Traffic Engineering and Management

Two Phase v/s Four Phase Signaling

Group 2

Table of Content

Introduction

Objective :

To compare the two-phase and four-phase signal configurations at a busy intersection and determine which one optimizes traffic flow better by reducing average wait times, improving throughput, and minimizing delays.

Scope of the Project :

The scope of this project is to evaluate and compare the effectiveness of two-phase and four-phase traffic signal timing configurations at a busy 4-way intersection. This will be done by simulating the impact of different signal timing setups on key traffic metrics, including average wait times, throughput, and delays.

Some key aspects :

Intersection Configuration

- The project focuses on a 4-way intersection with **two lanes per approach**, making it representative of typical urban intersections.
- Traffic flow is modeled for **north-south** and **east-west** directions, with vehicle flow rates of **1000 vehicles per hour** for north-south traffic and **700 vehicles per hour** for east-west traffic.

Signal Timing Configuration

- **Two-Phase Signal Configuration**: Alternates between two phases—one for the north-south direction and another for the east-west direction. Each direction gets equal green time(30 seconds).
- **Four-Phase Signal Configuration**: Each direction (northbound, southbound, eastbound, westbound) has its own dedicated green phase(15 seconds), reducing the time each direction has to wait for a green light.

Key Performance Metrics

- The analysis focuses on the following performance metrics:
  - **Average Wait Times**: The time vehicles spend waiting at the intersection before receiving a green light.
  - **Throughput**: The number of vehicles processed through the intersection per cycle (vehicles passing through the intersection).
  - **Delays and Queue Lengths**: The buildup of vehicles in each direction and the corresponding delays.

Simulation Environment

- The project uses **simulation tools** (such as SUMO & Python) to model the intersection and simulate traffic flow under different signal configurations.

Objective of the Analysis

- The core goal is to determine which signal timing configuration (two-phase or four-phase) provides **better traffic flow**, **reduces congestion**, and **minimizes delays** at the intersection. The analysis will aim to provide insights that can help inform urban traffic signal optimization strategies.

Scenario and Setup

The project focuses on a 4-way intersection with two lanes per approach and a 2-way intersection designed to simulate real-world traffic conditions. The intersection is set up to evaluate the effectiveness of two different traffic signal configurations under varying traffic flow conditions.

Intersection Layout:

- The intersection consists of **four approaches**: northbound, southbound, eastbound, and westbound, with **two lanes** per approach.
- The traffic flow is modeled with a vehicle arrival rate of **1000 vehicles per hour** for the north-south direction and **700 vehicles per hour** for the east-west direction.

Signal Configurations:

- **Two-phase Signal Setup:**
  - The intersection alternates between two phases: one for the north-south direction and another for the east-west direction.
  - Phase 1 (North-South): Green = 30 seconds, Yellow = 5 seconds, Red = 25 seconds.
  - Phase 2 (East-West): Green = 30 seconds, Yellow = 5 seconds, Red = 25 seconds.
- **Four Phase Signal Setup:**
  - Each approach (northbound, southbound, eastbound, and westbound) has its own dedicated green phase.
  - Phase 1 (Northbound): Green = 15 seconds, Yellow = 5 seconds, Red = 40 seconds.
  - Phase 2 (Southbound): Green = 15 seconds, Yellow = 5 seconds, Red = 40 seconds.
  - Phase 3 (Eastbound): Green = 15 seconds, Yellow = 5 seconds, Red = 40 seconds.
  - Phase 4 (Westbound): Green = 15 seconds, Yellow = 5 seconds, Red = 40 seconds.

Methodology

Simulation Design:

To create and run the simulation for both two-phase and four-phase signal configurations, the following structured approach was taken:

Two Phase Signal Configurations

Node Creation:

- The intersection's center node (center) is defined as a traffic light, while the nodes at the end of each approach (north, south, east, west) are points where traffic enters or exits the intersection.
- The intersection's structure was defined using an XML file specifying nodes for each approach and the center:

two_way_intersection.nod.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<nodes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/nodes_file.xsd">
    <node id="north" x="0" y="100" type="priority"/>
    <node id="south" x="0" y="-100" type="priority"/>
    <node id="east" x="100" y="0" type="priority"/>
    <node id="west" x="-100" y="0" type="priority"/>
    <node id="center" x="0" y="0" type="traffic_light"/>
</nodes>
```

Edge Configuration:

- The edges were defined to connect nodes, representing traffic lanes with specified speed limits:

two_way_intersection.edg.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<edges>
    <edge id="north_in" from="north" to="center" numLanes="2" speed="50"/>
    <edge id="north_out" from="center" to="north" numLanes="2" speed="50"/>

    <edge id="south_in" from="south" to="center" numLanes="2" speed="50"/>
    <edge id="south_out" from="center" to="south" numLanes="2" speed="50"/>

    <edge id="east_in" from="east" to="center" numLanes="2" speed="50"/>
    <edge id="east_out" from="center" to="east" numLanes="2" speed="50"/>

    <edge id="west_in" from="west" to="center" numLanes="2" speed="50"/>
    <edge id="west_out" from="center" to="west" numLanes="2" speed="50"/>
</edges>
```

Network and Route Creation:

- The nodes and edges were combined into a network file, and routes were specified to simulate vehicle flow.

