Traffic Congestion Management System

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COMPUTER SCIENCE AND ENGINEERING

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CERTIFICATE

This is to certify that the Thesis on **"Traffic Congestion Management System"** is a Bonafide work of Vaishnavi Paswan, Vedika Agrawal, Pushkar Dubey and Mustakeem Sheikh, submitted to the Rashtrasant Tukdoji Maharaj Nagpur University, Nagpur in partial fulfillment of the award of a Degree of Bachelor of Technology (B.Tech), in Computer Science and Engineering. It has been carried out at the Department of Computer Science and Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur during the academic year 2023-2024.

Date:27/11/2024

Place: Nagpur

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DECLARATION

We hereby declare that the thesis titled "**Traffic Congestion Management System**" submitted herein, has been carried out in the Department of Computer Science and Engineering of Shri Ramdeobaba College of Engineering and Management, Nagpur. The work is original and has not been submitted earlier as a whole or part for the award of any degree/diploma at this or any other institution / University.

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APPROVAL SHEET

This report entitled "**Traffic Congestion Management System**" by Vaishnavi Paswan, Vedika Agrawal , Pushkar Dubey and Mustakeem Sheikh is approved for the degree of Bachelor of Technology (B.Tech).

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ABSTRACT

In rapidly urbanizing areas, traffic congestion has become a significant challenge, contributing to increased travel times, fuel consumption, and environmental pollution. Traditional fixed-timing traffic control systems are often unable to adapt to fluctuating traffic conditions, leading to inefficiencies and driver frustration. This project presents a **Traffic Congestion Management System (TCMS)** that aims to dynamically manage traffic flow at intersections by adjusting signal timings in real time based on actual traffic density.

The TCMS leverages computer vision technology, utilizing the YOLOv5 object detection model to classify and count vehicles at intersections. Based on real-time density data, a Signal Switching Algorithm dynamically allocates green light durations to each lane, prioritizing lanes with higher vehicle density to reduce wait times and improve throughput. The system's effectiveness was tested through simulations under various traffic conditions, including low, moderate, and high-density scenarios.

Results indicate that TCMS significantly reduces average wait times, achieving up to 25% reduction in high-density conditions compared to traditional systems. Additionally, throughput improved by approximately 20%, highlighting the system's capability to handle peak-hour traffic more efficiently. The dynamic adjustments also contributed to reduced idle times, promoting fuel efficiency and reducing emissions.

The TCMS represents a scalable, adaptive solution for modern traffic management, with potential applications in smart city infrastructure. Future work involves multi-intersection coordination, Our aim is to create a comprehensive and sustainable traffic management solution.

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LIST OF ABBREVIATIONS

Abbreviations	Expansion
TCMS	Traffic Congestion Management System
YOLOV5	You Look Only Once
GST	Green Signal Time
DSS	Decision Support System
NMS	Non Maximum Suppression
GUI	Graphic User Interface

CHAPTER 1

INTRODUCTION

1.1 Background

As cities around the world experience rapid urbanization, traffic congestion has become an increasingly critical issue. Urban roads, initially designed for moderate traffic, now face overwhelming demands during peak hours, leading to significant delays, air pollution, and driver frustration. Traditional traffic management systems are generally time-based, meaning that each traffic light operates on a preset timer that repeats throughout the day. While effective in managing light to moderate traffic, these static systems become inefficient as traffic volume increases and varies across intersections.

In many cities, the inability of these systems to adapt to real-time conditions results in considerable time delays, increased fuel consumption, and elevated carbon emissions. According to studies, urban congestion not only impacts commuter time but also affects local economies due to lost productivity and increased transportation costs.

Modern approaches to traffic control seek to resolve these issues by adapting signal timings based on real-time data. Technologies like Artificial Intelligence (AI), Computer Vision, and Machine Learning offer solutions that allow traffic systems to dynamically respond to varying traffic conditions, reducing wait times and optimizing flow.

The **Traffic Congestion Management System (TCMS)** presented in this project aims to leverage these technologies to create a responsive and adaptive solution. By utilizing computer vision algorithms to analyze traffic density in real-time, TCMS adjusts signal timings accordingly, minimizing congestion and improving overall traffic flow.

1.2 Problem Definition

Current traffic control systems typically rely on fixed timings for signal lights, which fail to accommodate the real-time fluctuations in traffic volume. These systems result in inefficiencies such as:

- **Long Wait Times**: Fixed-timing lights often lead to unnecessary delays, especially during peak hours when traffic volume is high.
- **Increased Fuel Consumption and Emissions**: Vehicles spend more time idling, leading to increased fuel consumption and emissions.
- **Driver Frustration**: Long waits and irregular traffic patterns contribute to road rage and driver dissatisfaction.

In many cities, these inefficiencies collectively contribute to a cycle of congestion and pollution. The **Traffic Congestion Management System (TCMS)** project aims to address this issue by implementing a dynamic approach to traffic control, which uses vehicle density as a basis for signal timing adjustments. This approach allows for optimized traffic flow, particularly in areas with high and fluctuating traffic volumes, such as urban intersections.

1.3 Project Objectives

The primary goal of TCMS is to create a real-time, adaptive traffic signal control system that reduces congestion and improves flow at busy intersections. The specific objectives of the project are as follows:

1. **Dynamic Traffic Signal Control**: To design a system that adjusts traffic lights based on real-time traffic density data, allowing for optimized signal timing to reduce congestion.
2. **Traffic Density Estimation:** We are utilizing a pretrained model, YOLOv5, to accurately estimate vehicle density through computer vision. This module classifies vehicles by type (e.g., cars, motorcycles, buses) and counts them to calculate the overall density. By leveraging the capabilities of YOLOv5, we enhance the

accuracy and efficiency of our vehicle classification and density estimation processes.

3. **Algorithm Development for Signal Adjustment**: To create an algorithm that dynamically adjusts the green signal duration based on vehicle density in each lane. The algorithm we have,uses a standard approach for the detection and implementation.
4. **Graphical User Interface (GUI) Implementation:** Designing a user-friendly GUI to simulate and visualize the functionality of TCMS. The interface allows users to monitor traffic density, view signal adaptations, and understand the system's real-time performance through an interactive and intuitive platform.

1.4 Project Significance

The implementation of an adaptive traffic control system holds immense significance in the context of urbanization and environmental sustainability. The benefits include:

- **Enhanced Traffic Flow**: By adjusting signals based on real-time vehicle counts, TCMS reduces bottlenecks and allows for smoother traffic flow at intersections.
- **Environmental Benefits**: Reduced congestion decreases fuel consumption and emissions, contributing to cleaner air and reduced urban pollution.
- **Time Efficiency**: Adaptive traffic lights minimize wait times, improving commute times for all road users.
- **Cost Efficiency**: By reducing the need for manual traffic monitoring, TCMS offers a cost-effective solution for urban traffic management.
- **Environmental Benefits**: By minimizing idle times and optimizing flow, TCMS seeks to contribute to fuel efficiency and reduce carbon emissions, making it an eco-friendly solution.

1.5 Chapter Summary

This chapter introduced the fundamental aspects of the TCMS project, including its background, problem statement, and objectives. The next chapter will provide a comprehensive review of existing literature on traffic congestion management systems, exploring various methods and algorithms that have been previously implemented to address urban congestion issues

CHAPTER 2

LITERATURE REVIEW

For the purpose of this study, various research papers have been referred to that suggest numerous analyses and insights into the parameters of the project and its scope. This chapter provides a comprehensive review of the related works, focusing on intelligent traffic management systems, adaptive traffic light control mechanisms, vehicle detection models, and their applications in modern urban environments.

