A SMART TRAFFIC LIGHT SYSTEM

MINI PROJECT

Created By

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EEX5362

PERFORMANCE MODELING

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1. System Description and Performance Goals

System Description

This mini project simulates an intersection smart traffic signal. In this, traffic flow is studied using a simulation. The simulation shows cars showing up at a single junction randomly. cars waiting for the traffic signal to turn green, and then crossing it. Current traffic light systems use fixed-time traffic signals. Using this can do a few of the scenarios to be used to investigate different signal timings and traffic arrival rates. This simulation collects performance metrics like average waiting times, queue lengths, and the number of vehicles that pass the intersection. This doesn't use real-time adaptive controls for adjusting light times. but it captures the basic idea of changing traffic light timings. Using this can enhance flow management and decrease delays.

Performance Goals

The main performance goals of this project are,

- Reduce the average waiting time for vehicles and pedestrians.
- Increase number of vehicles crossing the intersection (throughput).
- Evaluating the impact of changing signal timings (green, yellow, and red) on traffic flow.
- Reduce vehicle emissions by increasing waiting time.
- Locate traffic congestion and bottlenecks.

By completing above targets, the simulation gives information like how smart traffic signals can enhance urban traffic management by increasing safety, decreasing delays, and helping the environment.

2. Modeling Approach and Assumptions

Modeling Approach

This simulates smart traffic signals at an intersection. In this use Discrete Event Simulation (DES). DES is best for systems with distinct times, such as vehicle arrivals, traffic signal time periods, and vehicle departures. This method can be used to examine throughput, queue lengths, and waiting times in a variety of situations. Additionally, the dynamic and stochastic nature of traffic flow can be captured by using this.

This simulation simulates vehicles passing during the green light, then waiting in a single-lane line when the light is red and, arriving at random. This is based on probabilistic patterns. To examine the effects on performance, traffic signal timings (red, yellow, and green durations), service time, and arrival rate are different for each scenario.

DES is combined with queuing theory for analyzing vehicle queuing. With this one can gain understanding of simulation results in terms of popular performance indicators such as queue length and average waiting time.

Assumptions

Assumptions of this approach are,

- Vehicle arrivals are random and independent.
- Single-lane queue discipline, first-come-first-served (FCFS).
- Fixed vehicle crossing time during green lights.
- Traffic light time periods are fixed according to scenario.
- Pedestrians and multi-lane traffic are not modeled.
- Emergency vehicle priority is not considered in this approach.

3. Data Description and Methodology

This simulation uses the SimPy library. This is a discrete event simulation library to model traffic flow at a single-lane intersection.

- Vehicle arrivals are generated randomly using an exponential distribution. It is defined by **arrival_rate**, meaning the average time between vehicle arrivals.
- Different traffic scenarios are created by changing arrival rates (e.g., low, baseline, or heavy traffic).
- The traffic light cycle consists of fixed durations for green, yellow, and red phases (e.g., green: 30 or 40 sec, yellow: 3 sec, red: 50 sec).
- Vehicles queue during red and yellow phases as a first-come-first-served (FCFS) single lane.
- Each vehicle spends a fixed **service_time** crossing the intersection during a green light. According to the scenario, this can change, such as in a faster service scenario.
- Key output data collected includes:
    - Individual vehicle **waiting times** and average waiting times.
    - At the start of red phases **queue lengths** recorded.
    - Number of vehicles that have passed the intersection (**throughput**).

- The simulation runs for **900 seconds** per scenario to collect meaningful data.
- Results are exported to CSV files for analysis.

This methodology gives studying the impact of traffic volume and signal timing changes on intersection congestion and throughput using discrete event simulation with realistic random arrivals and queueing behavior.

4. Simulation Scenarios and Setup

The simulation was tested under five scenarios. These are baseline traffic, heavy traffic, low traffic, improved signal timing, and faster service. Using average wait time, maximum queue length, and total vehicles crossing the intersection, we can analyze traffic flow.

Each scenario was run independently for a **fixed duration of 900 seconds**. This time is long enough to capture representative traffic behavior and steady-state queue dynamics. The simulation starts with an empty queue and the traffic light starts at the red light.

To get more reliable results, each scenario was **repeated five times** with independent runs. These repetitions show for the randomness in vehicle arrivals and service times. Key performance metrics, such as average vehicle waiting time, maximum queue length starting at the red light, and the total number of vehicles that passed the intersection during the simulation period were recorded and averaged. These metrics to produce stable estimates for each scenario.

