CNG Auto-rickshaw Policy Simulation For Kamarpara Road

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***Abstract*—Kamarpara Road is a road of around 1.4 km length between Kamarpara Bus Stand and Station Road. In this road, CNG Auto-rickshaws (called CNGs) carry passengers in both directions. The CNGs are allowed on the road for 12 hours (from 6 am to 6 pm). The path has only two terminals, so there is no stoppage in between. Passengers arrive and get on CNGs from both terminals. For simplicity, let's assume that there is a FIFO queue of passengers in each terminal. For every trip, a passenger pays Tk 10. In one trip, a CNG can carry at most 5 passengers. But if it finds less passengers, it waits until a threshold is reached. The policy followed by a CNG is defined by the minimum number of passengers it needs to carry before starting a trip. Currently, most CNG drivers wait for all 5 of his seats to be filled up before starting the trip, wasting a huge amount of time in the process. In this project, we try to simulate CNGs with different policies in order to find the best policy balancing the benefits of the CNG drivers and the passengers.**

***Index Terms*—CNG, Terminal, Passenger, Trip, Policy, Profit, Arrival, Departure, Delay.**

I. Introduction

Every CNG on the road has a capacity of exactly 5 passengers. So, a CNG can follow one of 5 policies: Policy 1, 2, 3, 4 or 5; where a CNG following Policy x will carry at least x passengers in every trip.

In every policy, the CNG driver faces a trade-off between time and fuel. A high passenger threshold ensures high profit in one trip which is fuel efficient. On the other hand, a low threshold ensures less waiting time which maximizes the time utilization (ensures more number of trips in same time). The relevant outcome for a passenger is the waiting time. Minimum waiting time maximizes customer satisfaction.

This simulation can be considered as a complex variation of the Multi-Server Queue System where each CNG acts as a server. It also possesses some properties of the Inventory System. The simulation can be extended for buses, for example: to compare seating service vs local service.

In the upcoming section, we will have a look at the description of the system which consists of the state variables, events, input, and output variables of the system. Then we will go through the simulation program, its classes, and their relationships. The flowcharts of some of the major functions of the system will be provided. Then, the result data will be presented and analyzed.

II. System Description

A. Problem Statement

Let's consider inter-arrival times of passengers are independent and exponentially distributed. A passenger that arrives on a terminal and finds at least one idle CNG immediately enters one of the CNGs. Any free CNG waiting at the terminal at that moment has an equal probability of picking up the passenger. If the passenger finds no free CNG at that moment, he enters a FIFO queue.

When a CNG arrives at a terminal, it picks up passengers from the queue. If it is following policy x, it will wait idly on the terminal until it has picked up x passengers. However, after picking up x customers, it will wait a small time δ to pick more customers if possible. After that it starts the trip. The duration of the trip is also exponentially distributed. The cost of a trip is normally distributed. After completing the trip, every passenger of the CNG pays Tk 10 and departs.

The simulation will begin with equal number of CNGs in both terminals in 'empty-and-idle' state; i.e., no passenger is present in the CNG or terminal and the CNG is idle. We will start waiting for passenger arrivals from time 0 to time 720. Here, time t represents t minutes after 6 am. Here, the number of total number of passengers served, n is a random variable.

B. Input Variables

The average inter-arrival times of the two terminals are different. As expected, Kamarpara Bus Stand is the busier end.

TABLE I
Inter-arrival Time

Terminal	Average Passenger Inter-arrival Time
Kamarpara	1 minutes and 12 seconds
Station Road	1 minutes and 30 seconds

Total Number of CNGs, $m = 10$.

Per Passenger Fare = Tk 10.

The mean cost of a trip is Tk 6 with a standard deviation of Tk 0.25. This data was collected from a CNG driver who said that he can complete 50 trips with a 300 Tk refill. Also, the current rate of CNG is 75 Tk/L and the usual mileage of CNG is around 20 km/L. From this calculation, the fuel cost of a

1.4 km trip is Tk 5.25 which is very close to the CNG driver's input.