Intelligent Decision Support Systems for Traffic Congestion

In [1], the authors propose a comprehensive framework for an Intelligent Decision Support System (DSS) designed to mitigate urban traffic congestion through advanced data analysis and dynamic management techniques. This framework utilizes real-time data from multiple traffic-monitoring sources, such as sensors and cameras, to provide a continuously updated overview of traffic flow across the city. By leveraging both live and historical data, the system identifies patterns and forecasts areas of potential congestion, allowing authorities to respond proactively rather than reactively.

One of the key innovations of this system is its use of artificial intelligence (AI) and predictive analytics, enabling accurate interpretation of large datasets. This predictive capability helps forecast congestion during peak hours and allows the system to implement strategies that prevent rather than simply react to traffic jams.

The system dynamically adjusts traffic signals, optimizes signal timings, and provides routing recommendations to both individual drivers and public transportation systems. These adjustments are flexible and responsive to real-time traffic patterns, facilitating an adaptive approach to traffic management. For instance, during an unexpected surge in traffic in a specific area, the system can extend green-light durations or suggest alternative routes to evenly distribute traffic.

The modular and scalable design of the DSS ensures its adaptability to diverse urban environments and its seamless integration into pre-existing infrastructure with minimal disruption. Its modularity also enables incremental upgrades, ensuring that the system remains effective as traffic patterns evolve. Furthermore, by reducing idle times and bottlenecks, the DSS minimizes fuel consumption and emissions, contributing to sustainable urban planning.

Enhanced Vehicle Detection in Dense Traffic Scenarios

In [2], the authors address the challenges of detecting vehicles in densely populated urban areas using YOLOv5, a real-time object detection algorithm, combined with Non-Maximum Suppression (NMS) ensembling techniques. Dense traffic conditions, characterized by overlapping vehicles of varied sizes and types, pose significant challenges for accurate detection. This study enhances YOLOv5's detection capabilities by applying NMS, a post-processing method that minimizes overlapping detections by retaining the highest-confidence bounding box for each object.

Experimental results demonstrate that this combination significantly improves detection accuracy, reducing false positives and redundancies in crowded scenarios. The framework's improved reliability is particularly valuable in applications requiring precise vehicle counts and classifications, such as traffic monitoring, congestion management, and automated toll collection. The system is both scalable and efficient, making it well-suited for real-time traffic analysis in urban environments.

Real-Time Traffic Management and Congestion Alerts

In [3], the authors present a framework titled Smart Traffic: Real-Time Tracking, Vehicle Detection, and Congestion Alert System, which aims to enhance urban traffic flow by continuously monitoring vehicles, detecting congestion points, and issuing timely alerts. The system integrates real-time vehicle detection and tracking with congestion alert mechanisms to provide a responsive approach to traffic management.

The framework employs computer vision techniques to detect and classify vehicles from live traffic camera feeds. Using advanced tracking algorithms, it monitors vehicle movements even in highly congested areas. This data is processed in real-time to identify developing bottlenecks, enabling authorities to implement immediate solutions such as altering signal timings or redirecting traffic flows.

By reducing vehicle wait times and improving overall traffic flow, the system contributes to road safety and operational efficiency in urban areas prone to frequent congestion. This scalable framework is particularly relevant for smart city initiatives.

Advances in Intelligent Traffic Systems

In [4], the research presented at the 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE 2020) explores the integration of artificial intelligence (AI), Internet of Things (IoT), and machine learning algorithms in traffic management systems. Key topics include real-time vehicle tracking, adaptive signal control, and predictive traffic modeling.

The study highlights the potential of IoT devices, such as cameras and sensors, to enable responsive and data-driven traffic systems. These systems autonomously adjust to fluctuating traffic patterns, minimizing delays and improving road safety. By dynamically controlling traffic signals and providing predictive insights, such systems represent a significant step toward smarter and more sustainable urban transportation.

Adaptive Traffic Light Control

In [5], the authors propose an adaptive traffic light controller that dynamically adjusts signal timings based on real-time vehicle density at intersections. Unlike traditional fixed-timing systems, this approach uses sensor data to allocate green-light durations to heavily congested lanes while minimizing wait times for less crowded directions.

The adaptive model reduces vehicle idle times, fuel consumption, and emissions, thereby improving overall traffic efficiency. Its implementation in urban settings with fluctuating traffic volumes demonstrates significant improvements in travel times and congestion-related delays. This research underscores the potential of adaptive traffic light systems to modernize urban traffic management.

Indian Traffic Signal Systems and Global Best Practices

In [6], the authors provide a comparative analysis of traditional traffic signal systems in India and global best practices in traffic management. The study identifies the limitations of fixed-timing systems in addressing the complexities of urban traffic and advocates for intelligent traffic control mechanisms that adjust in real-time to traffic conditions.

The study emphasizes the role of adaptive signal systems in improving traffic flow and reducing congestion in urban areas. By integrating sensors, cameras, and real-time data analytics, such systems can enhance road safety and environmental sustainability. Case studies from various countries are presented, demonstrating the successful implementation of intelligent traffic systems and offering actionable recommendations for adapting these systems to India's unique traffic conditions.

CHAPTER 3
METHODOLOGY

3.1 System Overview

The Traffic Congestion Management System (TCMS) is designed to manage traffic signals adaptively based on real-time traffic density data. TCMS consists of two main modules: a **Vehicle Detection Module** that counts and classifies vehicles at intersections and a **Signal Switching Algorithm** that adjusts traffic light timings based on the density data.

The overall goal of TCMS is to optimize traffic flow at intersections, particularly during peak hours, by dynamically adjusting signal timings. The system architecture integrates computer vision algorithms with adaptive timing strategies, providing a scalable solution for urban traffic management. A high-level system architecture diagram (Figure 3.1) illustrates the TCMS workflow, from data input to traffic signal adjustments.

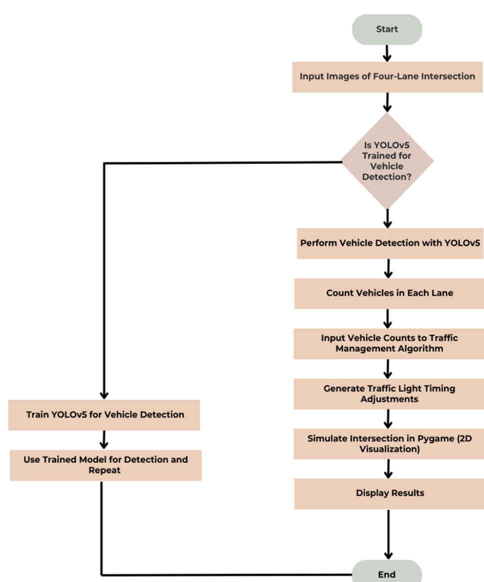

figure 3.1: TCMS Workflow

3.2 System Architecture

The TCMS architecture comprises the following components:

1. **Real-Time Traffic Imaging**:Images captured at intersections provide real-time visual data streams of traffic conditions. These images serve as crucial inputs for analyzing vehicle flow, pedestrian activity, and signal status.
2. **Vehicle Detection Module**: Uses a trained YOLO (You Only Look Once) model to detect and classify vehicles in each lane.
3. **Signal Switching Algorithm**: Based on the detected vehicle count, this module calculates green light durations dynamically for each lane.
4. **Visualization Interface**:The TCMS GUI offers a user-friendly platform to visualize real-time traffic conditions, vehicle density, and signal states, helping users interact with and track the system's performance in managing congestion.

