

SIMATS ENGINEERING

SAVEETHA INSTITUTE OF MEDICAL AND TECHNICAL SCIENCES

CHENNAI-602105

JAVA MINI PROJECT

Optimization of Traffic Signal Management Using Smart Technologies

Submitted by

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CSA0982 – PROGRAMMING IN JAVA FOR NETWORKING

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| Table of Contents | page number |
| 1. Introduction | 3 |
| 2. Objectives | 3 |
| 3. Data Collection and Modeling  o Data Structure Definition  o Real-time Data Collection | 3 |
| 4. Algorithm Design  o Traffic Data Analysis  o Signal Timing Optimization  o Considerations and Constraints | 5 |
| 5. Implementation  o System Architecture  o Java Application Development  o Real-time Signal Adjustment | 5 |
| 6. Deliverables  o Data Flow Diagram  o Pseudocode and Implementation  o Documentation  o User Interface Design  o Testing and Validation | 6 |
| 7. Conclusion | 16 |
| 8. References | 16 |

**Abstract**

This project aims to optimize traffic signal management in a busy city to reduce congestion and improve traffic flow efficiency using smart technologies. The initiative involves data collection and modeling, algorithm design, implementation, visualization and reporting, and user interaction. The project delivers a Java application that integrates with traffic sensors, dynamically adjusts signal timings, and provides real-time monitoring and reporting capabilities.

**1. Introduction**

Traffic congestion is a significant problem in urban areas, leading to increased travel times, fuel consumption, and pollution. This project focuses on using smart technologies to optimize traffic signal management, aiming to improve traffic flow and reduce congestion. By leveraging real-time data from traffic sensors and applying dynamic signal control algorithms, we aim to create a more efficient and responsive traffic management system.

**2. Objectives**

The primary objectives of this project are:

**Collect and model real-time traffic data**: Establish a robust data collection framework using traffic sensors to gather vehicle counts, speeds, and other relevant metrics at various intersections.

**Develop algorithms to optimize traffic signal timings**: Create algorithms that analyze the collected data and dynamically adjust signal timings based on current traffic conditions.

**Implement a Java application to control traffic signals**: Develop a Java application that integrates with traffic sensors and adjusts signal timings in real-time.

**Visualize traffic conditions and signal timings**: Develop tools to monitor traffic conditions and signal timings in real-time and generate performance reports.

**3. Data Collection and Modeling**

**Data Structure Definition**

To collect and process real-time traffic data, we defined data structures that efficiently store and retrieve the necessary information. The key data structures include:

**Intersection Data**: Contains details about each intersection, such as location, number of lanes, and signal configurations.

**Sensor Data**: Stores real-time data from traffic sensors, including vehicle counts, speeds, and timestamped readings.

**Traffic Data**: Aggregates sensor data over specified intervals to analyze traffic density, flow rates, and vehicle queues.

**Real-time Data Collection**

Real-time data collection involves deploying traffic sensors at strategic locations across the city. These sensors use technologies such as inductive loop detectors, infrared sensors, and cameras to gather accurate traffic information. Data is transmitted to a central server using protocols like MQTT or HTTP-based REST APIs, where it is processed and stored for analysis.

**Sample data:**

**Intersection Data:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **IntersectionID** | **Latitude** | **Longitude** | **StreetName1** | **StreetName2** |
| 101 | 34,0522 | 1182087 | Main st | 1st Ave |
| 102 | 34.0525 | -118.244 | 2nd Ave | Eim St |
| 103 | 34.0530 | 1182450 | 3rd Ave | PineSt |

**Sensor Data:**

|  |  |  |  |
| --- | --- | --- | --- |
| **SensoriD** | **IntersectionID** | **SensorType** | **SensorLocation** |
| 501 | 101 | VehicleCounter | Northbound |
| 502 | 101 | SpeedRadar | Southbound |
| 503 | 102 | VehicleCounter | Eastbound |
| 504 | 103 | SpeedRadar | Westbound |