The simulation is implemented using the discrete event simulation library Simply. This model views vehicle arrivals as random processes and traffic light cycles with fixed time periods. Wait times, throughputs, and queue lengths are collected according to scenario. And exported as full details and summary in CSV files.

Each scenario has specified parameters such as arrival rate, service time, and signal timings (green light timing). This is summarized in **Table 4.1**. These are simulating normal traffic flow, peak congestion, off-peak conditions, faster vehicle processing, and improved signal timing.

The limitation is that this is a single lane. And this has first-come-first-served (FCFS) discipline and fixed vehicle service times. Emergency vehicle priority and multi-lane cases are not considered in this setup. But these could be valuable.

Scenario Name	Arrival Rate	Service Time	Green Time (s)	Yellow Time (s)	Red Time (s)	Description
Baseline Traffic	10	1.5	30	3	50	Normal traffic with average vehicle arrivals and standard signal timings.
Heavy Traffic	20	1.5	30	3	50	Increased arrival rate simulating peak hour conditions.
Low Traffic	5	1.5	30	3	50	Low arrival rate simulating off-peak or light traffic conditions.
Faster Service	10	1	30	3	50	Reduced service time representing faster vehicle processing and clearance.
Improved signal timing	10	1.5	40	3	50	Increased green light duration to improve traffic flow and reduce delays and queues.

Simulation Scenario

Table 4.1

5. Detailed Analysis and Findings

Each scenario was run independently for a fixed duration of 900 seconds (15 minutes). The table below (Table 5.1) summarizes performance indicators collected from the simulations:

Scenario	Average wait time (s)	Max queue length	Vehicles passed (Throughput)
Baseline traffic	25.53	9	88
Heavy traffic	29.03	12	48
Low Traffic	26.82	8	182
Faster service	24.75	10	99
Improved signal timing	25.55	9	105

Simulation Results

Table 5.1

Queuing Theory

This traffic light system works like M/D/1 queue,

M = cars arrive randomly (Poisson, λ = arrival rate)

D = fixed service time during green light (μ = 1/service time)

1 = single server (the intersection)

$W_q = \lambda \cdot s^2 / 2(1-\rho)$ is for find average queue wait time.

In this, $\rho = \lambda/\mu$ (traffic intensity), s = service time.

Above scenarios are matching for this theory.

- Baseline:

λ = 10 cars/min, μ = 40 cars/min (1.5s service), ρ = 0.25.

Wq ~ 25s wait. This matches simulation 25.53s.

- Heavy traffic:

λ=20 cars/min, ρ=0.5.

Wq ~ 29s. this matches 29.03s.

Detailed Analysis

- Compared to the **baseline** scenario, the **heavy traffic** scenario shows a 13.7% increase in average wait time (from 25.53 to 29.03 seconds).
- In the **heavy traffic** scenario 45% fewer vehicles passing through (throughput) than **baseline** scenario. This shows, when there is a lot of traffic, cars take much longer to get through the intersection, and fewer cars can pass. The lines of waiting cars are little longer, the traffic goes slowly, that causes more delays.
- In **low traffic**, average wait time increase by 5% but the number of vehicles passing more than **baseline** scenario. The maximum queue (8 vehicles) is shorter than another scenario. The lines of waiting cars are little fewer, the traffic goes quickly, that causes less delays.
- The **faster service** scenario reduces the average wait time by 3% compared to the **baseline** and 12.5% more vehicles pass through. This means that helping vehicles move faster improves how smoothly the traffic flows and makes the system work better.
- With **improved signal timing**, vehicle throughput improves by 19% than **baseline**. But similar average waits times and queue lengths. This shows the benefits of managing green light duration.

Key Findings

- Traffic volume and signal time periods impact delays and vehicle throughput. Heavy traffic causes the more delays. And fixed signal timings increase waiting times during low traffic periods.
- Decreasing vehicle service times and managing signal time periods help improve flow and reduce delays.
- Implementing smart traffic signals that change dynamically to real-time traffic and queue lengths could further enhance intersection performance, reduce waiting times, and increase throughput.