Traffic Light Logic:

- The traffic lights were coded with specified phases for both configurations. For the two-phase setup:

traffic_light.tll.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<additional>
    <tlLogic id="center" type="static" programID="2phase" offset="0">
        <!-- Phase 1: North-South -->
        <phase duration="30" state="GGGggrrrrrGGGggrrrrr"/> <!-- North-South green -->
        <phase duration="5" state="yyyyyrrrrryyyyyrrrrr"/>  <!-- North-South yellow -->

        <!-- Phase 2: East-West -->
        <phase duration="30" state="rrrrrGGGggrrrrrGGGgg"/> <!-- East-West green -->
        <phase duration="5" state="rrrrryyyyyrrrrryyyyy"/>  <!-- East-West yellow -->
    </tlLogic>
</additional>
```

SUMO Configuration File

- A configuration file that compiles all other XML files (network, routes, and additional files like traffic lights) into one executable setup for the SUMO simulation.
- **Purpose**: It orchestrates the entire simulation process, including start and end times and output settings for reporting results.

sumo_config.sumocfg

```xml
<?xml version="1.0" encoding="UTF-8"?>

<configuration xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/sumoConfiguration.xsd">

    <input>
        <net-file value="two_way_intersection.net.xml"/>
        <route-files value="two_way_intersection.rou.xml"/>
        <additional-files value="traffic_light.tll.xml"/>
    </input>

    <time>
        <begin value="0"/>
        <end value="3600"/>
    </time>

    <report>
    <output-prefix value="results"/>
    <summary-output value="summary.xml"/>
    <tripinfo-output value="tripinfo.xml"/>
    <queue-output value="queue.xml"/>
    <emission-output value="emissions.xml"/>
</report>


</configuration>
```

Key output metrics were gathered from the SUMO simulation results for performance analysis:

1. Average Wait Times

- **Definition**: The average time vehicles spent waiting at red lights.
- **Method**: Data from `tripinfo.xml`, which logs travel and waiting times for each vehicle, was used to calculate the overall average wait time.

2. Throughput

- **Definition**: The number of vehicles passing through the intersection per hour.
- **Method**: The total number of vehicles processed, as recorded in `summary.xml`, was divided by the simulation duration to find the hourly throughput.

3. Comparison of Delays

- **Definition**: The difference between observed queue lengths and expected results.
- **Method**: Data from `queue.xml`, detailing the number of waiting vehicles over time, was analyzed to compare average and peak queue lengths for both signal configurations.

These metrics provided insights into the efficiency and congestion levels of the two-phase and four-phase signal setups.

Four Phase Signal Configurations

The four-phase signal timing simulation was constructed using the following elements:

1. **Network Design**

- Nodes: Defined using an XML configuration, nodes were placed at key points:

two_way_intersection.nod.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<nodes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/nodes_file.xsd">
    <node id="north" x="0" y="100" type="priority"/>
    <node id="south" x="0" y="-100" type="priority"/>
    <node id="east" x="100" y="0" type="priority"/>
    <node id="west" x="-100" y="0" type="priority"/>
    <node id="center" x="0" y="0" type="traffic_light"/>
</nodes>
```

- These nodes represented entry and exit points, with the center node acting as the traffic light control.

2. Edges:

- The connections between nodes were defined as follows:

```xml
<edge id="north_in" from="north" to="center" numLanes="2" speed="50"/>
<edge id="north_out" from="center" to="north" numLanes="2" speed="50"/>
<edge id="south_in" from="south" to="center" numLanes="2" speed="50"/>
<edge id="south_out" from="center" to="south" numLanes="2" speed="50"/>
<edge id="east_in" from="east" to="center" numLanes="2" speed="50"/>
<edge id="east_out" from="center" to="east" numLanes="2" speed="50"/>
<edge id="west_in" from="west" to="center" numLanes="2" speed="50"/>
<edge id="west_out" from="center" to="west" numLanes="2" speed="50"/>
```

3. . Traffic Light Logic

- The traffic light logic was coded in an `additional` XML file, where each phase represented a specific direction:

Combining Files in the Final SUMO Configuration

To run the four-phase simulation, all components were integrated into a single SUMO configuration file. This configuration file (`sumo.cfg`) served as the master file, linking together the network, traffic routes, and traffic light logic.

Key output metrics were gathered from the SUMO simulation results for performance analysis:

1. Average Wait Times

- **Definition**: The average time vehicles spent waiting at red lights.
- **Method**: Data from `tripinfo.xml`, which logs travel and waiting times for each vehicle, was used to calculate the overall average wait time.

2. Throughput

- **Definition**: The number of vehicles passing through the intersection per hour.
- **Method**: The total number of vehicles processed, as recorded in `summary.xml`, was divided by the simulation duration to find the hourly throughput.

3. Comparison of Delays

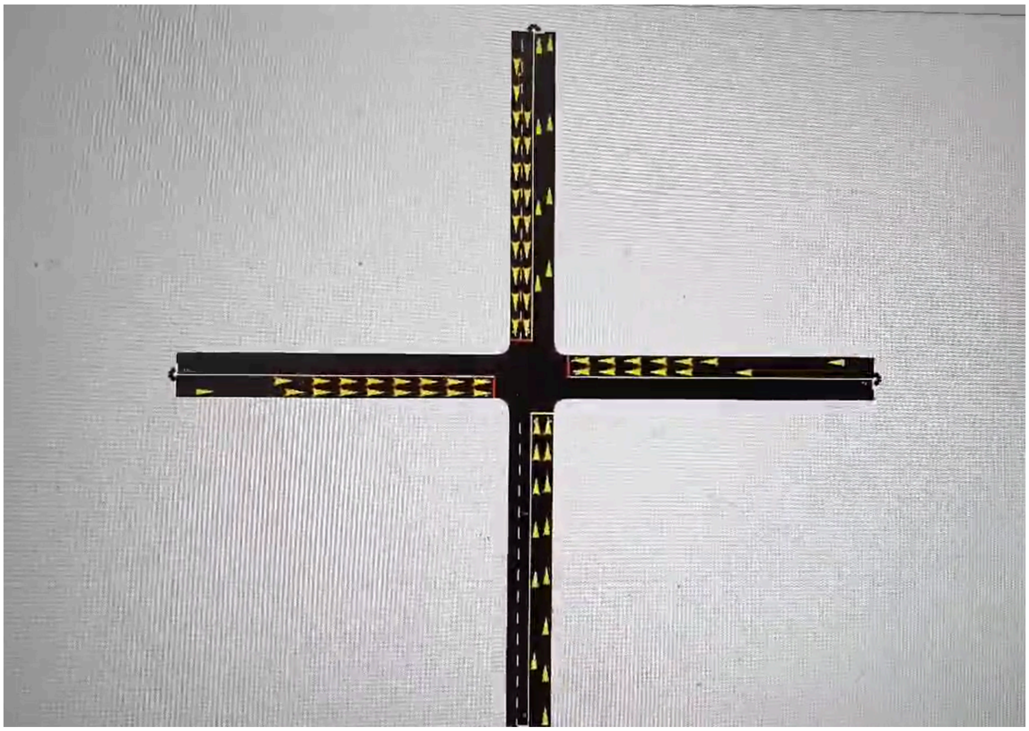
- **Definition**: The difference between observed queue lengths and expected results.
- **Method**: Data from `queue.xml`, detailing the number of waiting vehicles over time, was analyzed to compare average and peak queue lengths for both signal configurations.