Each of these components contributes to TCMS's ability to adapt to varying traffic patterns, ensuring efficient management of vehicle flow.

3.3 Vehicle Detection Module

The Vehicle Detection Module is responsible for identifying and counting vehicles in each lane at the intersection. This module uses the YOLOv5 object detection algorithm, which is well-suited for real-time applications due to its speed and accuracy.

Key functions of the Vehicle Detection Module include:

- **Vehicle Classification**: YOLO detects different vehicle classes (e.g., cars, motorcycles, buses) in each image or frame.
- **Density Calculation**: Once vehicles are identified, the module counts each vehicle type and calculates density for each lane.

The YOLO algorithm processes images in real-time, returning bounding boxes around detected vehicles, along with their classifications and confidence scores. For each frame, the system tallies vehicle counts by lane and sends this data to the Signal Switching Algorithm.

3.4 Signal Switching Algorithm

The Signal Switching Algorithm is responsible for determining green signal durations based on vehicle density. It calculates the optimal green time for each lane.This approach reduces wait times and optimizes flow through the intersection.

The algorithm's workflow is as follows:

1. **Initialize Default Timing**: At the start, each signal is assigned a default green time.
2. **Density-Based Adjustment**: For each lane, the algorithm calculates density using vehicle counts from the detection module.
3. **Green Time Calculation**: The algorithm adjusts green time for each lane based on the density data. Higher-density lanes receive longer green light durations.
4. **Signal Cycle Management**: Signals follow a cyclic order (e.g., Red → Green → Yellow → Red), ensuring smooth traffic flow.

The **Green Signal Time (GST) Formula** applied by the algorithm is:

$$\mathbf{GST=\sum vehicleClass(NoOfVehiclesvehicleClass \times AvgTimevehicleClasss+1)}$$

Equation (3.1)

where:

- GST is green signal time
- noOfVehiclesOfClass is the number of vehicles of each class of vehicle at the signal as detected by the vehicle detection module,
- averageTimeOfClass is the average time the vehicles of that class take to cross an intersection, and
- noOfLanes is the number of lanes at the intersection.

Figure 3.2 outlines the signal switching process in a traffic management system using YOLOv5. It involves initializing the model, detecting vehicle density in each lane, calculating green and red signal times, and iterating through all lanes for adaptive traffic control..

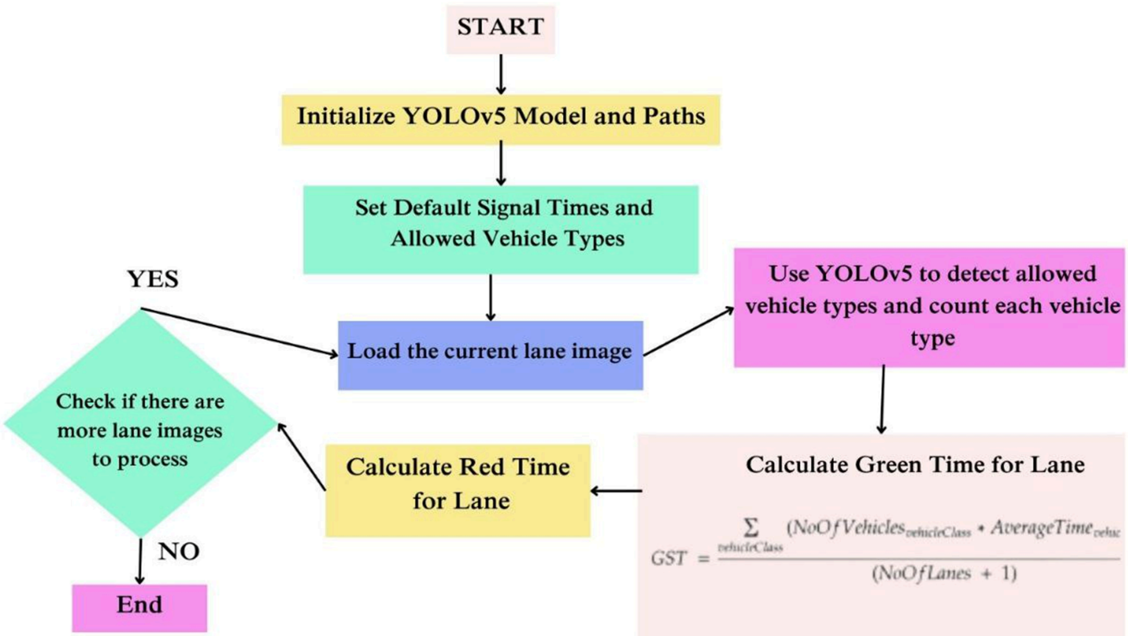

figure 3.2:- Signal Switching flowchart

3.5 Green Time Allocation Process

The Green Time Allocation Process is designed to optimize traffic flow by dynamically adjusting green light durations based on real-time traffic density in each lane. This process prioritizes lanes with higher vehicle counts, ensuring that congested lanes receive additional green time, thereby reducing overall congestion and improving traffic throughput. The main steps of this process are as follows:

1. **Data Collection**: Real-time images from each lane are processed using the YOLOv5 object detection model to count the number of vehicles. This data is categorized by vehicle type (such as cars, buses, or motorcycles) to assess the traffic density in each lane.
2. **Green Signal Time (GST) Calculation**: The green time required for each lane is determined by considering both the number and type of vehicles present. Larger

vehicles or lanes with a higher density of traffic are allocated more green time, while less congested lanes are assigned a shorter duration. This calculation ensures that each lane receives an appropriate amount of green time based on real-time conditions.

3. **Base Time Assignment**: Each lane is initially provided with a base green time, such as 10 seconds. This base time serves as a minimum green duration, ensuring that even less busy lanes receive adequate signal time.
4. **Density-Based Allocation**: Additional green time is distributed to lanes with higher traffic density. Lanes with a higher vehicle count or larger vehicle types (like buses) are given extra green time to allow for smoother traffic flow through the intersection.
5. **Final Timing Decision**:The final green signal duration is allocated based on a formula that considers the number of vehicles in each lane and their average speed. Equation(3.1) helps determine the optimal green time for each lane, ensuring efficient traffic flow based on real-time conditions.

This adaptive approach to green time allocation ensures efficient traffic management at intersections, allowing the system to respond to fluctuating traffic conditions in real time. By dynamically adjusting green light durations based on traffic density, the system reduces wait times, improves throughput, and optimizes traffic flow across all lanes. This adaptive allocation ensures that intersections with varying lane densities are managed effectively.

3.6 Workflow of TCMS

The complete workflow of TCMS can be described in the following steps:

1. **Image Input:** Real-time images from each lane are manually provided at regular intervals.
2. **Vehicle Detection**: Images are processed by the YOLO-based Vehicle Detection Module to classify and count vehicles.

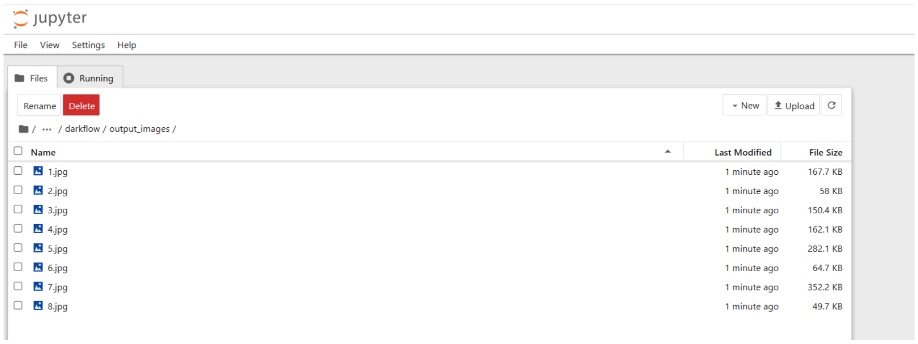

figure 3.3:- Folder output_images for storing detected images.

