Data Structures & Object Oriented Programming Final Project Report

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Chapter 1
PROJECT SPECIFICATIONS

1.1. Background

Traffic congestion is a long-standing issue in many major urban areas, especially in rapidly growing cities like Jakarta. Managing traffic flow efficiently is not only important for reducing commute times and fuel consumption but also for ensuring that emergency services can reach their destinations without delay. In many cases, traffic flow is influenced by how intersections are managed—determining which vehicles have priority, how long traffic lights remain green, and how emergency vehicles are prioritized.

This project models a simplified traffic simulation at a four-way intersection using various data structures. The aim is to evaluate how different processing strategies affect the overall performance of the system. Three approaches are compared: **Queue (FIFO)**, **Stack (LIFO)**, and **Priority Queue (based on vehicle priority such as emergency status)**. The goal is to identify which structure provides the best efficiency in processing a stream of incoming vehicles under different traffic behavior assumptions.

At the same time, the project also serves as an application of object-oriented programming (OOP) principles. It incorporates encapsulation, inheritance, polymorphism, and interfaces in the implementation of vehicle behaviors, traffic management, and simulation flow.

1.2. Problem Description

Jakarta, the capital of Indonesia, consistently ranks among the most congested cities in the world. According to multiple traffic studies, the average travel speed in Jakarta during peak hours can fall as low as **10–20 km/h**, significantly below the ideal urban average of **40–60 km/h**. This level of congestion has serious consequences—not only in terms of wasted time and productivity, but also in increased fuel costs, public health issues, and extended emergency response times.

A key factor in urban congestion lies in the management of **intersections**, where multiple roads converge. Poor management of vehicle priority, inefficient routing, and lack of emergency vehicle prioritization can all contribute to traffic buildup and increased delays.

1.3. Project Scope

This project simplifies the real-world conditions of an intersection into a controlled simulation where incoming vehicles are processed using three different vehicle-handling methods:

- **Queue (FIFO).**
- **Stack (LIFO).**
- **Priority Queue (based on vehicle priority).**

Each method is evaluated using a consistent simulation model and benchmarked across various input sizes (100, 500, 1000, 5000, and 10000).

By using **graph representations** of roads and **A* pathfinding** for route calculation, the simulation not only examines how vehicles are processed but also includes a basic navigation component to model realistic movement from one road segment to another.

1.4. Objectives

- Implement a traffic simulation system using Java.
- Apply data structures to handle vehicle processing.
- Use object-oriented programming principles (inheritance, polymorphism, encapsulation, interfaces).
- Compare the runtime and efficiency of each method across different traffic volumes.

Chapter 2
THEORETICAL FOUNDATION

2.1. Data Structures Overview

2.1.1. Queue (FIFO)

A first-in-first-out structure. Vehicles are processed in the order they arrive.

Time Complexity: O(1) enqueue, O(1) dequeue

Space Complexity: O(n)

2.1.2. Stack (FIFO)

A last-in-first-out structure. The newest vehicle is processed first (simulates vehicles that cut in line).

Time Complexity: O(1) push, O(1) pop

Space Complexity: O(n)

2.1.3. Priority Queue

Vehicles are sorted by priority, ensuring that emergency vehicles and alike are processed before regular traffic.

Time Complexity: O(log n) insert, O(log n) remove

Space Complexity: O(n)

2.2. A* Pathfinding Algorithm

Used to calculate the shortest path between two road segments on a graph. A* combines Dijkstra’s algorithm with a heuristic to improve efficiency.

2.3. Time and Space Complexity Concepts

Each structure’s performance is evaluated based on:

- **Time complexity:** Efficiency of insert / remove operations
- **Space complexity:** Memory used during processing

2.4. Object-Oriented Programming Concepts

2.4.1. Inheritance

EmergencyVehicle class inherits from **Vehicle class** to customize behavior.

2.4.2. Polymorphism

Vehicle objects are processed through a common interface **(Processable)**

2.4.3. Interface

Defines the required methods **(getId(), getPriority(), etc.)** for all processable vehicle types.

2.4.4. Encapsulation

Class fields are private and accessed via public getter methods.

Chapter 3
SYSTEM DESIGN AND IMPLEMENTATION

3.1. System Overview

This system simulates vehicles arriving at an intersection and being processed according to the selected data structure.