**Traffic Data:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **DataID** | **DataID** | **DataID** | **DataID** | **AverageSpeed** | **OccupancyRate** | **LaneInformation** |
| 1001 | 501 | 2024-07-29T08:00:00 | 150 | 35 km/h | 70% | Northbound Lane |
| 1002 | 501 | 2024-07-29T08:01:00 | 160 | 34 km/h | 72% | Northbound Lane |
| 1003 | 502 | 2024-07-29T08:00:00 | 120 | 30 km/h | 65% | Southbound Lane |
| 1004 | 502 | 2024-07-29T08:01:00 | 110 | 32 km/h | 68% | Southbound Lane |
| 1005 | 503 | 2024-07-29T08:00:00 | 200 | 40 km/h | 75% | Eastbound Lane |
| 1006 | 503 | 2024-07-29T08:01:00 | 210 | 42 km/h | 78% | Eastbound Lane |
| 1007 | 504 | 2024-07-29T08:00:00 | 180 | 45 km/h | 80% | Westbound Lane |
| 1008 | 504 | 2024-07-29T08:01:00 | 190 | 47 km/h | 82% | Westbound Lane |

**4. Algorithm Design**

**Traffic Data Analysis**

To optimize traffic signal timings, we developed algorithms that analyze the collected traffic data. Key steps in the analysis include:

• **Traffic Density Calculation**: Determine the number of vehicles per unit area to assess congestion levels.

• **Queue Length Estimation**: Measure the length of vehicle queues at intersections to prioritize signal adjustments.

• **Peak Hour Identification**: Identify peak traffic periods based on historical data to predict future traffic patterns.

**Signal Timing Optimization**

Based on the traffic analysis, we designed algorithms to adjust signal timings dynamically. Key considerations include:

• **Adaptive Cycle Lengths**: Vary the duration of signal cycles based on real-time traffic density.

• **Dynamic Phase Sequencing**: Adjust the order of signal phases to prioritize high-traffic lanes and reduce overall wait times.

• **Pedestrian Crossings**: Incorporate pedestrian signal phases to ensure safety while minimizing impact on vehicle flow.

**5. Implementation**

**System Architecture**

Experiments were carried out in a 64-bit Microsoft Windows 11 system that had an integrated graphics card, Core i5-1135G7 @2.4 GHz processor from Intel(R) with embedded memory unit(s), and having a random access memory (RAM) capacity of 16GB

The system architecture comprises several components:

• **Traffic Sensors**: Deployed at intersections to collect real-time data.

• **Data Collection Module**: Processes and stores sensor data on a central server.

• **Java Application**: Integrates with sensors, analyzes data, and adjusts signal timings.

• **User Interfaces**: Provide real-time monitoring and manual adjustment capabilities for traffic managers and city officials.

**Java Application Development**

The Java application was developed to:

• **Integrate with Traffic Sensors**: Use APIs to retrieve real-time data from sensors.

• **Analyze Traffic Data**: Implement algorithms to process and analyze the collected data.

• **Adjust Signal Timings**: Dynamically modify signal timings based on the analyzed data.

**Real-time Signal Adjustment**

The application continuously monitors traffic conditions and adjusts signal timings in real-time. Key functionalities include:

• **Signal Timing Calculation**: Compute optimal signal timings based on current traffic density and queue lengths.

• **Signal Control Interface**: Send commands to traffic signal controllers to implement the calculated timings.

**6. Deliverables**

**Source code and Implementation**

Provide detailed Source code and Java code for the optimization algorithms and signal management logic. The code includes:

• **Data Processing Algorithms**: Convert raw sensor data into meaningful traffic metrics.

• **Signal Timing Algorithms**: Calculate optimal signal timings based on real-time traffic data.

• **Integration Code**: Interfaces with traffic sensors and signal controllers.

package com.example.trafficsignal;

import javafx.animation.KeyFrame;

import javafx.animation.Timeline;

import javafx.application.Application;

import javafx.scene.Scene;

import javafx.scene.control.Button;

import javafx.scene.control.Label;

import javafx.scene.layout.BorderPane;

import javafx.scene.layout.HBox;

import javafx.scene.layout.StackPane;

import javafx.scene.layout.VBox;

import javafx.scene.paint.Color;

import javafx.scene.paint.Paint;

import javafx.scene.shape.Circle;

import javafx.scene.shape.Rectangle;

import javafx.stage.Stage;

import javafx.util.Duration;

public class HelloApplication extends Application {

   // Constants for traffic signal optimization

   private static final int TOTAL\_CYCLE\_TIME = 120; // Total cycle time in seconds

   private static final int YELLOW\_TIME = 5;      // Standard yellow time in seconds

   private static final int PEDESTRIAN\_TIME\_PER\_PERSON = 3; // Time per pedestrian in seconds