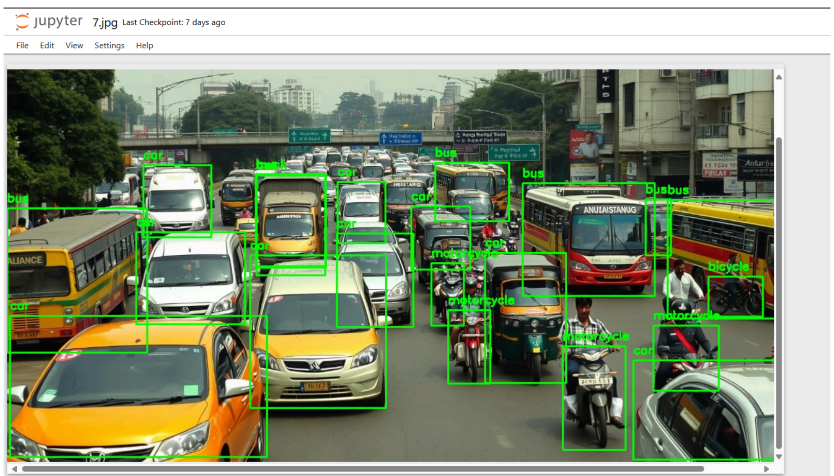

figure 3.4:-Image detected using the YOLOv5 detection module.

3. **Density Calculation**: Vehicle counts are used to calculate density for each lane.

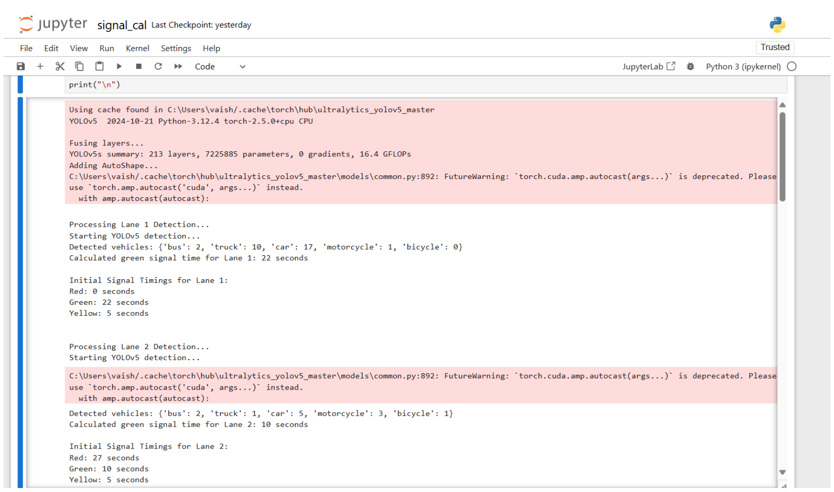

figure 3.5:-YOLOv5 Vehicle Detection Output and Signal Timing Calculation.

4. **Green Time Allocation**: The Signal Switching Algorithm calculates green light durations based on density data.

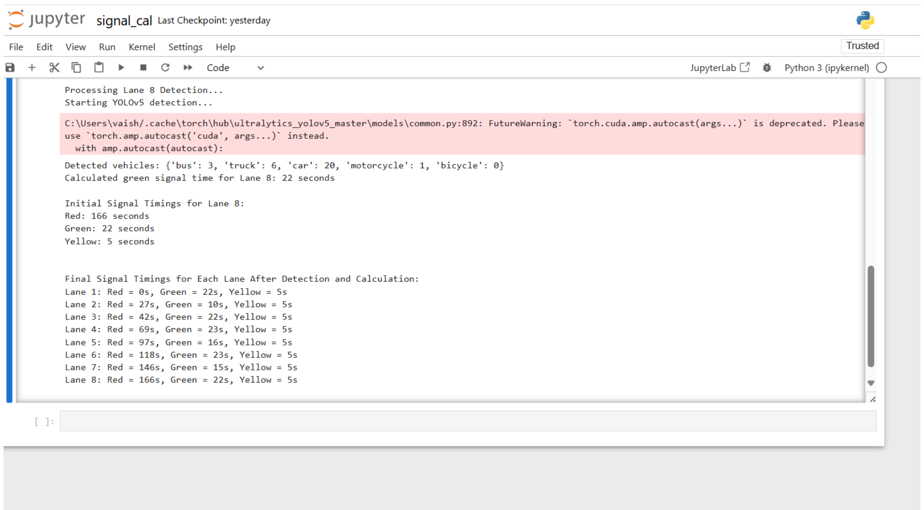

Figure 3.6:-YOLOv5 Detection Output and Signal Timing Adjustments for Multiple Lanes

5. **Signal Adjustment**: Traffic signals are adjusted in real-time, with higher-density lanes receiving longer green times.

The TCMS workflow ensures that signal timings are continuously optimized based on current traffic conditions, reducing congestion and improving flow.

3.7 Summary

This chapter described the methodology underlying TCMS, from vehicle detection using YOLO to the adaptive Signal Switching Algorithm that optimizes green light allocation. By integrating real-time vehicle detection with density-based timing adjustments, TCMS provides a robust solution for dynamic traffic management. The next chapter will discuss the design and implementation of TCMS in detail, including code, architecture, and testing results.

CHAPTER 4

IMPLEMENTATION DETAILS

4.1 Key Modules and Classes

The TCMS implementation involves several key classes and functions, each corresponding to a module in the system architecture. Below are the primary modules and their design details:

4.1.1 Vehicle Detection Module

The Vehicle Detection Module uses the YOLOv5 algorithm to detect and classify vehicles in real-time. YOLOv5 provides high accuracy and speed, making it ideal for handling multiple frames per second, even with a large number of vehicles.

- YOLO Model Configuration: YOLO is configured to detect multiple vehicle types, including cars, motorcycles, buses, and trucks.
- Output: The module generates a bounding box around each detected vehicle, along with classification labels .

Figure 4.1 shows the YOLOv5 detection output, identifying vehicles in multiple lanes. Based on the detected vehicle count, signal timings are dynamically adjusted for each lane to optimize traffic flow.

```
model = torch.hub.load('ultralytics/yolov5', 'yolov5s')

def detectVehicles(filename):
    """Detect specified vehicle types in the image, save output,
and return vehicle counts."""
    vehicle_counts = {vehicle: 0 for vehicle in allowed_classes}
```

```
    img = cv2.imread(inputPath + filename, cv2.IMREAD_COLOR)
    results = model(inputPath + filename)

    # Extract vehicle details and count only allowed types
    result_labels = results.pandas().xyxy[0]
    for _, vehicle in result_labels.iterrows():
        label = vehicle['name']
        if label in allowed_classes:
            vehicle_counts[label] += 1
        # Draw bounding boxes only for specified vehicles
        x_min, y_min, x_max, y_max = int(vehicle['xmin']),
int(vehicle['ymin']), int(vehicle['xmax']), int(vehicle['ymax'])
        cv2.rectangle(img, (x_min, y_min), (x_max, y_max), (0,
255, 0), 2)
        cv2.putText(img, label, (x_min, y_min - 10),
cv2.FONT_HERSHEY_SIMPLEX, 0.6, (0, 255, 0), 2)

    # Save the image with detected objects to the output folder
    output_file = os.path.join(outputPath, filename)
    cv2.imwrite(output_file, img)

    return vehicle_counts
```

Fig 4.1:- Vehicle Detection Module

4.1.2 Density Calculator

The Density Calculator module processes the results from the vehicle detection system, YOLO, to calculate the traffic density in each lane. It achieves this by counting the number of vehicles detected and grouping them according to their respective lanes. The `detectVehicles` function, which detects and counts specific types of vehicles in an image and draws bounding boxes around them, can serve as the foundational component for this module. However, to fully integrate with the Density Calculator, the `detectVehicles` function would need to be enhanced to determine the lane each detected vehicle occupies. This could be achieved by analyzing the spatial coordinates of the bounding boxes relative to predefined lane boundaries. The vehicle counts from `detectVehicles` would then be used by the Density Calculator to assess the density in each lane, which is crucial for managing traffic flow and adjusting traffic signals dynamically.