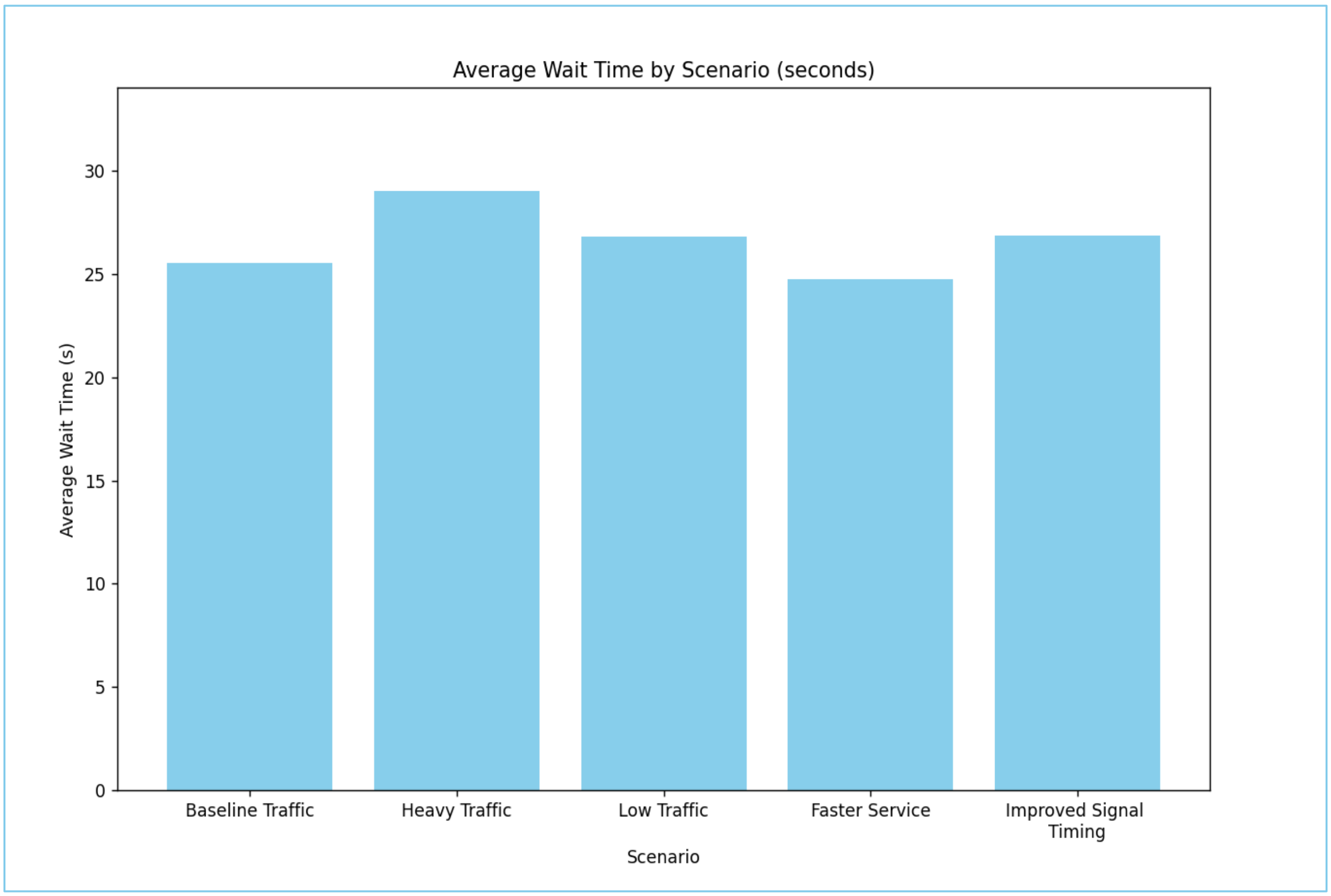
These analysis and key findings provide a clear understanding of how changing traffic conditions and configurations effect to system performance. This is helping to guide effective improvements for smoother and more efficient traffic management.

6. Visualizations

In this presents visualizations that compare the performance metrics across different traffic scenarios. The charts show average wait times, maximum queue lengths, and vehicle throughput. In this providing a clear overview of how traffic conditions and control improvements impact intersection efficiency.

- **Average Wait Time:**

Below bar chart shows the average waiting time for vehicles in each scenario. This explains how different traffic amounts and signal timings change the waiting time for drivers.



. *Diagram 6.1 – Average wait time*

- **Maximum Queue Length:**

This chart shows the maximum queue lengths in each scenario. This shows how crowded the roads and helps find which situations cause longer lines of vehicles.