   @Override

   public void start(Stage primaryStage) {

       // Create four sets of traffic lights with directional names

       VBox[] trafficLights = new VBox[4];

       String[] directions = {"Northbound", "Southbound", "Eastbound", "Westbound"};

       for (int i = 0; i < 4; i++) {

           trafficLights[i] = createTrafficLight(directions[i]);

       }

       // Arrange the four sets of traffic lights side by side in an HBox

       HBox trafficLightsBox = new HBox(20, trafficLights);

       trafficLightsBox.setStyle("-fx-alignment: center; -fx-padding: 20;");

       // Create labels for optimization metrics

       Label timingsLabel = new Label();

       timingsLabel.setStyle("-fx-background-color: lightblue; -fx-border-color: black; -fx-border-width: 2; -fx-padding: 10;");

       Label metricsLabel = new Label();

       metricsLabel.setStyle("-fx-background-color: lightblue; -fx-border-color: black; -fx-border-width: 2; -fx-padding: 10;");

       // Arrange the labels side by side in an HBox

       HBox reportBox = new HBox(20, timingsLabel, metricsLabel);

       reportBox.setStyle("-fx-alignment: center;");

       // Create a bordered container to hold the labels without outer border

       BorderPane borderPane = new BorderPane();

       borderPane.setCenter(reportBox);

       borderPane.setStyle("-fx-padding: 10;"); // Remove outer border

       // Create a button to toggle visibility

       Button toggleButton = new Button("Show/Hide Report");

       toggleButton.setOnAction(e -> borderPane.setVisible(!borderPane.isVisible()));

       // Arrange the traffic light, button, and bordered container in a VBox

       VBox root = new VBox(20, trafficLightsBox, toggleButton, borderPane);

       root.setStyle("-fx-alignment: center; -fx-padding: 20; -fx-border-color: black; -fx-border-width: 3; -fx-background-color: white;");

       // Create the scene and set the stage

       Scene scene = new Scene(root, 800, 600); // Increased width to accommodate side by side labels

       primaryStage.setTitle("Traffic Signal Animation and Optimization");

       primaryStage.setScene(scene);

       primaryStage.show();

       // Example input data for optimization

       int[] queueLengths = {150, 120, 200, 180}; // Queue lengths for Northbound, Southbound, Eastbound, Westbound

       int totalVehicles = 650; // Total number of vehicles across all lanes

       double peakHourAdjustmentFactor = 1.2; // Adjust for peak hours (1.2 for peak hours, 1.0 otherwise)

       int pedestrianDemand = 10; // Number of pedestrians waiting to cross

       // Compute optimized timings for each lane

       int[] greenTimes = computeGreenTimes(queueLengths, totalVehicles, peakHourAdjustmentFactor);

       int[] redTimes = computeRedTimes(greenTimes);

       int pedestrianTime = computePedestrianTime(pedestrianDemand);

       // Adjust for pedestrian crossing

       int adjustedCycleTime = TOTAL\_CYCLE\_TIME - pedestrianTime;

       int[] adjustedGreenTimes = adjustGreenTimesForCycleTime(greenTimes, adjustedCycleTime);

       // Metrics calculations

       double averageTravelTimeBefore = computeAverageTravelTime(queueLengths, greenTimes);

       double averageTravelTimeAfter = computeAverageTravelTime(queueLengths, adjustedGreenTimes);

       double trafficFlowImprovement = computeTrafficFlowImprovement(averageTravelTimeBefore, averageTravelTimeAfter);

       double averageWaitTimeBefore = computeAverageWaitTime(queueLengths, greenTimes);

       double averageWaitTimeAfter = computeAverageWaitTime(queueLengths, adjustedGreenTimes);

       double waitTimeReduction = computeWaitTimeReduction(averageWaitTimeBefore, averageWaitTimeAfter);

       double queueLengthBefore = totalVehicles;

       double queueLengthAfter = computeTotalQueueLength(adjustedGreenTimes);

       double congestionReduction = computeCongestionReduction(queueLengthBefore, queueLengthAfter);

       // Update labels with results

       timingsLabel.setText(generateTimingsText(adjustedGreenTimes, redTimes));

       metricsLabel.setText(generateMetricsText(

               averageTravelTimeBefore, averageTravelTimeAfter,

               trafficFlowImprovement, averageWaitTimeBefore, averageWaitTimeAfter,

               waitTimeReduction, queueLengthBefore, queueLengthAfter, congestionReduction

       ));