These metrics provided insights into the efficiency and congestion levels of the two-phase and four-phase signal setups.

Result & Analysis

Data Visualization:

1. **Two Way Intersection**



According to the collected data from the simulation, the following results were obtained for the two way intersection method

Distribution of Queuing time

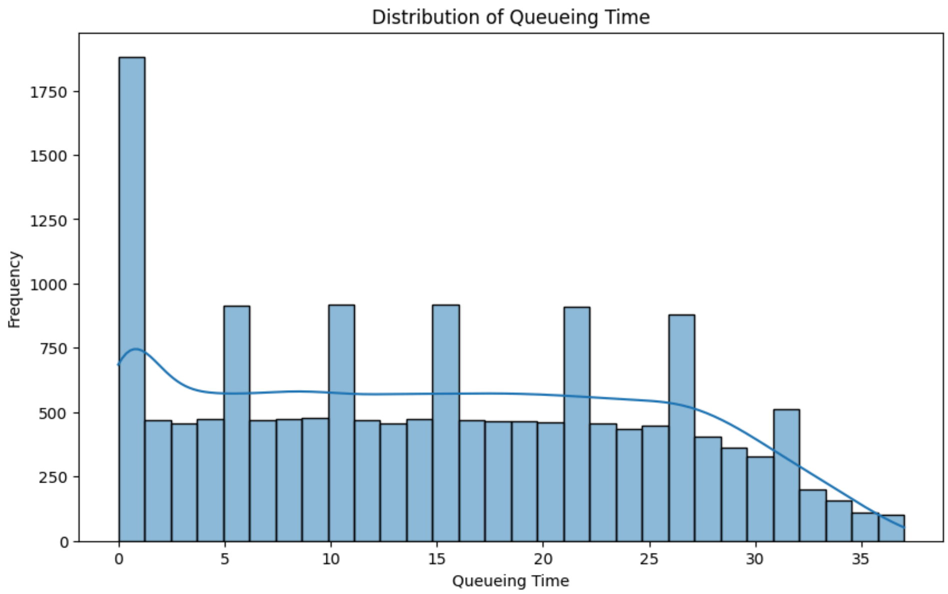
Data	TimeStep	Queuing_Time	Queuing_length	Queuing_length_exp
count	16015.000000	16015.000000	16015.000000	16015.000000
mean	1812.456572	14.967281	14.983413	18.508548
std_dev	1032.097098	10.131423	9.773604	10.021751
min	17.000000	0.000000	0.000000	5.100000
25%	917.500000	6.000000	6.000000	6.000000
50%	1818.000000	15.000000	13.500000	21.000000
75%	2703.000000	23.000000	21.000000	28.500000
max	3599.000000	37.000000	43.550000	43.920000

Queuing Time

Queuing time is the duration a vehicle waits at an intersection before moving. It reflects traffic congestion and the efficiency of signal timings.

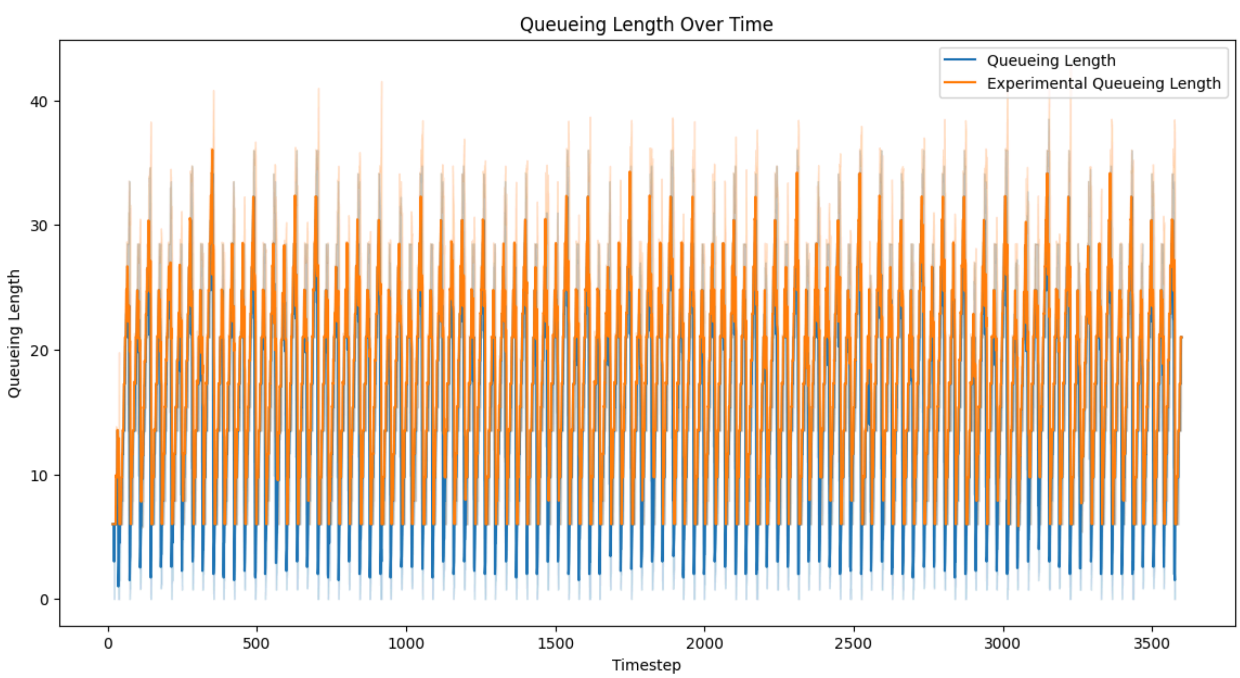
Key Points:

- Definition: Time spent waiting at red lights before proceeding.
- Impact: Longer queuing times indicate congestion or inefficient signal phases.
- Stats: Average queuing time is 14.97 seconds, with a maximum of 37 seconds.



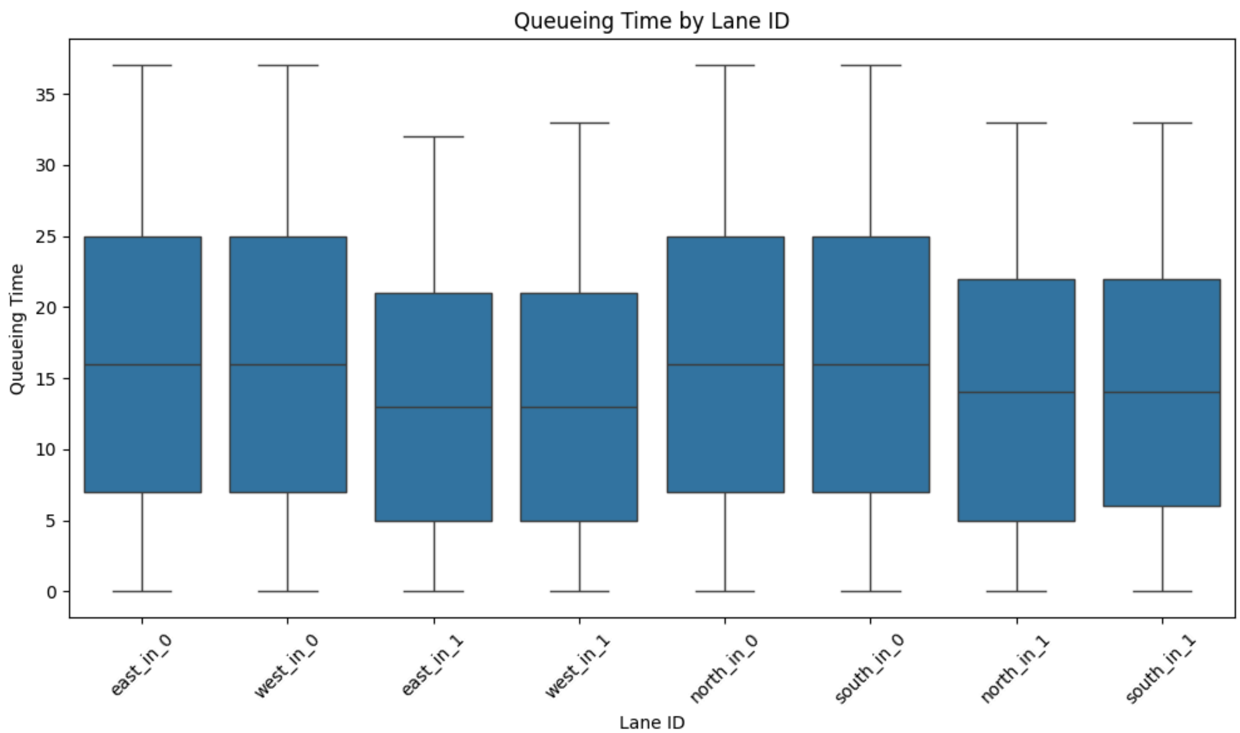
Queuing length over time

- It represents the number of vehicles waiting at an intersection during each timestep. It fluctuates based on traffic flow, signal phases, and congestion. Tracking this helps assess signal effectiveness and overall traffic management.



Queuing time by Lane ID

- It refers to the amount of time vehicles spend waiting in each specific lane at an intersection. It helps identify which lanes experience more congestion and delays. Analyzing this data can guide optimizations for lane usage and signal timing to improve traffic flow.