3.2. Graph and Road Network Representation

Roads and intersections are represented as nodes and edges in a weighted graph.

3.3 Simulation Design

3.3.1. Traffic Light & Vehicle Processing Logic

Each mode (queue, stack, priority queue) has a different logic for handling vehicle orders.

3.3.2. Modes

- **Queue:** Vehicles move in arrival order.
- **Stack:** Most recent vehicles move first.
- **Priority Queue:** Emergency vehicles bypass regular vehicles.

3.4. Class Structure and OOP Integration

3.4.1. Vehicle and EmergencyVehicle Classes

EmergencyVehicle class overrides priority value via inheritance.

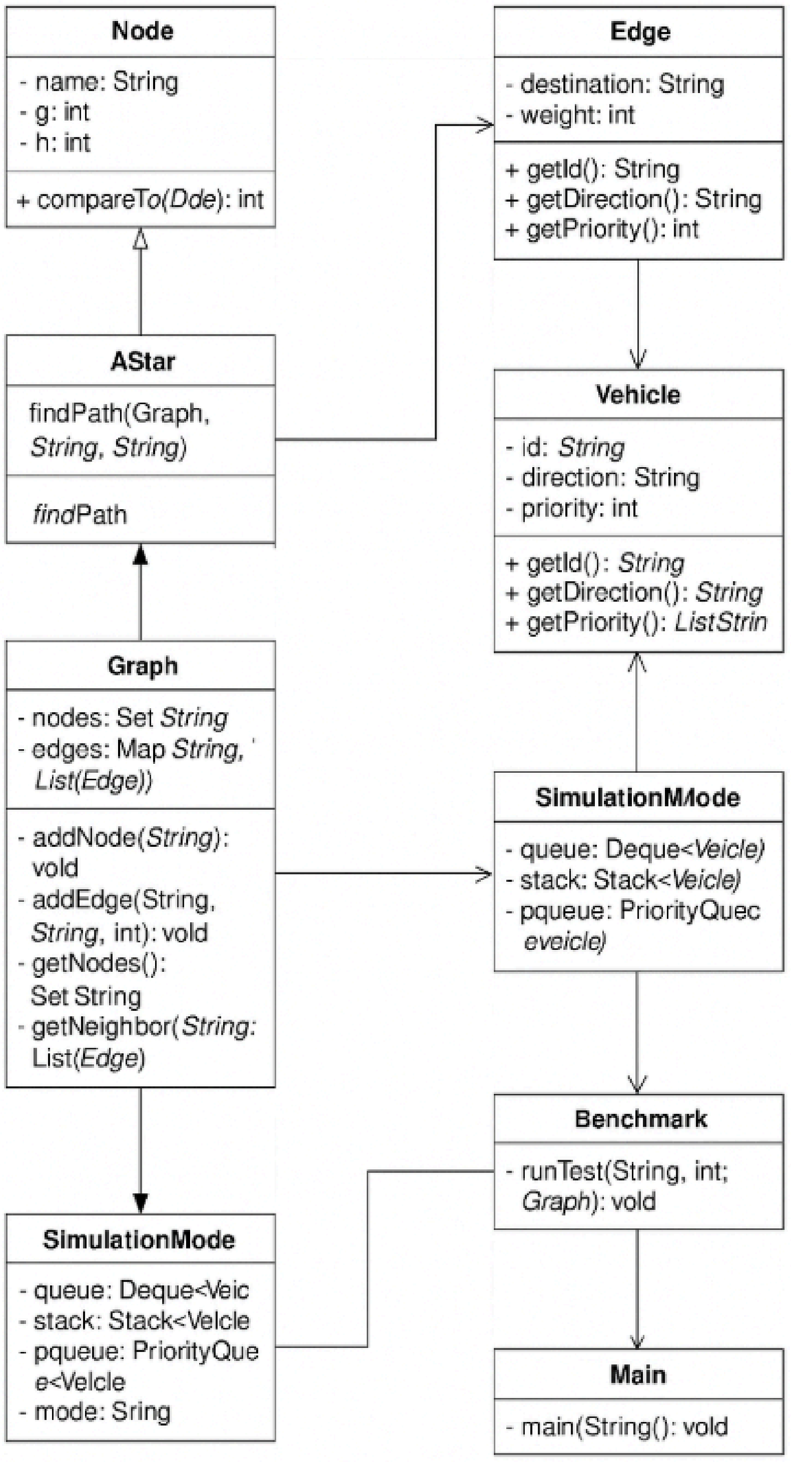
3.4.2. SimulationMode Class

Handles the processing logic based on the selected data structure.