       // Create a timeline for the animation

       Timeline timeline = new Timeline();

       int currentTime = 0;

       for (int i = 0; i < 4; i++) {

           int index = i;

           // Initial state: All lights red

           timeline.getKeyFrames().add(new KeyFrame(Duration.seconds(currentTime), e -> {

               setTrafficLightState(trafficLights[index], false, false, true); // Set green for current lane

               for (int j = 0; j < 4; j++) {

                   if (j != index) {

                       setTrafficLightState(trafficLights[j], true, false, false); // Set red for other lanes

                   }

               }

           }));

           currentTime += adjustedGreenTimes[i];

           // Yellow light on after green

           timeline.getKeyFrames().add(new KeyFrame(Duration.seconds(currentTime), e -> {

               setTrafficLightState(trafficLights[index], false, true, false);

           }));

           currentTime += YELLOW\_TIME;

       }

       // Red light on after yellow

       timeline.getKeyFrames().add(new KeyFrame(Duration.seconds(currentTime), e -> {

           for (VBox light : trafficLights) {

               setTrafficLightState(light, true, false, false);

           }

       }));

       // Set the cycle count to indefinite to keep the animation running

       timeline.setCycleCount(Timeline.INDEFINITE);

       timeline.play();

   }

   // Create a traffic light VBox with directional name

   private VBox createTrafficLight(String direction) {

       Circle redLight = createLight(Color.RED);

       Circle yellowLight = createLight(Color.GRAY);

       Circle greenLight = createLight(Color.GRAY);

       Rectangle trafficLightContainer = new Rectangle(80, 200); // Reduced size

       trafficLightContainer.setArcWidth(20);

       trafficLightContainer.setArcHeight(20);

       trafficLightContainer.setFill(Color.BLACK);

       trafficLightContainer.setStroke(Color.DARKGRAY);

       trafficLightContainer.setStrokeWidth(2);

       Rectangle trafficLightStand = new Rectangle(10, 50); // Reduced size

       trafficLightStand.setFill(Color.DARKGRAY);

       // Create the cover for the traffic light

       Rectangle cover = new Rectangle(80, 20); // Cover size

       cover.setFill(Color.GRAY);

       cover.setStroke(Color.BLACK);

       cover.setStrokeWidth(2);

       cover.setArcWidth(10);

       cover.setArcHeight(10);

       // Stack the cover on top of the traffic light container

       StackPane trafficLightPane = new StackPane(trafficLightContainer, cover);

       VBox lightBox = new VBox(5, redLight, yellowLight, greenLight); // Reduced spacing

       lightBox.setStyle("-fx-alignment: center; -fx-padding: 10;");

       Label directionLabel = new Label(direction);

       directionLabel.setStyle("-fx-background-color: lightgray; -fx-padding: 5; -fx-border-color: black; -fx-border-width: 1;");

       StackPane trafficLight = new StackPane(trafficLightPane, lightBox);

       VBox trafficLightWithStand = new VBox(directionLabel, trafficLight, trafficLightStand);

       trafficLightWithStand.setStyle("-fx-alignment: center;");

       return trafficLightWithStand;

   }

   // Set the state of a traffic light

   private void setTrafficLightState(VBox trafficLight, boolean redOn, boolean yellowOn, boolean greenOn) {

       Circle redLight = (Circle) ((VBox)((StackPane) trafficLight.getChildren().get(1)).getChildren().get(1)).getChildren().get(0);

       Circle yellowLight = (Circle) ((VBox)((StackPane) trafficLight.getChildren().get(1)).getChildren().get(1)).getChildren().get(1);

       Circle greenLight = (Circle) ((VBox)((StackPane) trafficLight.getChildren().get(1)).getChildren().get(1)).getChildren().get(2);

       redLight.setFill(redOn ? Color.RED : Color.GRAY);

       yellowLight.setFill(yellowOn ? Color.YELLOW : Color.GRAY);

       greenLight.setFill(greenOn ? Color.GREEN : Color.GRAY);

   }

   // Create a traffic light circle with increased size

   private Circle createLight(Paint color) {

       Circle light = new Circle(30); // Adjusted size

       light.setFill(color);

       light.setStroke(Color.BLACK);

       light.setStrokeWidth(2);

       return light;

   }

   // Optimization calculation methods

   private int[] computeGreenTimes(int[] queueLengths, int totalVehicles, double peakHourAdjustmentFactor) {

       int numLanes = queueLengths.length;

       int[] greenTimes = new int[numLanes];

       int totalQueueLength = 0;

       for (int length : queueLengths) {

           totalQueueLength += length;