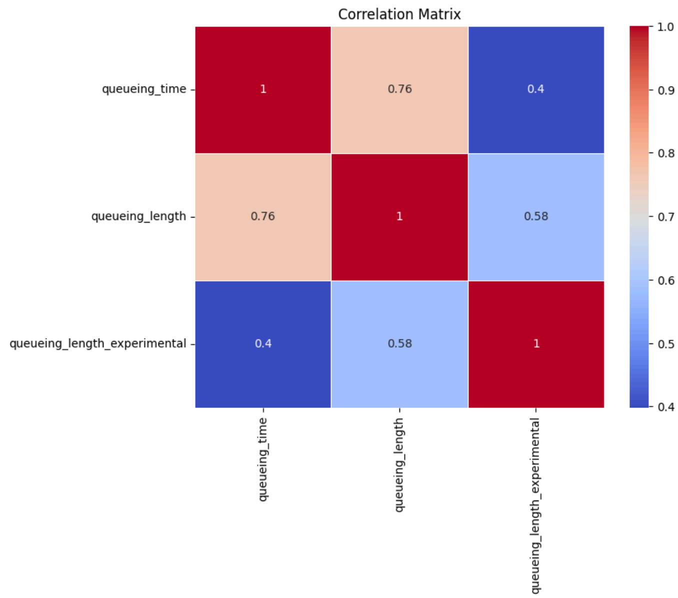


Correlation Matrix

The correlation matrix shows the relationship between multiple variables. In this case, it compares the correlation between

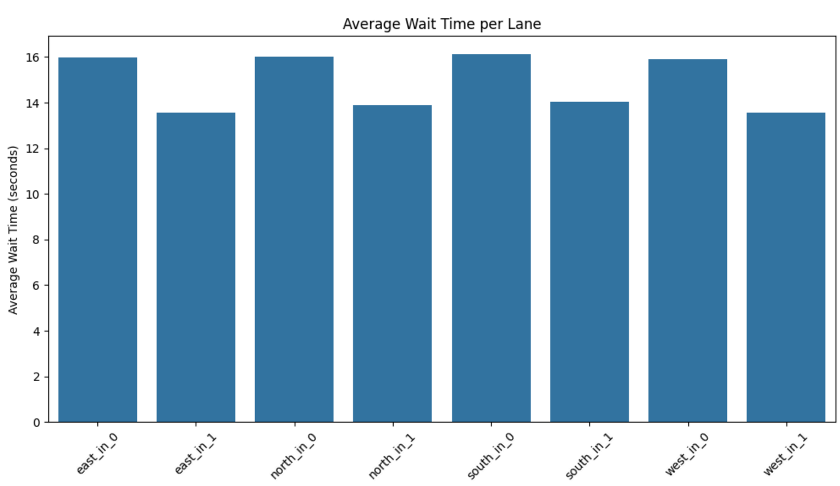
- queueing time
- queueing length
- experimental queueing length

A value closer to 1 indicates a strong positive correlation, while values near -1 show a negative correlation. This helps identify how these metrics are related and can guide traffic signal optimizations.



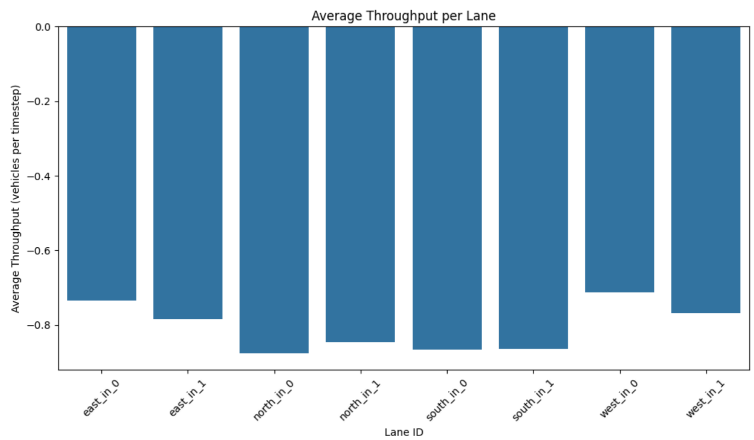
Average wait time per lane

- It refers to the mean amount of time vehicles spend waiting at a red light in each lane at an intersection. This metric helps identify congestion hotspots, showing which lanes experience longer delays. By analyzing wait times per lane, traffic management strategies can be tailored to improve flow and reduce delays at specific approaches.



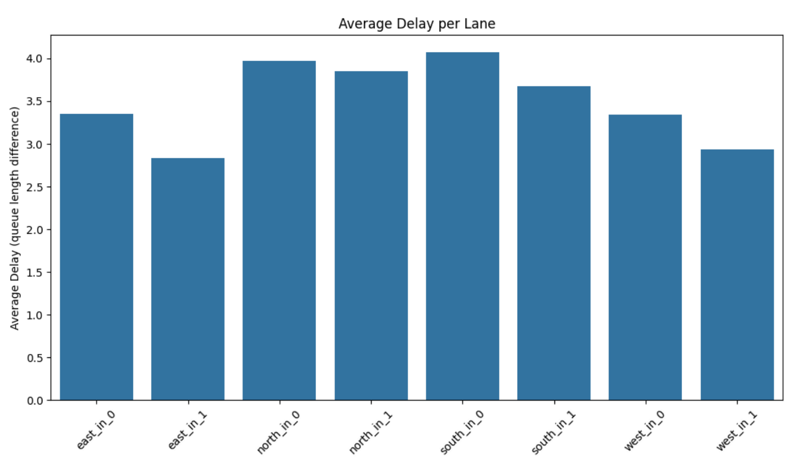
Average throughput per lane

- It refers to the average number of vehicles passing through a specific lane of an intersection during a given time period. It is a key indicator of how efficiently each lane is processing traffic. By analyzing throughput, traffic planners can assess the effectiveness of signal timings and lane usage, identifying opportunities to optimize traffic flow and reduce congestion.