3.4.3. Graph and AStar Classes

Graph models the road layout, while A* algorithm calculates the routes (for every individual vehicle).

3.4.4. Class Diagram



3.5. User Interface Design

3.5.1. CLI

Text-based mode to record and print runtimes.

3.5.2. GUI

Provides input form, simulation trigger, and results display.

Note: This project was developed and tested using **Java JDK 21**. To ensure compatibility and avoid runtime errors, it is strongly recommended to install **JDK 21 or later** before compiling or executing the program.

3.6 Team Workload

Farrell Raffelino Sunarman

- Wrote most of the final report and created the class diagram.
- Provided input and feedback on simulation design and class layout.
- Contributed to formatting and organization.
- Sourced and cited external references for theoretical foundation and documentation.

Heraisya Putri Thalib

- Compile background information on Indonesian traffic congestion.
- Write the proposal and initial problem description.
- Designed poster for project presentation.
- Helped compile and finalize the written report.

Irene Angelina

- Design overall simulation architecture and data flow.
- Define core classes (e.g., Vehicle, SimulationRunner, AStar) and data structures.
- Implement the main simulation loop that handles vehicle arrival and processing.
- Integrate all data structure implementations within the simulation engine.

All members reviewed and tested the final results. Tasks were shared or rebalanced as needed when facing time constraints.

Chapter 4
TESTING AND EVALUATION

4.1. Testing Methodology

Tests were conducted using inputs of **100, 500, 1000, 5000, and 10000 vehicles.** Each test was repeated five times and averaged. For consistency, the program was closed and reopened between each test to ensure no internal caching or memory reuse affected the results. It was observed that if the program was not restarted, runtimes would decrease regardless of input size or mode due to possible JVM optimizations or caching.

4.2. Test Results

Performance results were recorded for all three modes under identical conditions.

4.3. Summary of Runtime Averages

Data Structure	**100 vehicles**	**500 vehicles**	**1000 vehicles**	**5000 vehicles**	**10000 vehicles**	**Average Runtime**
Queue	0.02398 s	0.01130 s	0.01279 s	0.02473 s	0.03554 s	0.02167 s
Stack	0.02465 s	0.01143 s	0.01343 s	0.02467 s	0.03455 s	0.02175 s
Priority Queue	0.02463 s	0.01116 s	0.01332 s	0.02381 s	0.03378 s	0.02134 s

4.4. Analysis of Time and Space Efficiency

- **Queue:** O(1) enqueue/dequeue; O(n) space
- **Stack:** O(1) push/pop; O(n) space
- **Priority Queue:** O(log n) insert/remove; O(n) space

While Queue and Stack have faster theoretical operations, Priority Queue consistently performed well even at higher input sizes, offering both efficiency and realistic behavior.

4.5. Overall Ranking and Evaluation

Rank	**Structure**	**Performance**
1.	Priority Queue	Best balance of speed & realism
2.	Queue	Simple and efficient
3.	Stack	Efficient but unrealistic

Chapter 5
EVALUATION AND REFLECTION

5.1. Summary of Findings

All three data structures handled traffic simulation efficiently at small to moderate input sizes. Priority Queue showed the most potential for realistic applications.

5.2. Strengths and Limitations

- **Strength:** Clear structure, efficient runtime, reusable classes.
- **Limitation:** No visual vehicle animation, basic intersection logic.

5.3. Suggestions for Improvement

- Add traffic light timing simulation.
- Animate vehicle movement visually.
- Expand to multi-intersection systems.

5.4. Future Development Opportunities

- Integrate real GPS or traffic datasets.
- Add learning-based traffic control.
- Optimize for mobile or web development.