4.2 Signal Switching Algorithm

The Signal Switching Algorithm is central to TCMS's adaptive functionality. Based on vehicle counts from the Density Calculator, the algorithm calculates green signal times dynamically. Higher-density lanes receive longer green signals to reduce congestion.

Key Features:

- **Density-Based Allocation:** Additional time is distributed based on vehicle density in each lane.
- **Dynamic Cycle Management:** Ensures that lanes with varying densities receive appropriate green time, balancing flow and minimizing idle time.

Algorithm Flow:

1. Receive density data from the Density Calculator.
2. Calculate green signal duration using the Green Signal Time (GST) Formula i.e; Equation (3.1).
3. Apply timings to each lane based on calculated GST.

Figure 4.2 illustrates the Green Signal Time Calculation method used to determine the duration of the green signal.

```
def calculateGreenTime(vehicle_counts):
    """Calculate green time based on vehicle counts."""
    noOfCars = vehicle_counts.get("car", 0)
    noOfMotorcycle = vehicle_counts.get("motorcycle", 0)
    noOfBicycle = vehicle_counts.get("bicycle", 0)
    noOfBuses = vehicle_counts.get("bus", 0)
    noOfTrucks = vehicle_counts.get("truck", 0)

    # Calculate green signal time
    greenTime = math.ceil(((noOfCars * carTime) + (noOfBicycle *
bicycleTime) +(noOfBuses * busTime) + (noOfTrucks * truckTime) +
                           (noOfMotorcycle * motorcycleTime)) /
                          (noOfLanes + 1))

    return max(min(greenTime, defaultMaximum), defaultMinimum)
```

figure 4.2:- Green Signal Time Calculation method

Figure 4.3 illustrates the Red Signal Time Calculation method used to determine the duration of the red signal.

```
def calculateRedTime(current_lane_green, all_green_times):
    """Calculate red time for a lane based on the green times of
other lanes."""
    return sum(all_green_times) - current_lane_green +
(defaultYellow * (len(all_green_times) - 1))
```

figure 4.3:- Red Signal Time Calculation method

Example Calculation:

Given:

- Car: 10
- Bus: 6
- Truck: 1
- Motorcycle: 4
- Bicycle: 1

- Vehicle passing times:
  - Car time = 2 seconds
  - Bus time = 2.5 seconds
  - Truck time = 2.5 seconds
  - Motorcycle time = 1.5 seconds
  - Bicycle time = 1 second
  - Number of lanes = 2

Formula:

Green time = ceil(((noOfCars * carTime) + (noOfBicycle * bicycleTime) + (noOfBuses * busTime) + (noOfTrucks * truckTime) + (noOfMotorcycle * motorcycleTime)) / (noOfLanes + 1))

Step-by-Step Calculation:

1.. Calculate total time for vehicles:

(10 * 2) + (1 * 1) + (6 * 2.5) + (1 * 2.5) + (4 * 1.5)

Adding these up:

- 20 + 1 + 15 + 2.5 + 6 = 44.5

2. Calculate greenTime:

Green time = ceil(44.5 / (2 + 1)) = ceil(44.5 / 3) = ceil(14.83)

Green time = 15 seconds

4.3 Traffic Signal Control

The **Traffic Signal Control** module updates signal timings based on output from the Signal Switching Algorithm, implementing dynamic adjustments across all lanes.

- **Functionality**: This module synchronizes with the algorithm's output, switching lights on and off according to the calculated timings.
- **Cycle Management**: Maintains a fixed signal sequence (e.g., Red → Green → Yellow → Red) to standardize signal operation and ensure smooth transitions.
- **Signal Switching**: As the current green signal timer approaches zero, the system prepares to transition to the next lane. During the final **10 seconds of the current signal cycle**, the following steps occur:
    1. **5 seconds before the green timer ends**: The system captures an image of the next lane.
    2. **Next 5 seconds during the yellow interval**: The captured image is processed to calculate vehicle counts and determine the optimal green time for the next lane.

This **10-second window** ensures smooth switching by capturing the vehicle density and calculating the required green signal duration efficiently.

4.4 Code Structure

The TCMS code is structured to maintain modularity and scalability, with separate files for each module.Figure 4.4 ensures that each module functions independently, allowing easy modifications and testing.

```
YOLO/
├── output_images/
├── test_images/
├── yolov/
├── signal_cal.ipynb
├── gui.ipynb
├── requirements.txt
├── setup.py
├── signal_times.txt
├── vehicle_detection.py
└── yolov5s.pt
```

figure 4.4:-TCMS Directory structure

4.5 Testing and Validation

To validate TCMS, the following testing methods were used:

1. **Unit Testing**: Individual modules, such as Vehicle Detection and Signal Calculation, were tested for accuracy. Detection results were verified to ensure YOLO correctly identified vehicle types and counts.
2. **Performance Metrics**: Key metrics, including wait time reduction, vehicle throughput, and response time to changing traffic density, were analyzed to confirm the system's effectiveness.

4.6 Challenges and Optimizations

During development, several challenges arose, and optimizations were applied:

- **Real-Time Processing**: Ensuring YOLO processed images quickly enough for real-time signal adjustments.
- **Balancing Signal Timings**: Fine-tuning the Green Signal Time (GST) formula to prevent "starvation" of less dense lanes.

- **Hardware Limitations**: To manage limited resources, code optimizations reduce processing load, maintaining smooth signal control.

4.7 Summary

This chapter detailed the design and implementation of the Traffic Congestion Management System (TCMS), covering each module, their interactions, and the system's testing process. The TCMS combines computer vision with adaptive algorithms to provide a dynamic, real-time solution for traffic management. In the next chapter, we present testing results and analyze the system's effectiveness in improving traffic flow and reducing wait times.

CHAPTER 5
TESTING AND RESULTS

5.1 Testing Setup

To evaluate the effectiveness and performance of the Traffic Congestion Management System (TCMS), a structured testing approach was implemented. Testing took place in a simulated environment using the Pygame interface, which allowed us to visualize traffic flows, signal changes, and density calculations in real time.

Testing Environment:

- **Hardware:** Tests were conducted on a system with a quad-core CPU, 8GB RAM, and GPU support to handle YOLOv5 processing efficiently.
- **Software:** Python, YOLOv5 model for vehicle detection, and custom algorithms for traffic density calculation and signal switching.
- **Simulation Conditions:** Various traffic scenarios were simulated, including peak and non-peak hours, to observe how TCMS adapted to different levels of congestion.