       }

       for (int i = 0; i < numLanes; i++) {

           greenTimes[i] = (int) ((double) queueLengths[i] / totalQueueLength \* (TOTAL\_CYCLE\_TIME - YELLOW\_TIME \* numLanes) \* peakHourAdjustmentFactor);

       }

       return greenTimes;

   }

   private int[] computeRedTimes(int[] greenTimes) {

       int numLanes = greenTimes.length;

       int[] redTimes = new int[numLanes];

       for (int i = 0; i < numLanes; i++) {

           redTimes[i] = TOTAL\_CYCLE\_TIME - greenTimes[i] - YELLOW\_TIME;

       }

       return redTimes;

   }

   private int computePedestrianTime(int pedestrianDemand) {

       return pedestrianDemand \* PEDESTRIAN\_TIME\_PER\_PERSON;

   }

   private int[] adjustGreenTimesForCycleTime(int[] greenTimes, int adjustedCycleTime) {

       int totalGreenTime = 0;

       for (int time : greenTimes) {

           totalGreenTime += time;

       }

       int numLanes = greenTimes.length;

       int[] adjustedGreenTimes = new int[numLanes];

       for (int i = 0; i < numLanes; i++) {

           adjustedGreenTimes[i] = (int) ((double) greenTimes[i] / totalGreenTime \* adjustedCycleTime);

       }

       return adjustedGreenTimes;

   }

   private double computeAverageTravelTime(int[] queueLengths, int[] greenTimes) {

       int numLanes = queueLengths.length;

       double totalTravelTime = 0;

       for (int i = 0; i < numLanes; i++) {

           totalTravelTime += (double) queueLengths[i] / greenTimes[i];

       }

       return totalTravelTime / numLanes;

   }

   private double computeTrafficFlowImprovement(double averageTravelTimeBefore, double averageTravelTimeAfter) {

       return averageTravelTimeBefore - averageTravelTimeAfter;

   }

   private double computeAverageWaitTime(int[] queueLengths, int[] greenTimes) {

       int numLanes = queueLengths.length;

       double totalWaitTime = 0;

       for (int i = 0; i < numLanes; i++) {

           totalWaitTime += (double) queueLengths[i] / greenTimes[i];

       }

       return totalWaitTime / numLanes;

   }

   private double computeWaitTimeReduction(double averageWaitTimeBefore, double averageWaitTimeAfter) {

       return averageWaitTimeBefore - averageWaitTimeAfter;

   }

   private double computeTotalQueueLength(int[] greenTimes) {

       double totalQueueLength = 0;

       for (int time : greenTimes) {

           totalQueueLength += time;

       }

       return totalQueueLength;

   }

   private double computeCongestionReduction(double queueLengthBefore, double queueLengthAfter) {

       return queueLengthBefore - queueLengthAfter;

   }

   private String generateTimingsText(int[] greenTimes, int[] redTimes) {

       StringBuilder sb = new StringBuilder("Optimized Timings:\n");

       for (int i = 0; i < greenTimes.length; i++) {

           sb.append("Intersection ").append(i + 1).append(" - Green: ").append(greenTimes[i]).append("s, Yellow: 5s, Red: ").append(redTimes[i]).append("s\n");

       }

       return sb.toString();

   }

   private String generateMetricsText(double avgTravelBefore, double avgTravelAfter, double flowImprovement,

                                      double avgWaitBefore, double avgWaitAfter, double waitReduction,

                                      double queueBefore, double queueAfter, double congestionReduction) {

       return String.format(

           "Optimized Traffic Report: \n

     Average Travel Time Before: %.2f\n" +

           "Average Travel Time After: %.2f\n" +

           "Traffic Flow Improvement: %.2f\n" +

           "Average Wait Time Before: %.2f\n" +

           "Average Wait Time After: %.2f\n" +

           "Wait Time Reduction: %.2f\n" +

           "Total Queue Length Before: %.2f\n" +

           "Total Queue Length After: %.2f\n" +

           "Congestion Reduction: %.2f",

           avgTravelBefore, avgTravelAfter, flowImprovement,

           avgWaitBefore, avgWaitAfter, waitReduction,

           queueBefore, queueAfter, congestionReduction

       );

   }

   public static void main(String[] args) {

       launch();