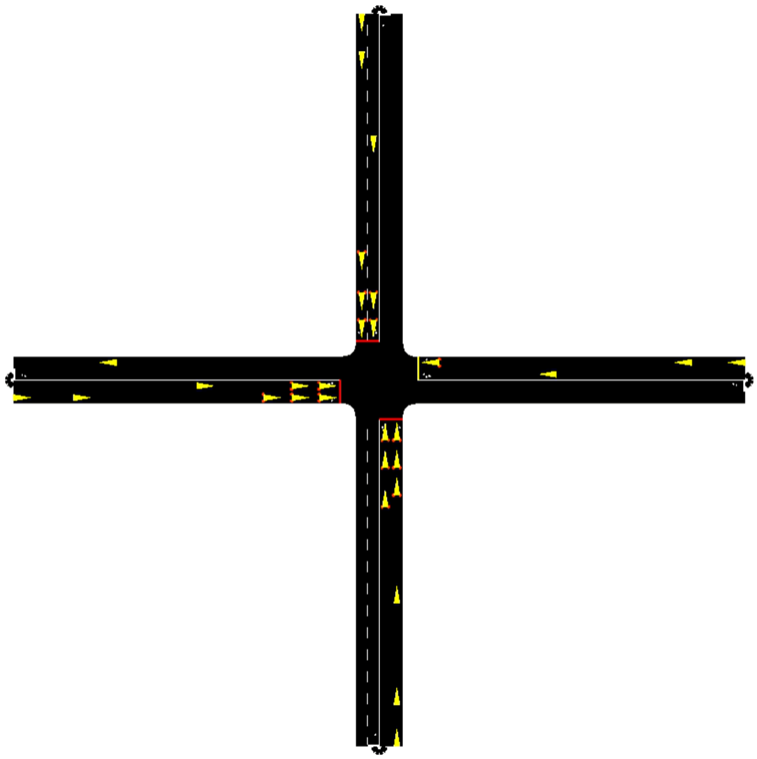


Average delay per lane

- It measures the average time vehicles are delayed at an intersection in each lane, typically due to traffic signals or congestion. It reflects the difference between the time vehicles would take to travel without delays and the actual time spent waiting. This metric helps identify lanes with excessive delays, guiding adjustments in signal timings or lane management to improve traffic flow and reduce wait times.



2. Four Way Intersection



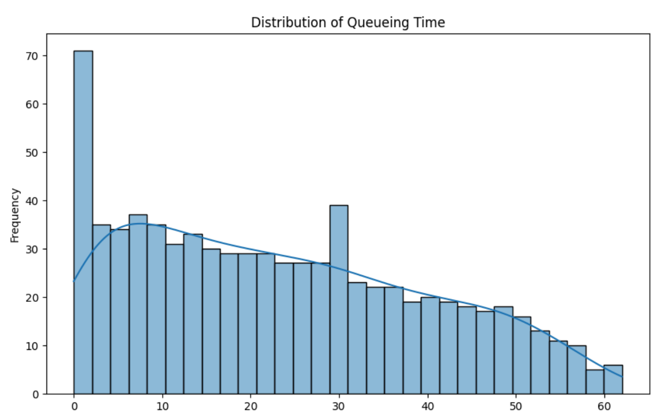
According to the collected data from the simulation, the following results were obtained for the four way intersection method

Distribution of Queuing time

Data	TimeStep	Queuing_Time	Queuing_length	Queuing_length_exp
count	752.000000	752.000000	752.000000	752.000000
mean	76.489362	23.406915	26.155957	28.908896
std_dev	31.216778	16.475357	16.862113	16.814973
min	17.000000	0.000000	0.000000	5.140000
25%	50.000000	9.000000	13.500000	13.500000
50%	78.000000	21.000000	28.500000	28.500000
75%	103.000000	36.000000	36.012500	43.510000
max	128.000000	62.000000	66.060000	66.350000

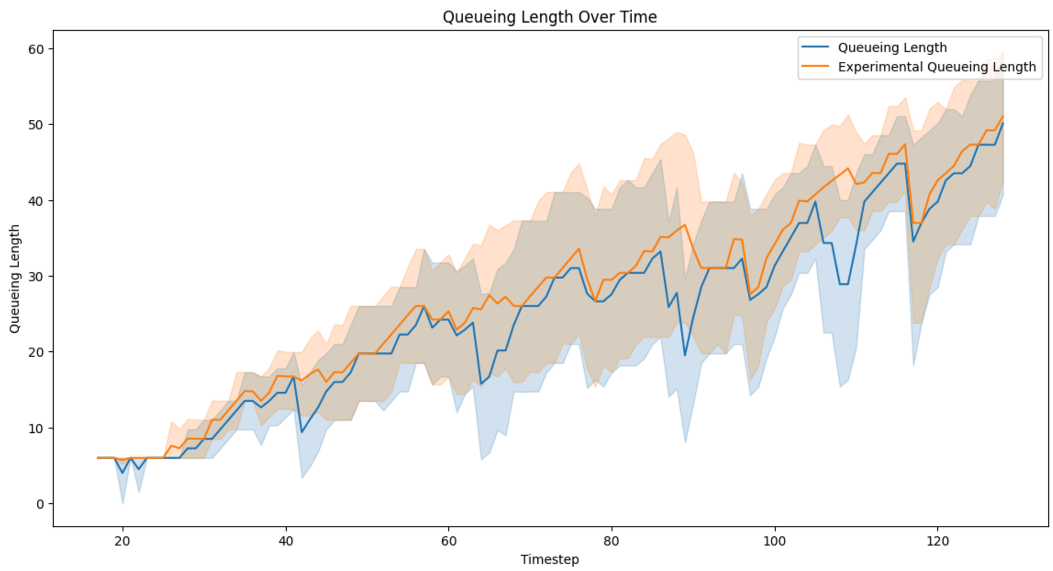
Queuing Time:

- The duration a vehicle waits at an intersection before moving.
- Reflects traffic congestion and signal timing efficiency.
- Longer queuing times often indicate traffic delays, inefficient signal phases, or high vehicle flow.
- Average queuing time in the dataset is 23.41 seconds, with a range from 0 to 62 seconds.
- Reducing queuing time helps in improving traffic flow and minimizing delays.