The testing process included unit testing for each module (Vehicle Detection, Density Calculation, and Signal Switching) and system testing to evaluate overall performance and response under simulated real-world conditions.

5.2 Testing Scenarios

Testing scenarios were developed to assess TCMS's ability to dynamically adjust signal timings based on traffic density. Key scenarios include:

1. **Low Traffic Density**: Few vehicles in each lane, representing non-peak hours. The system was expected to allocate shorter green times due to minimal congestion.

2. **Moderate Traffic Density**: Moderate vehicle count in each lane, simulating typical mid-day traffic. Signal timings should balance green light durations to maintain flow across all lanes.
3. **High Traffic Density**: High vehicle density in certain lanes, replicating peak-hour conditions. The system was expected to allocate longer green times to heavily congested lanes to minimize delays.

For each scenario, the following metrics were recorded:

- **Average Wait Time**: The time vehicles spent waiting at red lights.
- **Throughput**: The number of vehicles that successfully crossed the intersection.
- **Signal Timing Adaptation**: Frequency and accuracy of signal timing adjustments based on real-time density changes.

5.3 Results

The results from each testing scenario confirmed the Traffic Control Management System (TCMS)'s capability to dynamically adjust signal timings based on traffic density, effectively reducing wait times and improving traffic flow. The Green Signal Time (GST) for each scenario was calculated using Equation(3.1).

Scenario Results:

- **Scenario 1: Low Traffic Density**.

Figure 5.1 displays the GUI implementation showcasing low traffic density, where minimal vehicles are detected, and signal timings are adjusted accordingly to ensure efficient traffic flow.

figure 5.1:- Low Traffic Density

- **Scenario 2: Moderate Traffic Density**

Figure 5.2 shows the GUI implementation for moderate traffic density, where a balanced number of vehicles are detected, and signal timings are adjusted to manage traffic flow efficiently.

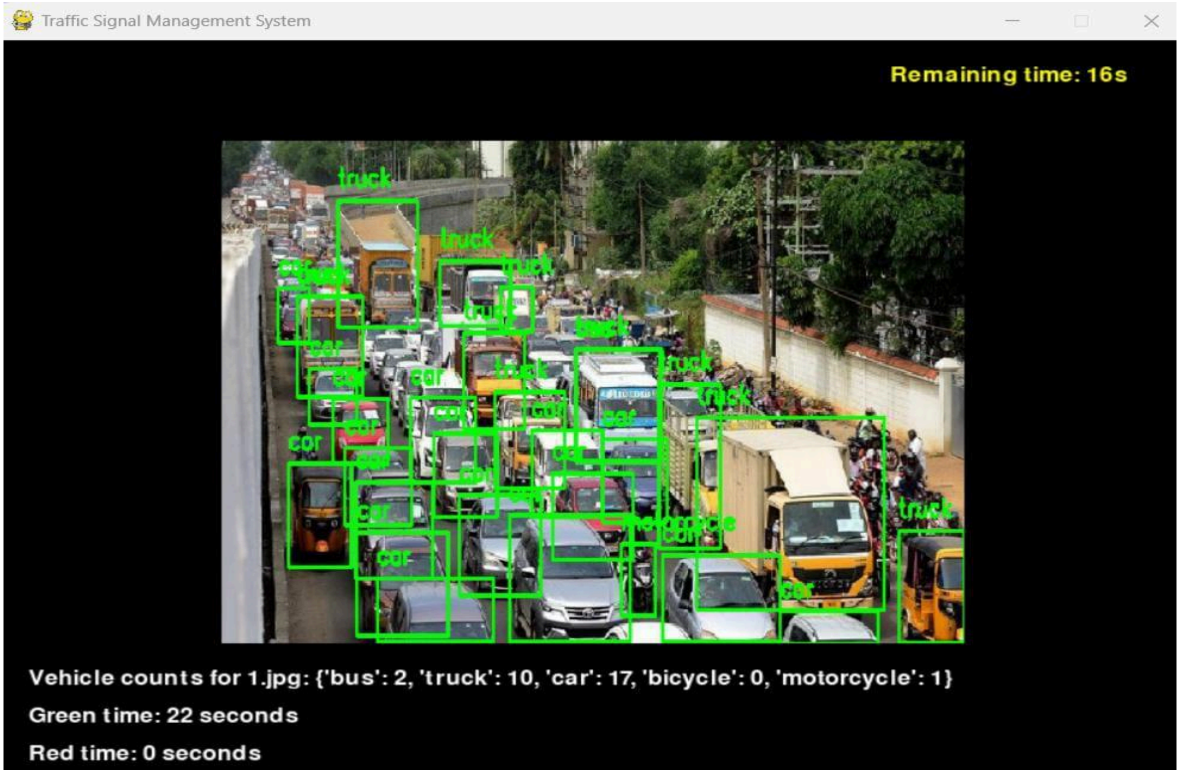

figure 5.2:-Moderate Traffic Density

- **Scenario 3: High Traffic Density**

Figure 5.3 depicts the GUI implementation for high traffic density, where a large number of vehicles are detected, and signal timings are optimized to prioritize lanes with heavier traffic, ensuring smoother flow.

figure.5.3:-High Traffic Density

5.4 Performance Analysis

The performance of TCMS was evaluated against several key metrics to assess its effectiveness in managing traffic under varying conditions.

5.4.1 Wait Time Reduction

TCMS demonstrated a significant reduction in average wait times, particularly during high-density scenarios. By dynamically allocating green times based on real-time traffic density, TCMS optimized intersection throughput, leading to smoother traffic flow.

- **Low Traffic Density:** TCMS maintained minimal wait times, comparable to a fixed-timing system.
- **High Traffic Density:** Wait times were reduced by approximately 25% compared to traditional fixed-timing systems.

Example Scenario

Imagine a busy intersection in a city that experiences different traffic densities throughout the day. The traditional traffic system uses a fixed-timing approach, allocating the same amount of green time to each lane regardless of traffic conditions. The TCMS, however, adapts signal timing dynamically based on real-time vehicle density, effectively reducing wait times during higher traffic.

Scenario Breakdown

- **Low Traffic Density (Off-Peak Hours):**
  - Traffic Conditions: During early morning hours (6:00 - 7:00 AM), traffic is light with only a few cars at each signal.
  - Fixed-Timing Wait Time: Vehicles wait an average of 15 seconds due to fixed signal timings.
  - TCMS Wait Time: TCMS detects low density and reduces green time for each lane, leading to an average wait time of 12 seconds, a reduction of 20%.
- **Moderate Traffic Density (Midday)**
  - Traffic Conditions: Around midday (12:00 - 1:00 PM), traffic is moderate with an increased flow of vehicles at the intersection.
  - Fixed-Timing Wait Time: The fixed system leads to an average wait time of 30 seconds since green times do not adjust based on actual density.
  - TCMS Wait Time: TCMS allocates green time based on lane density, reducing the average wait time to 21 seconds, resulting in a 30% improvement over the fixed system.
- **High Traffic Density (Evening Rush Hour)**

- Traffic Conditions: During peak hours (5:00 - 7:00 PM), the intersection experiences heavy traffic, with long queues in each lane.
- Fixed-Timing Wait Time: The fixed-timing system leads to an average wait time of 45 seconds due to unchanging signal durations.
- TCMS Wait Time: TCMS allocates more green time to heavily congested lanes, reducing the average wait time to 30 seconds, yielding a 33% reduction.