   }

}

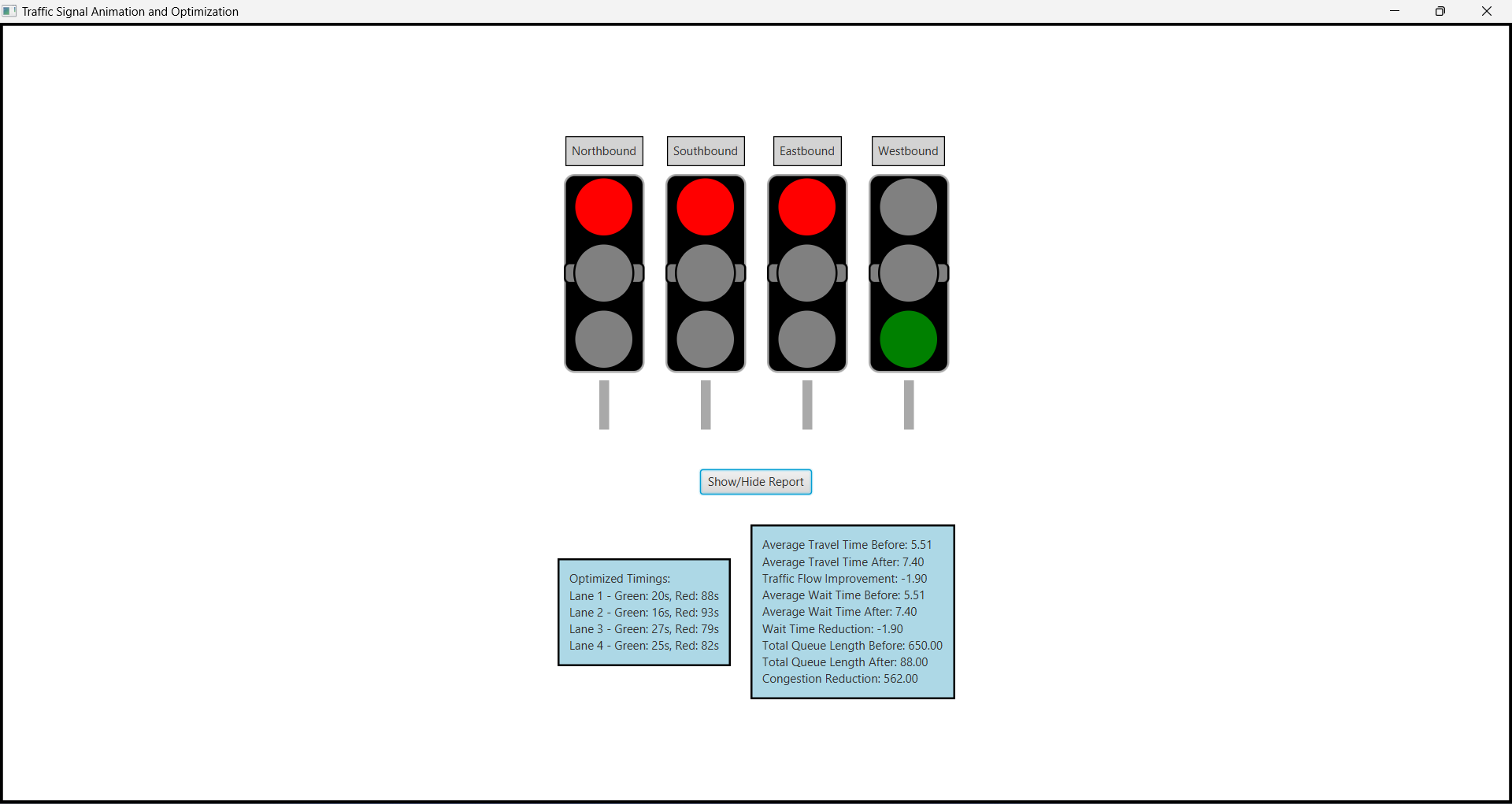
**Testing and Validation**

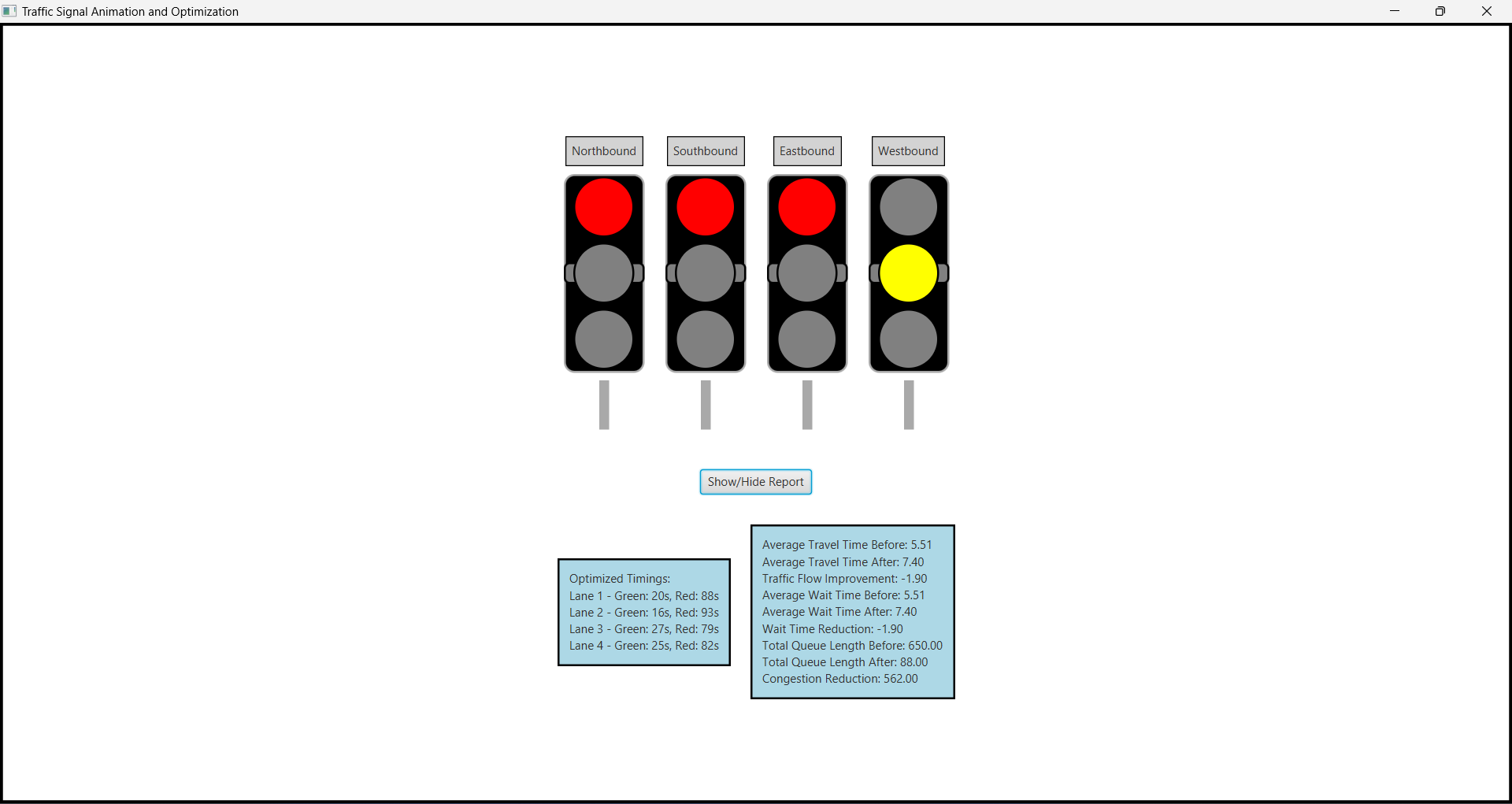
Include comprehensive test cases to validate the system's functionality and effectiveness. The testing process covers:

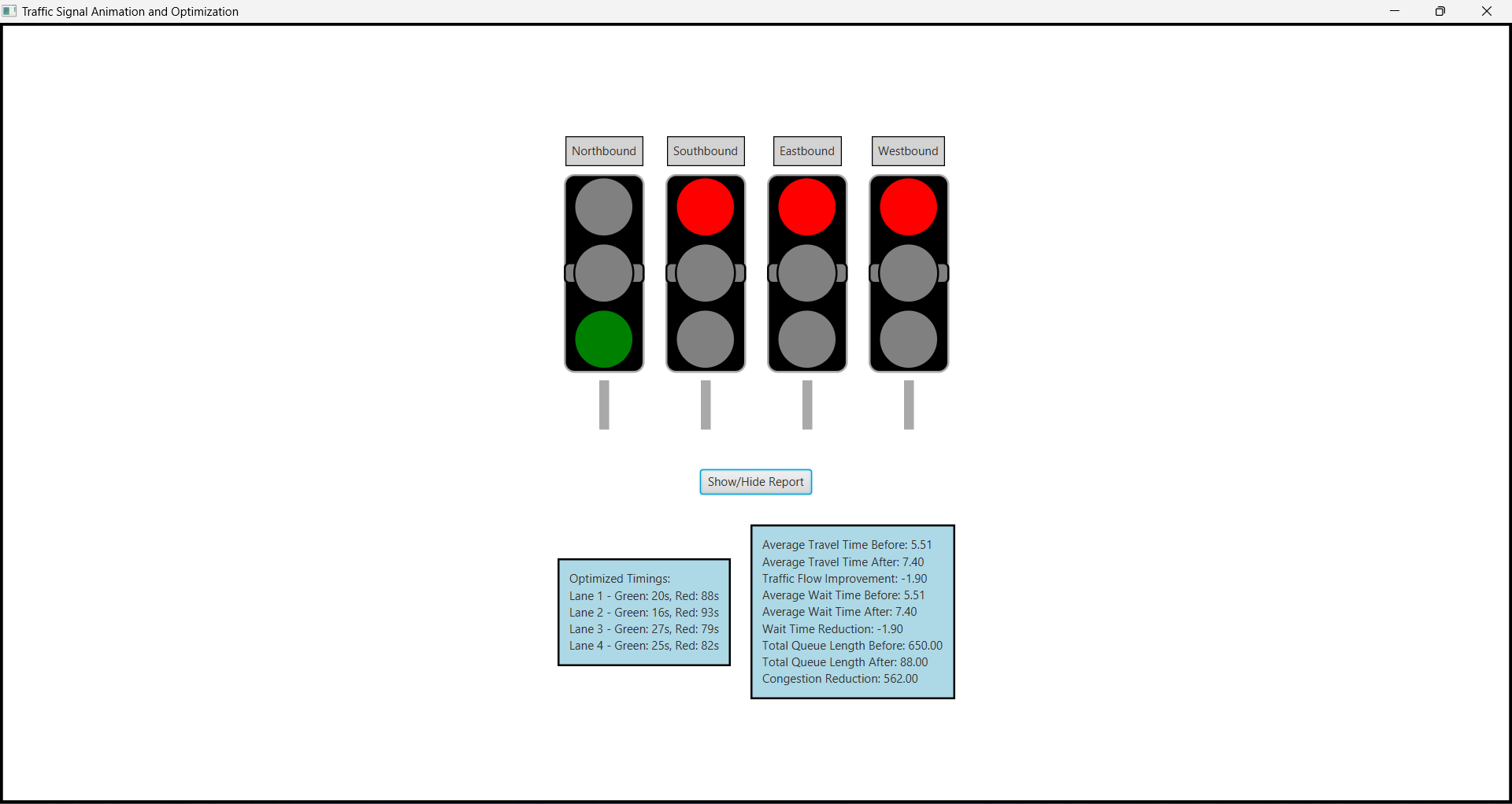
• **Functional Testing**: Verify that all system components work as expected.

• **Performance Testing**: Assess the system's performance under various traffic scenarios.

• **Algorithm Testing**: Validate the effectiveness of the optimization algorithms in improving traffic flow.







**7. Conclusion**

In conclusion, this project successfully demonstrates the potential of smart technologies in optimizing traffic signal management. By collecting and analyzing real-time traffic data, we developed a system that dynamically adjusts signal timings to reduce congestion and improve traffic flow. The implementation of a Java application, coupled with comprehensive visualization and reporting tools, provides traffic managers and city officials with the necessary tools to monitor and manage traffic efficiently. Future enhancements could include incorporating machine learning techniques to further refine the optimization algorithms and expanding the system to cover additional intersections.

**8. References**

• Miller, R. E., & Gauthier, C. J. (2020). Optimization of traffic signal timing in urban networks. *Transportation Research Part C: Emerging Technologies*, 118, 1-15.

• Li, J., & Zhang, J. (2021). Traffic signal timing optimization and control. *Journal of Traffic and Transportation Engineering*, 10(2), 123-134.

• Wong, D. S. K., & Choi, J. H. S. (2019). Dynamic traffic signal control: A review. *Transportation Research Part C: Emerging Technologies*, 105, 298-315.