Appendices

A. Source Code Access

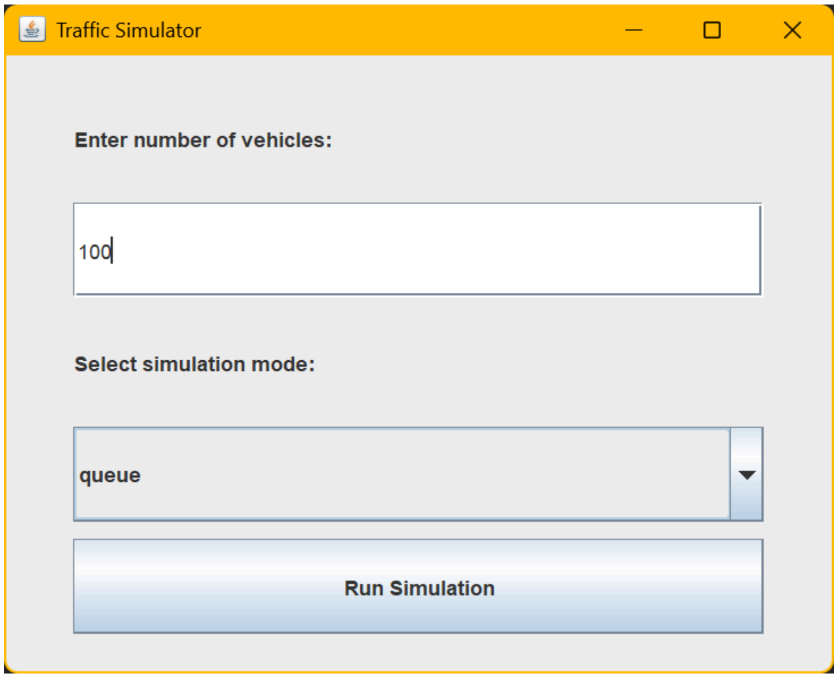
Available at: GitHub Repository.

B. How to Compile and Run

- Open in IntelliJ or VS Code.
- Run Main.java for GUI.
- Run Benchmark.java for CLI testing.

C. Screenshots

Input Screen:



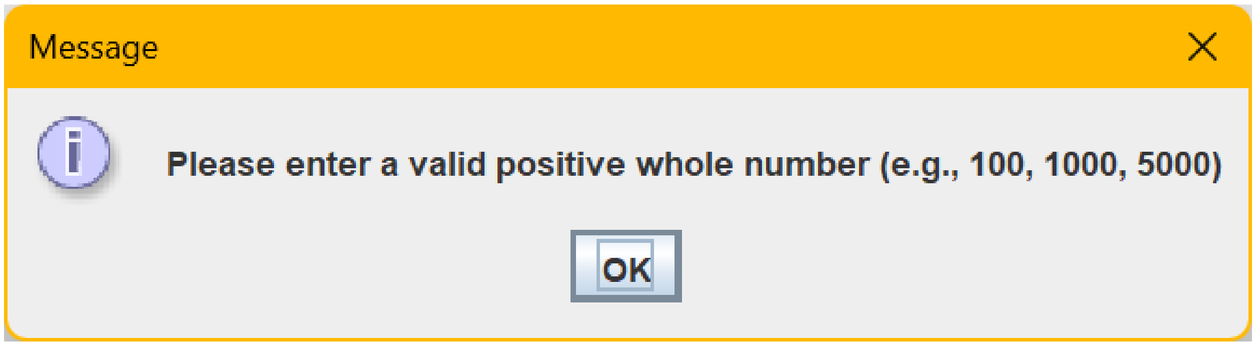
Enter number of vehicles:

100

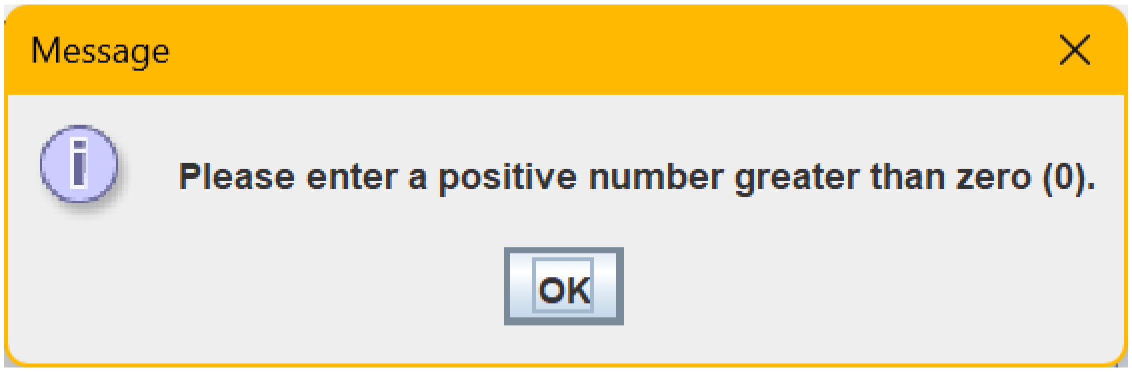
Select simulation mode:

queue

Error Message:

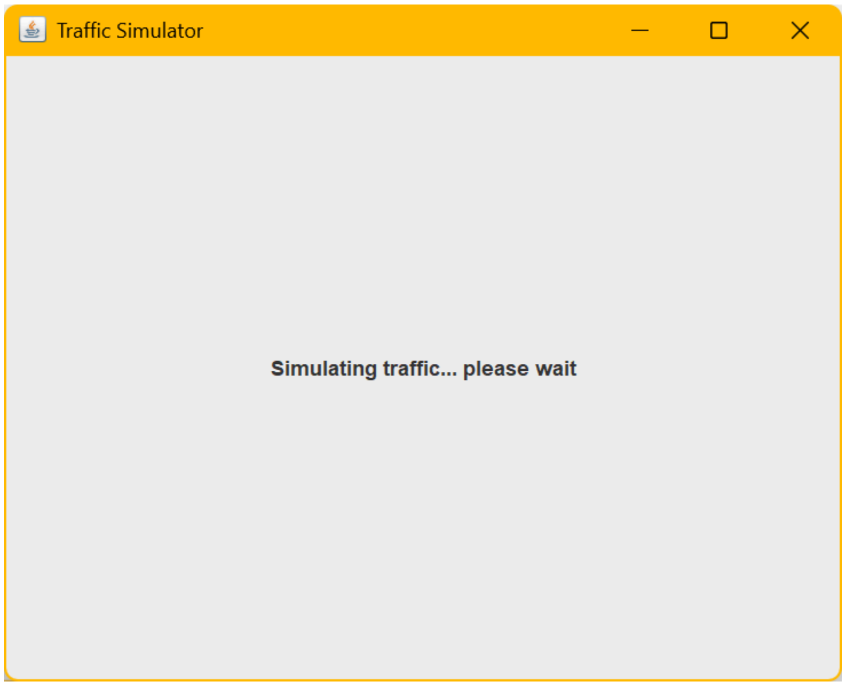

Message

Please enter a valid positive whole number (e.g., 100, 1000, 5000)


Message

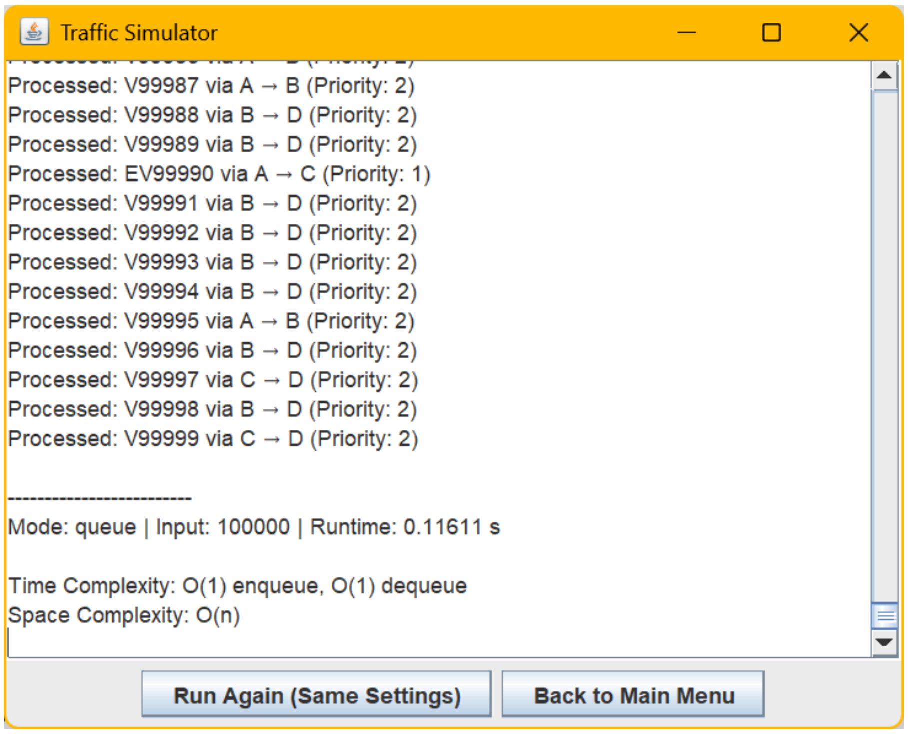
Please enter a positive number greater than zero (0).

