**EEX5362 Performance Modelling**

**Deliverable 01**

**by**

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**System Details and Performance Objectives**

1. **System Overview**

* **System Name:** Highway Off-Ramp with Limited Exit Capacity (Kahathuduwa Exit)
* **System Type:** Queueing-Based Traffic Flow System modeled using Discrete Event Simulation (SimPy)
* **Description:**

This simulation represents vehicle movement through a highway off-ramp with a limited number of exit lanes. Vehicles arrive at the ramp randomly and are served on a **first-come, first-served (FCFS)** basis. When all lanes are occupied, incoming vehicles wait in a queue until a lane becomes available. The system aims to analyze how different lane configurations, arrival rates, and driver behaviors affect congestion, waiting times, and throughput. The results are intended to help improve ramp design and traffic management strategies.

1. **High-Level Problem Statement**

Highway off-ramps can act as **traffic bottlenecks**, especially during peak periods. At the Kahathuduwa exit, high vehicle inflow frequently causes long queues, sometimes spilling onto the main highway. This leads to decreased throughput, longer travel times, and potential safety risks.

The project’s goal is to **assess how ramp performance is affected** by factors such as lane count, vehicle arrival frequency, and exit duration. Insights from this study will support recommendations for **infrastructure improvements or operational strategies** to enhance traffic flow.

1. **Stakeholders**

* **Drivers:** Interested in minimizing waiting time and avoiding congestion.
* **Traffic Authorities:** Need data to optimize lane allocation, ramp control, and signage.
* **Local Community:** Affected by congestion-related delays, noise, and emissions.

1. **Dataset Description**

Traffic observations were conducted at **Kahathuduwa** Highway exit to understand vehicle flow on the off-ramp. The study recorded **vehicle arrival intervals, exit durations**, and **lane usage** under different traffic scenarios. Each scenario was observed for **30 minutes (1800 seconds)** to capture realistic traffic behavior.

**Variables:**

* **Vehicle Arrival Interval (s)** – Time gap between consecutive vehicles entering the off-ramp.
* **Number of Lanes** – Total lanes available for vehicles to exit the ramp.
* **Scenario Type** – The traffic condition being simulated (e.g., Morning Peak, Evening Peak, Weekend, Accident, New Ramp Design).
* **Exit Duration (s)** – Time a vehicle takes to leave the off-ramp.
* **Observation Period (s)** – Total duration for which traffic is recorded or simulated (e.g., 1800 seconds).
* **Vehicle Throughput** – Total number of vehicles that successfully exit during the observation period.
* **Average Waiting Time (s)** – Mean time vehicles spend waiting in the queue before exiting.
* **Queue Length** – Number of vehicles waiting at a given time.
* **Ramp Utilization** – Measure of how effectively the available lanes are used.
* **Delay per Vehicle (s)** – Extra time a vehicle experiences due to congestion or reduced capacity.

**Collected Data Summary:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario** | **Vehicle Arrival Interval (s)** | **Exit Duration (s)** | **Number of Lanes** |
| Morning Peak | 2–3 | 3.5–3.6 | 1 |
| Evening Peak | 2.5–3 | 3.5–3.7 | 1 |
| Weekend Traffic | 5–6 | 3.5–3.6 | 1 |
| Accident (Lane Blocked) | 2–3 | 3.5–3.6 | 1 |
| New Ramp Design | 2–2.5 | 3.5 | 2 |

**5. Performance Objectives**

This simulation focuses on:

* **Minimizing Waiting Time:** Reduce the average queue duration (mean and 95th percentile).
* **Maximizing Throughput:** Increase the number of vehicles served per simulation interval.
* **Identifying Bottlenecks:** Determine conditions that lead to significant congestion.
* **Evaluating Lane Configurations:** Measure how adding lanes impacts flow efficiency.
* **Improving Predictability:** Reduce variability in waiting times across scenarios.

**6. Modeling Approach**

* **Simulation Tool:** Python (SimPy)
* **Model Type:** Discrete Event Simulation (DES)
* **Queue Discipline:** First-Come, First-Served (FCFS)
* **Servers:** Ramp lanes (lane\_count)
* **Service Process:** Variable exit durations reflecting driver behavior
* **Simulation Duration:** 1,800 seconds (30 minutes)

**Key Outputs:**

1. **Average Waiting Time**

* Represents the typical duration vehicles spend waiting in line before exiting the ramp. This helps assess overall congestion.

1. **Maximum Queue Length**

* The largest number of vehicles waiting at any point on the ramp during the simulation. This highlights peak congestion and the worst-case queue scenario.

1. **Average Exit Duration**

* The mean time vehicles take to leave the ramp once they start moving. It reflects how efficiently traffic flows under different conditions.

1. **Throughput (vehicles per second)**

* Indicates the rate at which vehicles successfully exit the ramp. Higher throughput reflects smoother traffic flow and better ramp performance.

1. **Visualizations (Histograms and Bar Charts)**

* **Histograms:** Display the distribution of waiting times or exit durations among vehicles.
* **Bar Charts:** Compare metrics across different traffic scenarios, such as morning peak versus weekend traffic.
* These visual tools help identify trends, bottlenecks, and performance differences clearly.

**7. Results Summary**

Simulation results highlighted:

* Adding a second lane during peak traffic reduced **average waiting times by 50–75%**.
* Single-lane heavy traffic caused **non-linear growth in queues**, indicating saturation.
* Throughput improved from ~0.20 vehicles/second (Morning Peak) to ~0.38 vehicles/second (Improved Ramp).
* Wait-time variability decreased under improved configurations, suggesting more reliable performance.

**8. Insights and Recommendations**

* **Increasing lane capacity** or **implementing ramp metering** effectively reduces congestion.
* Modeling **time-dependent arrival rates** better reflects rush-hour conditions.
* Running **multiple replications** improves model reliability.
* Integrating **downstream road networks** in future studies can identify additional bottlenecks.

**9. Expected Outcomes**

* Quantitative evidence of how ramp design changes affect traffic flow and waiting times.
* A **reusable simulation model** for analyzing similar highway off-ramps.
* **Actionable recommendations** for traffic engineers and planners to optimize congestion management.