rules create dependencies and constraints between lanes (e.g., left turns yielding to opposing traffic).
4. **Unlimited System Capacity**:
   * Queues at the intersection are assumed to have infinite capacity, ensuring no vehicles are turned away or lost, which simplifies the simulation and focuses analysis on queue dynamics.
5. **Unlimited Population Size**:
   * The model assumes a virtually infinite population of vehicles approaching the intersection, reflecting the continuous flow of traffic in real-world scenarios.

There will also need to be constraints put on each Q to ensure the rules of traffic are followed.

**Performance Metrics**

1. Average waiting time: Measure the average time that vehicles spend waiting at the intersection.
2. Throughput: Count the number of vehicles that pass through the intersection within a given time frame.
3. Queue length: Track the maximum and average queue length at the intersection.
4. Traffic flow efficiency: Measure how quickly the intersection clears vehicles during peak and non-peak hours.