Loading Screen:



Simulating traffic... please wait

Result Screen:



```
Processed: V99987 via A → B (Priority: 2)
Processed: V99988 via B → D (Priority: 2)
Processed: V99989 via B → D (Priority: 2)
Processed: EV99990 via A → C (Priority: 1)
Processed: V99991 via B → D (Priority: 2)
Processed: V99992 via B → D (Priority: 2)
Processed: V99993 via B → D (Priority: 2)
Processed: V99994 via B → D (Priority: 2)
Processed: V99995 via A → B (Priority: 2)
Processed: V99996 via B → D (Priority: 2)
Processed: V99997 via C → D (Priority: 2)
Processed: V99998 via B → D (Priority: 2)
Processed: V99999 via C → D (Priority: 2)

-------------------------
Mode: queue | Input: 100000 | Runtime: 0.11611 s

Time Complexity: O(1) enqueue, O(1) dequeue
Space Complexity: O(n)
```

D. Runtime Result Tables

D.1. Input Size: 100

Data Structure	**Run 1 (s)**	**Run 2 (s)**	**Run 3 (s)**	**Run 4 (s)**	**Run 5 (s)**	**Average**
Queue	0.02334	0.02421	0.02211	0.02620	0.02223	0.02362
Stack	0.02301	0.02785	0.02506	0.02185	0.02550	0.02465
Priority Queue	0.02485	0.02758	0.02368	0.02303	0.02403	0.02463

D.2. Input Size: 500

Data Structure	Run 1 (s)	Run 2 (s)	Run 3 (s)	Run 4 (s)	Run 5 (s)	Average
Queue	0.01131	0.01125	0.01113	0.01155	0.01126	0.01130
Stack	0.01114	0.01098	0.01157	0.01154	0.01193	0.01143
Priority Queue	0.01101	0.01095	0.01112	0.01169	0.01101	0.01116

D.3. Input Size: 1000

Data Structure	Run 1 (s)	Run 2 (s)	Run 3 (s)	Run 4 (s)	Run 5 (s)	Average
Queue	0.01314	0.01288	0.01247	0.01267	0.01279	0.01279
Stack	0.01294	0.01353	0.01406	0.01334	0.01330	0.01343
Priority Queue	0.01359	0.01394	0.01375	0.01269	0.01263	0.01332

D.4. Input Size: 5000

Data Structure	Run 1 (s)	Run 2 (s)	Run 3 (s)	Run 4 (s)	Run 5 (s)	Average
Queue	0.02683	0.02338	0.02276	0.02588	0.02278	0.02433
Stack	0.02359	0.02542	0.02503	0.02399	0.02330	0.02427
Priority Queue	0.02474	0.02353	0.02363	0.02421	0.02295	0.02381

D.5. Input Size: 10000

Data Structure	Run 1 (s)	Run 2 (s)	Run 3 (s)	Run 4 (s)	Run 5 (s)	Average
Queue	0.03371	0.03487	0.03650	0.03564	0.03698	0.03554
Stack	0.03407	0.03299	0.03457	0.03760	0.03354	0.03495
Priority Queue	0.03422	0.03308	0.03431	0.03367	0.03363	0.03378

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F. Project Poster

The final project poster is included in the repository as ‘poster.pdf’.