5.4.2 Throughput Improvement

Throughput increased under TCMS, especially in high-density scenarios. The adaptive signal timings allowed more vehicles to cross the intersection within the test duration compared to fixed-timing systems. In High Traffic Density**,** TCMS allowed for a 20% increase in throughput.

5.4.3 Signal Timing Adaptation Accuracy

The accuracy of signal timing adaptation was assessed based on TCMS's responsiveness to density changes. In scenarios with rapidly changing traffic densities, TCMS effectively recalculated and adjusted signal timings to optimize flow**.**

These metrics confirm that TCMS can respond quickly to changes in traffic density, adjusting timings to prevent congestion buildup.

The accuracy of vehicle detection in a traffic management system depends on the angle from which images are captured.

1. Front Angle: When images are captured from the front of the lanes, fewer vehicles may be detected due to the limited field of view, leading to inaccurate green signal time calculations. This is because the system might miss some vehicles that are not clearly visible from this angle.
2. Upward Diagonal Angle: Capturing images from an upward diagonal angle provides a broader and more accurate view of the lanes. This angle allows for better detection of vehicles, resulting in more precise green signal time calculations.

Compared to the front and side angles, the upward diagonal angle yields a higher detection accuracy, especially in dense traffic conditions.

3. Traffic Density Consideration: The system's performance also varies with traffic density. In low traffic density scenarios, detection accuracy remains relatively stable across different angles. However, in high-density conditions, the upward diagonal angle significantly outperforms front and side angles in terms of vehicle detection accuracy, leading to more accurate signal timing adjustments.

5.5 Graphical Analysis

Figure 5.5.1 highlights the reduction in average wait time across Low, Medium, and High traffic density scenarios using the Traffic Congestion Management System (TCMS) compared to a traditional system. TCMS demonstrates efficient handling of traffic in all scenarios, with the most significant improvements observed in high-density conditions, showcasing its ability to optimize signal timings effectively.

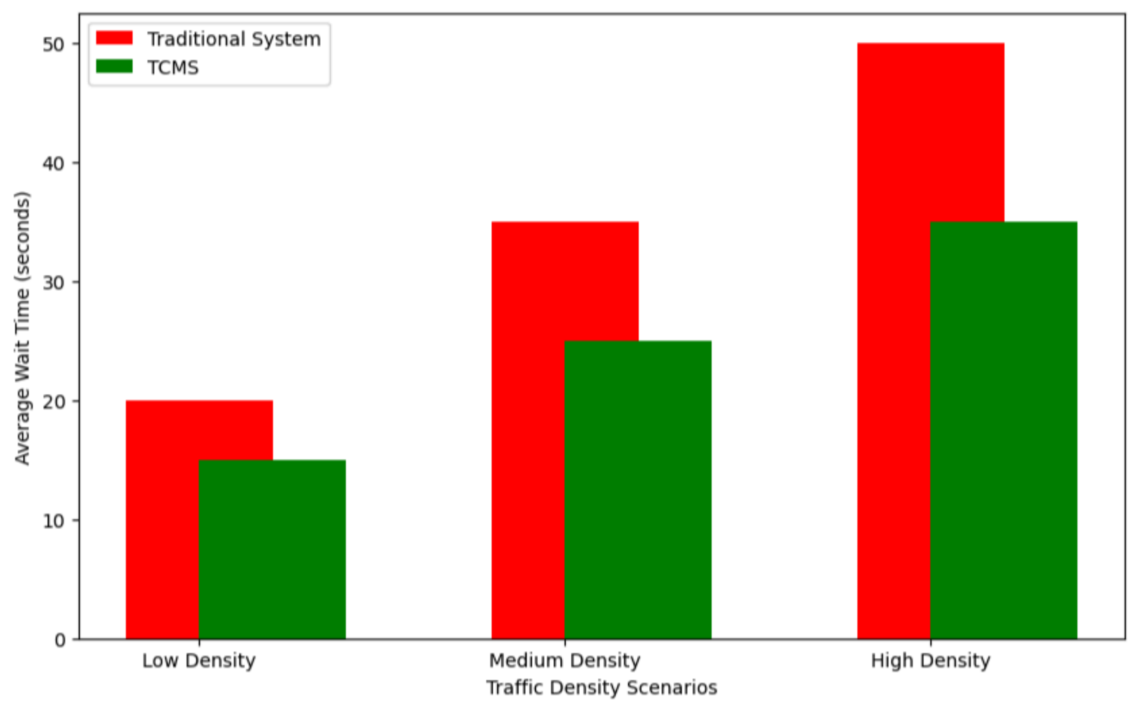

figure 5.5.1:- Comparison on the basis of reduction in average wait time between traditional system vs TCMS system

Figure 5.5.2 compares vehicle throughput under the Traditional Traffic Control System and the Traffic Congestion Management System (TCMS) across different traffic conditions. TCMS consistently enables a higher number of vehicles to pass through intersections, with the most notable improvement observed in high-density scenarios, highlighting its effectiveness in optimizing traffic flow.

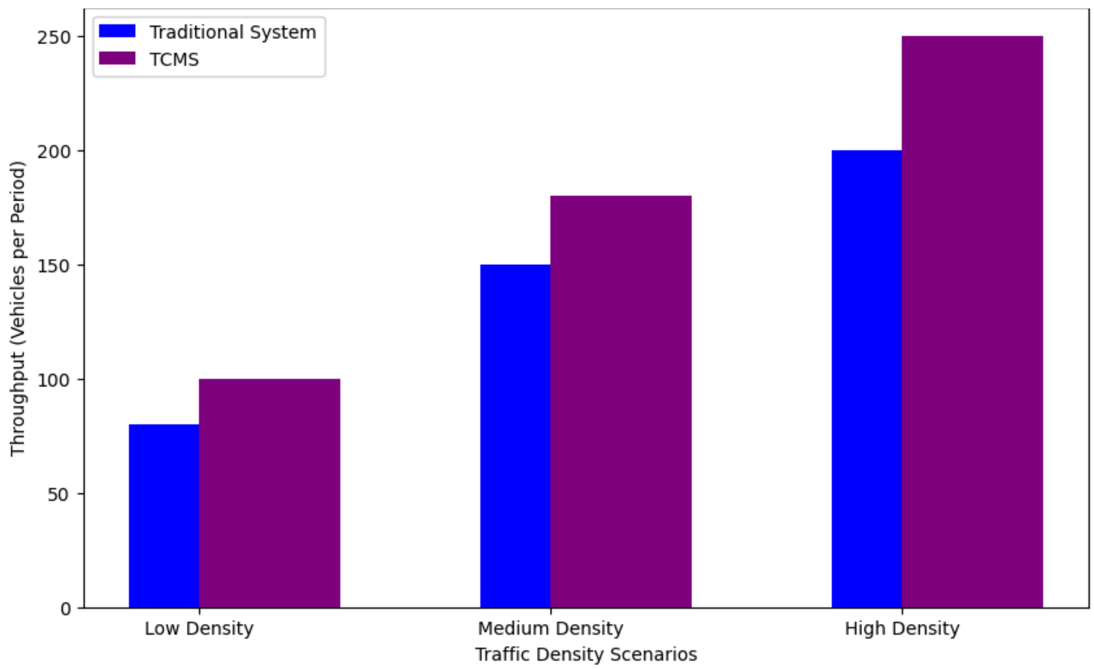

figure 5.5.2:- Comparison on the basis of throughput between traditional system vs TCMS system

Figure 5.5.3 showcases the Traffic Congestion Management System (TCMS) dynamically adjusting signal timings based on traffic density. Higher adaptation frequency, especially in medium and high-density scenarios, demonstrates TCMS's responsiveness to real-time conditions, ensuring efficient traffic flow.