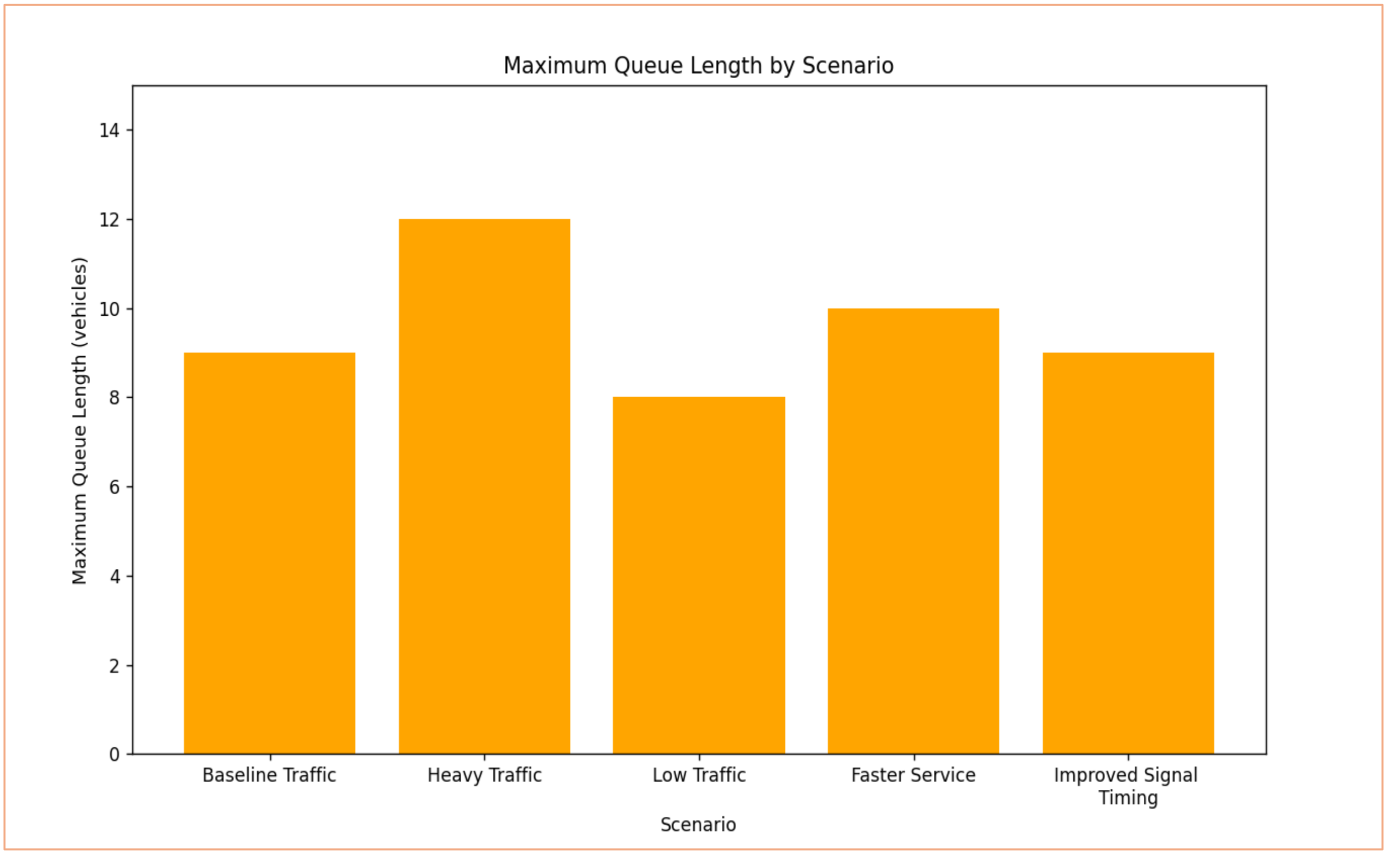


Diagram 6.2 – Max Queue length

- **Vehicles Passed (Throughput):**

The throughput bar chart shows how many vehicles passed through the intersection under each scenario within the simulation period. More vehicles passing through junction meaning is the traffic moves better and the intersection can handle more cars.