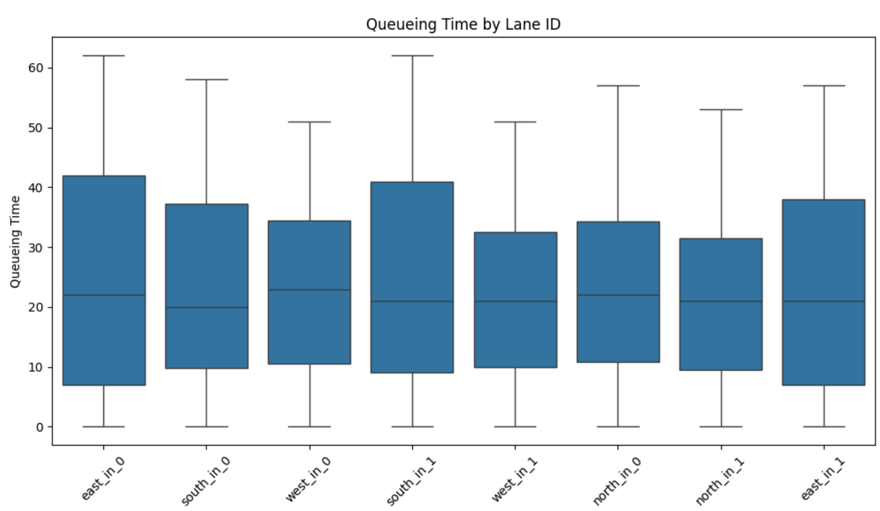
Queuing length over time

- It represents the number of vehicles waiting at an intersection during each timestep. It fluctuates based on traffic flow, signal phases, and congestion. Tracking this helps assess signal effectiveness and overall traffic management



Queuing time by Lane ID

- It refers to the amount of time vehicles spend waiting in each specific lane at an intersection. It helps identify which lanes experience more congestion and delays. Analyzing this data can guide optimizations for lane usage and signal timing to improve traffic flow.

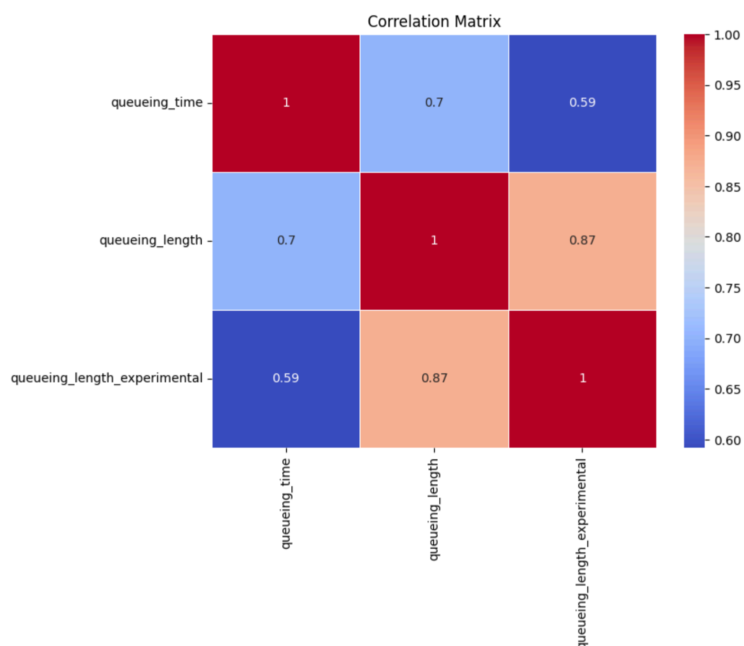


Correlation Matrix

The correlation matrix shows the relationship between multiple variables. In this case, it compares the correlation between

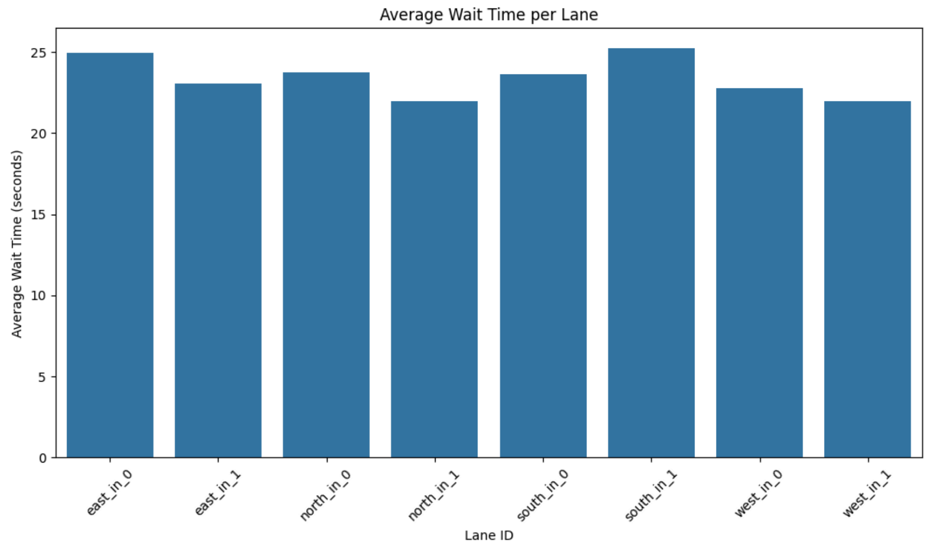
- queueing time
- queueing length
- experimental queueing length

A value closer to 1 indicates a strong positive correlation, while values near -1 show a negative correlation. This helps identify how these metrics are related and can guide traffic signal optimizations.