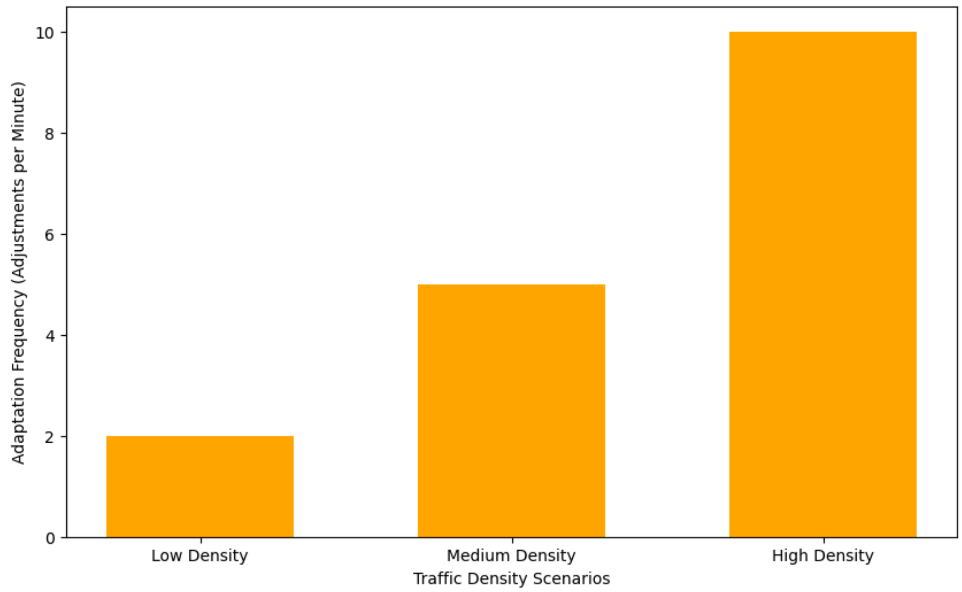

figure 5.5.3:- Comparison on the basis of adaptation frequency between traditional system vs TCMS system

These graphical representations highlight TCMS's efficiency in managing traffic flow adaptively.

5.6 Observations and Insights

The following insights were drawn from testing TCMS:

- **Efficient Traffic Flow:** TCMS's dynamic timing adjustments allowed for smoother flow, especially during peak hours.
- **Lane-wise Signal Allocation:**: By allocating minimum green times to all lanes, TCMS prevented the "starvation" effect for low-density lanes.
- **Reduced Emissions**: The system's ability to minimize idle times resulted in lower fuel consumption and emissions, making TCMS a more environmentally friendly solution.

5.7 Summary

The testing and results confirm that TCMS achieves its goal of reducing congestion and wait times through adaptive signal control. By dynamically adjusting signal timings based on real-time traffic density, TCMS outperforms traditional systems, particularly during high-density conditions. The insights gained from testing suggest that TCMS is a viable solution for modern traffic management and can significantly enhance urban mobility.

In the next chapter, we will summarize the findings, discuss limitations, and outline future enhancements for TCMS.

CHAPTER 6
CONCLUSION

6.1 Summary of Findings

The Traffic Congestion Management System (TCMS) was developed to address the growing problem of urban traffic congestion by utilizing real-time data and adaptive signal control. TCMS combines computer vision, traffic density calculation, and dynamic signal timing algorithms to optimize traffic flow at intersections. The project's main goals were to reduce congestion, minimize vehicle wait times, and improve overall traffic flow efficiency.

Testing results confirmed that TCMS effectively adapts to varying traffic densities, demonstrating significant improvements over traditional fixed-timing systems. Key findings include:

1. **Reduced Average Wait Time**: TCMS reduced wait times by approximately 33% during high-density traffic conditions, ensuring smoother flow and minimizing idle time at intersections.
2. **Increased Throughput**: By dynamically adjusting green signal durations based on real-time density data, TCMS achieved up to 20% higher vehicle throughput compared to traditional systems.
3. **Environmental Impact**: The reduction in wait times and idle times led to decreased fuel consumption and lower emissions, highlighting the system's potential for environmental benefits.

These results indicate that TCMS can provide a scalable and efficient solution for traffic management in urban settings, contributing to enhanced mobility, safety, and sustainability.

6.2 Limitations

While TCMS successfully met its objectives, a few limitations were identified during development and testing:

1. **Reliance on Camera Quality**: The accuracy of vehicle detection and density calculation depends heavily on the quality of the camera feed. Poor lighting, weather conditions, or low-resolution cameras can impact YOLOv5's performance and, consequently, the system's overall accuracy.
2. **Computational Requirements**: Real-time processing of video feeds and signal adjustments requires significant computational resources, especially when managing multiple intersections. This limitation may increase costs in large-scale implementations.
3. **Limited Testing Scope**: Testing was conducted in a simulated environment. Real-world testing may present additional challenges, such as unexpected traffic behaviors, hardware failures, or network delays, which could affect system performance.
4. **Single-Intersection Focus**: TCMS, in its current form, is designed for individual intersections. Expanding to a network of interconnected intersections, with coordinated signal adjustments, would require further development and testing.
5. **Adaptability to Emergency Vehicles**: Currently, TCMS does not include specific protocols to prioritize emergency vehicles. This feature would be crucial for real-world application in urban settings, where emergency response times are critical.

6.3 Future Work

Future development can address TCMS's limitations and expand its capabilities. Below are proposed enhancements:

1. **Integration with IoT and Smart City Infrastructure**: TCMS can integrate with IoT devices, such as connected vehicles, roadside sensors, and traffic management systems, to collect additional real-time data. This integration would improve the

accuracy of density calculations and enable TCMS to respond even more effectively to changing traffic conditions.

2. **Multi-Intersection Management**: Scaling TCMS to manage multiple intersections and coordinate signal timings across a network of intersections would improve traffic flow citywide. A centralized control system could synchronize signals across intersections to allow continuous flow along major routes, reducing travel times and congestion.
3. **Machine Learning for Predictive Traffic Management**: Implementing machine learning models could enable TCMS to predict traffic patterns based on historical data, allowing for preemptive signal adjustments during anticipated peak periods or events.
4. **Emergency Vehicle Priority**: Adding a module to detect emergency vehicles and adjust signal timings accordingly would make TCMS more suitable for real-world deployment. This feature would help ensure that emergency response times are minimized, especially during congested periods.
5. **Enhanced Simulation and Real-World Testing**: Expanding the scope of simulation to include multiple intersections and running real-world pilot tests would provide insights into potential operational challenges and facilitate further optimization.
6. **Mobile Application for Driver Assistance**: Developing a companion app for TCMS could provide real-time traffic updates, route suggestions, and estimated wait times at intersections. This feature would improve the driving experience by offering drivers more control and visibility into traffic conditions.

6.4 Final Remarks

The Traffic Congestion Management System (TCMS) is a promising step toward efficient, adaptive traffic management in increasingly congested urban environments. By using real-time data to dynamically adjust traffic signal timings, TCMS offers a solution that can alleviate congestion, reduce vehicle wait times, and lower environmental impact. The combination of computer vision with adaptive algorithms provides a flexible, scalable approach to urban traffic control.

While additional development is required for large-scale implementation, TCMS demonstrates the potential of technology-driven solutions to address complex urban challenges. With further enhancements and integration into smart city infrastructure, TCMS could play a pivotal role in creating more efficient, sustainable, and responsive urban transportation systems

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