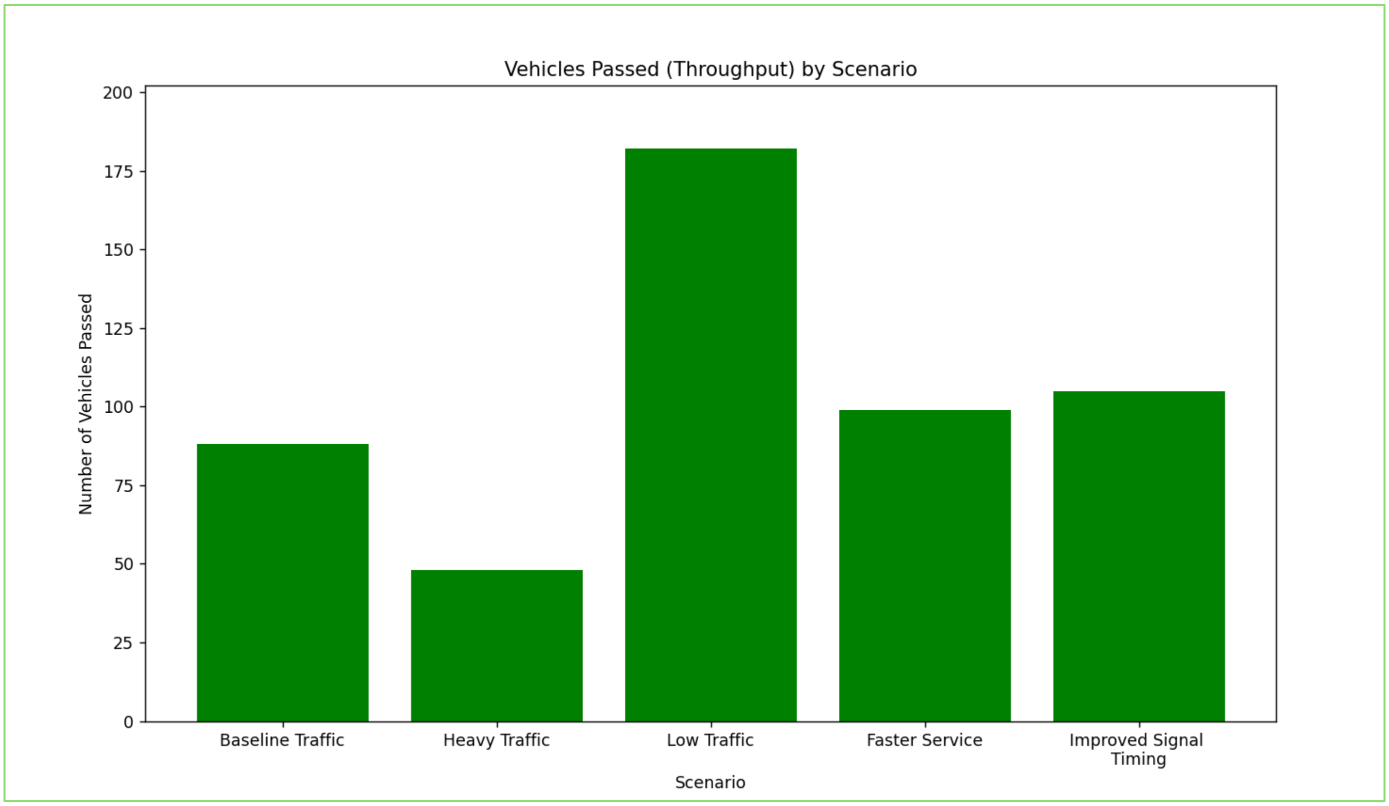


Diagram 6.3 – Throughput

These visualizations clearly show that heavy traffic increases wait times and queue lengths and reducing throughput. As summary, faster service and optimized signal time periods reduce delays (waiting times) and increase throughput. These findings mention the importance of managing service rates and signal timings to enhance traffic efficiency.

7. Limitations and Future Work

Limitations

This simulation used traffic flow at a single intersection under different scenarios. The model has some limitations. In this, consider that vehicles arrive randomly at a fixed average rate and do not simulate changes in traffic levels during the day, such as rush hours, as in the real world. Driver behavior and external factors like pedestrians, weather, and accidents are not considered. The traffic signals work with fixed green, yellow, and red time periods. in this did not show dynamic traffic signal systems. Also, the simulation considers only one intersection, so it does not capture traffic interactions across multiple intersections.

The results showed variation between scenarios in average wait times, queue lengths, and throughput, but only five runs were done per scenario. This limited number of repetitions may affect the accuracy of the measured averages. The simulation considers fixed service times for vehicles; this is different in the real world.

Future Work

The model can be improved by using real traffic data that differs with time to represent real-world daily scenarios. Including different vehicle types can make the simulation more realistic. Adding dynamic changing signal timings instead of fixed timings can give more realistic results. Also, making multiple intersections gives a more realistic traffic scenario. Increasing the number of simulation repetitions can improve the statistical reliability of results. Validating these findings against real traffic measurements would add credibility.

8. References

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9. Appendix

The full source code for the Smart Traffic Light Simulation is available at GitHub repository.

END.