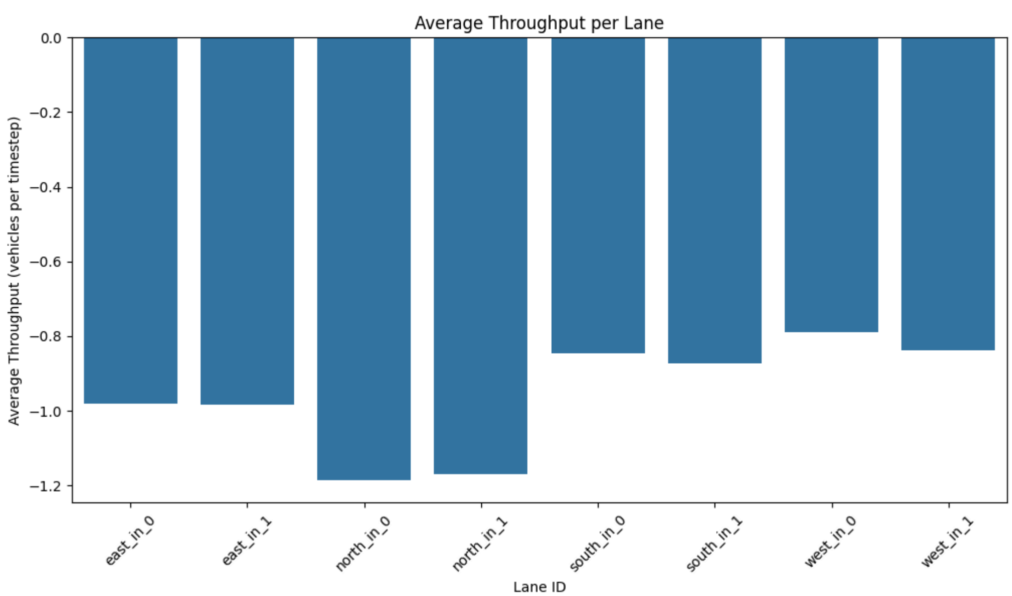
Average wait time per lane

- It refers to the mean amount of time vehicles spend waiting at a red light in each lane at an intersection. This metric helps identify congestion hotspots, showing which lanes experience longer delays. By analyzing wait times per lane, traffic management strategies can be tailored to improve flow and reduce delays at specific approaches.



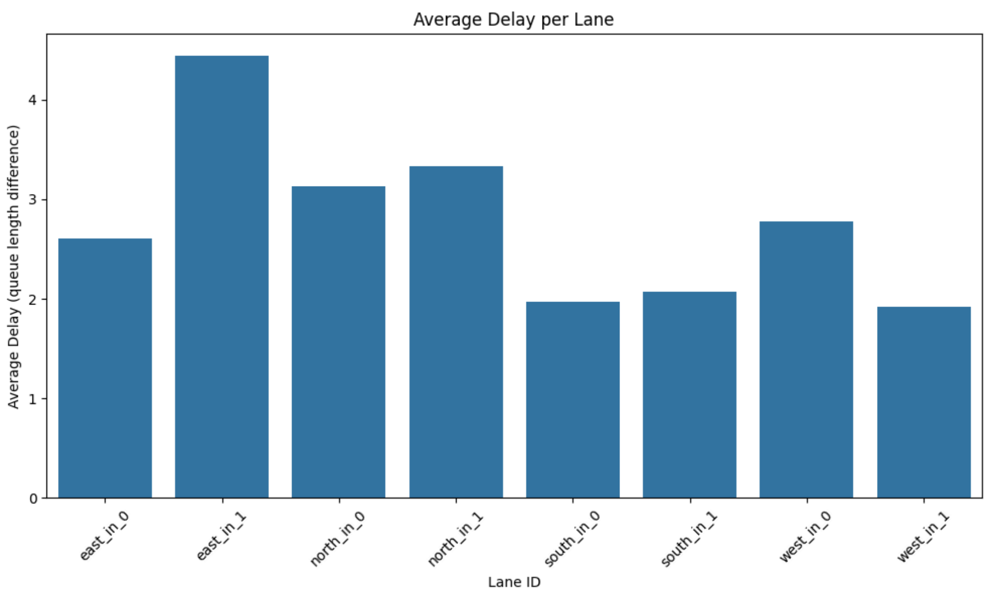
Average throughput per lane

- It refers to the average number of vehicles passing through a specific lane of an intersection during a given time period. It is a key indicator of how efficiently each lane is processing traffic. By analyzing throughput, traffic planners can assess the effectiveness of signal timings and lane usage, identifying opportunities to optimize traffic flow and reduce congestion.



Average delay per lane

- It measures the average time vehicles are delayed at an intersection in each lane, typically due to traffic signals or congestion. It reflects the difference between the time vehicles would take to travel without delays and the actual time spent waiting. This metric helps identify lanes with excessive delays, guiding adjustments in signal timings or lane management to improve traffic flow and reduce wait times.



Conclusion

Therefore, 4 Phase Signals are more efficient which can be as illustrated by the following parameters.

Parameter	2 Phase	4 Phase
Mean of Average Wait Time Per Lane	25 min	15 min
Mean of Average Throughput Lane	-0.8	-1.0
Mean of Average Delay Per Lane	3.5 min	2.7 min

References

GitHub Link of Sumo Files : https://github.com/professorx3x/traffic_sumo_project

Analysis of 2 Phase Diagram:

https://colab.research.google.com/drive/1jTDMeR5cPh2vUvHo4ft67Gbn8YOSv7iC#scrollTo=jwQwRQrdRP6n

Analysis of 4 Phase Diagram:

https://colab.research.google.com/drive/1KcJnlM4pYkvBXd-I3s_AB7pjipwCE42t

THANK YOU!