For finding the average trip duration, a sample was recorded using a personal stopwatch. The results are listed in the following table:

TABLE II
SAMPLE TRIP DURATION

Date	**Trip Duration**
19 Sep, 2022	1 minute and 5 seconds
19 Sep, 2022	38 seconds
20 Sep, 2022	1 minute and 17 seconds
22 Sep, 2022	1 minute and 13 seconds
28 Sep, 2022	57 seconds
03 Oct, 2022	2 minutes and 3 seconds
05 Oct, 2022	1 minute and 4 seconds
16 Oct, 2022	40 seconds
19 Oct, 2022	51 seconds
07 Nov, 2022	3 minutes and 8 seconds
10 Nov, 2022	1 minute

So, Average Trip Duration = 1 minute and 16 seconds.

C. State Variables

The state of the system is defined by the state of the terminals and the CNGs.

1) Terminal State Variables: The state of a terminal in a certain point of time t is represented by two variables:

$$c(t) = \text{number of CNGs at the terminal at time t}$$
$$q(t) = \text{passenger queue length at time t}$$

2) CNG State Variables: The state of a CNG in a certain point of time t is represented by three variables:

$$\text{CNG State, } x(t) = \begin{cases} 0, & \text{if CNG is idle at time t} \\ 1, & \text{if CNG is busy at time t} \end{cases}$$

$$\begin{aligned} l(t) =& \text{at time t, the terminal from where} \\ & \text{the next passenger will be picked up} \\ s(t) =& \text{number of passengers at time t} \end{aligned}$$

D. Event Set

$$\text{Event Set, } E = \{Arrival, Start\,Trip, Departure\}$$

Arrival works on a Terminal and the other two events work on a CNG.
Arrival increases either the number of passengers of a CNG on that terminal, or the queue length of the terminal.
Start Trip changes the CNG state from idle to busy and changes its terminal.
Departure changes the number of passenger of a CNG to 0 and changes the CNG state from busy to idle. After that, it may increase the number of passengers of the CNG and decrease from the terminal.

E. State Equations

The state equations of the system:

$$c(t^+) = \begin{cases} m/2, & t = 0 \\ c(t) + 1, & \text{departure of a CNG at time t} \\ c(t) - 1, & \text{start trip of a CNG at time t} \\ c(t), & \text{otherwise} \end{cases}$$

$$q(t^+) = \begin{cases} \text{No free CNG? } q(t) + 1 : 0, & \text{arrival at time t} \\ q(t) = 0?\ 0 : q(t) - 1, & \text{passenger boards CNG} \\ & \text{at time t} \\ q(t), & \text{otherwise} \end{cases}$$

$$x(t^+) = \begin{cases} x(t) = 0?\ 1 : x(t), & \text{start trip at time t} \\ s(t) < threshold?\ 0 : x(t), & \text{departure at time t} \\ x(t), & \text{otherwise} \end{cases}$$

$$s(t^+) = \begin{cases} s(t) + 1, & \text{passenger boards CNG at time t} \\ 0, & \text{departure at time t} \end{cases}$$

F. Statistical and Output Variables

1) Variables associated with passenger i:

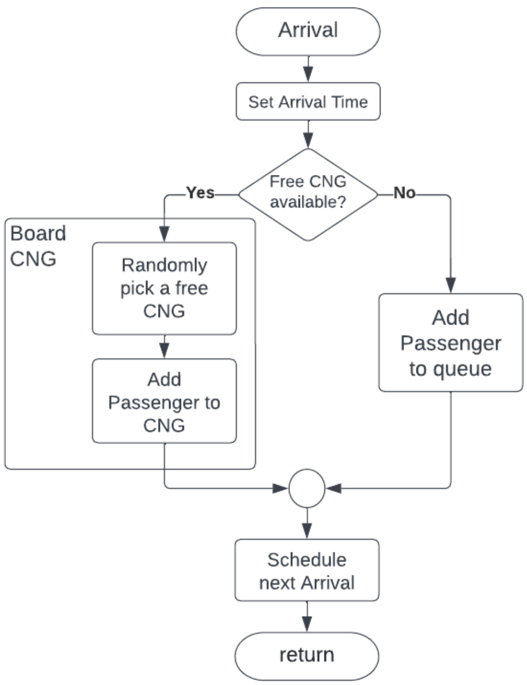
$$\begin{aligned} &\text{Arrival Time} \geq 0 \\ &\text{Boarding Time} \geq \text{Arrival Time} \\ &\text{Trip Start Time} \geq \text{Boarding Time} \\ &\text{Departure Time} \geq \text{Trip Start Time} \\ &\text{Queue Delay} = \text{Boarding Time} - \text{Arrival Time} \\ &\text{Halting Delay} = \text{Trip Start Time} - \text{Boarding Time} \\ &\text{Road Delay} = \text{Departure Time} - \text{Trip Start time} \\ &\text{Waiting Time} = \text{Queue Delay} + \text{Halting Delay} \\ &\text{Total Delay} = \text{Waiting Time} + \text{Road Delay} \end{aligned}$$

2) Variables associated with CNG i:

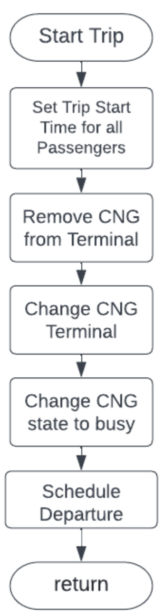
$$\begin{aligned} &\text{Passenger Count} \\ &\text{Trip Count} \\ &\text{Profit} \\ &\text{Fuel Efficiency} = 5 * \text{Passenger Count}/\text{Trip Count} \end{aligned}$$

G. Event Routines

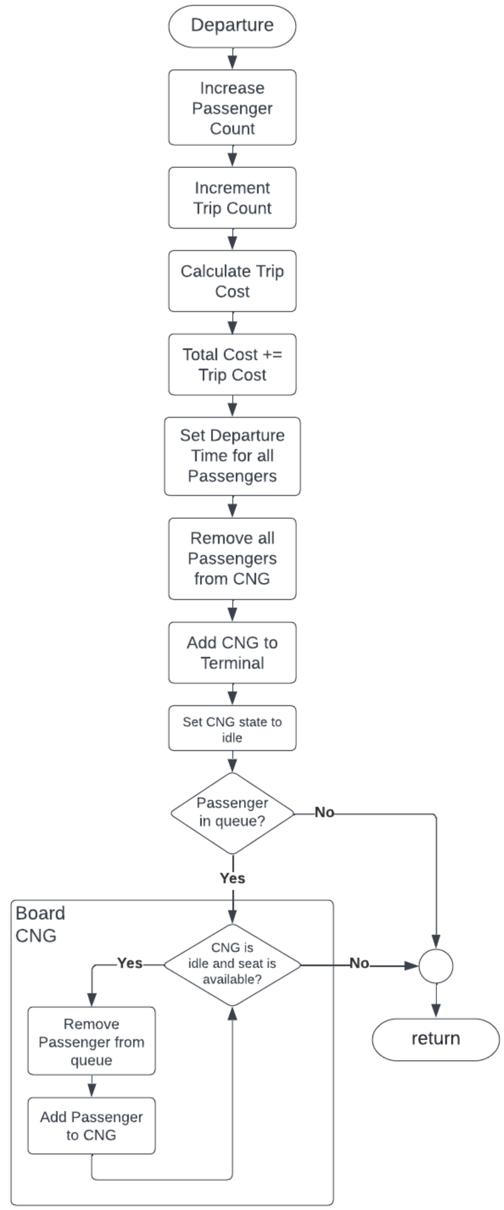
1) Arrival Event:
Flow-chart for Arrival Event:



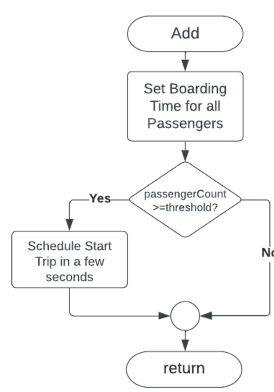
2) Start Trip Event:
Flow-chart for Start Trip Event:



3) Departure Event:
Flow-chart for Departure Event:

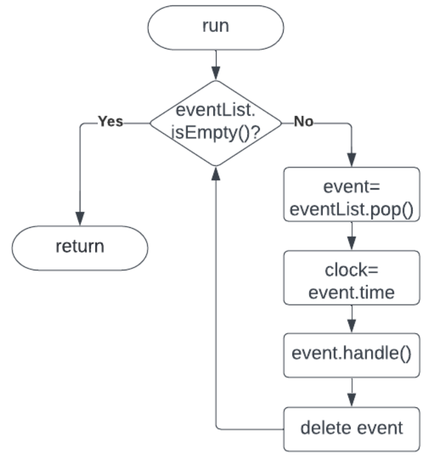


Utility function for adding a Passenger to a CNG:



III. Simulation Program Description

The program consists of five major classes: Simulator, Event, Terminal, CNG and Passenger. Among these, Terminal, CNG and Passenger can be defined as System classes. Minor classes include a FIFO Queue, a min Heap and a static class for generating random numbers and variates.
The Event class is abstract. Its child classes represent the Arrival, Start Trip and Departure event. Each of those classes have a handler function which manipulates the state of the three system classes.
The system classes consists of the system variables and containers, and the statistical variables. Handling an event involves updating the statistical variables and creating changes to the system variables.
Finally, we have the Simulator class which mainly comprises of the event list and system clock. The event list is a min heap where the upcoming events are stored. The Simulator has a run function which pops an event from the event list and handles it. In every occurrence of a new event, the clock is updated.



The full source code of the simulation program along with the trace files can be found here:
https://github.com/rafio-iut/Simulation-and-Modeling-Lab/tree/main/Project%20-%20CNG%20Simulation

IV. Result

The simulation was run for 10 days and the data is stored in trace files. A MATLAB script (summarize.m) was used to perform statistical calculations on the raw data and get the results.

TABLE III
Data Summary

Policy		1	2	3	4	5
Passenger Count	Mean	127.15	110.4	106.65	99.65	96
	Standard Deviation	17.131919	14.37981	13.963392	13.940758	8.675434
Trip Count	Mean	88.85	46.35	33.4	24.25	19.2
	Standard Deviation	9.863676	5.769931	4.172592	3.338373	1.735087
Profit	Mean	737.45	825.2	865.45	851.05	844.05
	Standard Deviation	130.354365	110.47486	115.928506	119.361668	76.139398
Fuel Efficiency	Mean	0.286395	0.476243	0.638269	0.821661	1
	Standard Deviation	0.024524	0.014706	0.01556	0.011695	0
Queue Delay	Mean	1.634201	1.317245	0.866401	0.747936	0.559817
	Standard Deviation	3.127356	2.898203	2.856057	2.29572	2.112765
Halting Delay	Mean	0.099067	2.926358	6.546526	10.136307	13.89552
	Standard Deviation	0.008123	6.814339	11.888438	15.613473	19.247287
Road Delay	Mean	1.291664	1.202754	1.191547	1.192302	1.199708
	Standard Deviation	1.299931	1.192741	1.125574	1.155305	1.197408
Waiting Time	Mean	1.733268	4.243603	7.412928	10.884243	14.455337
	Standard Deviation	3.127831	6.885027	11.777698	15.308022	18.983051
Total Delay	Mean	3.024932	5.446358	8.604475	12.076545	15.655046
	Standard Deviation	3.427993	7.025473	11.833287	15.365306	18.949401

V. Analysis

A. Delay

As expected, the total delay has a direct positive correlation with the threshold. From the observation, we can see that the total delay is mostly determined by the halting delay. The more passenger a CNG needs, the more it has to wait in the terminal before starting a trip. So, in terms of delay, the best policy is Policy 1.

B. Profit

As stated before, in every policy, the CNG driver faces a trade-off between time and fuel. From the observation, we can see that as the threshold value increases, number of trips per day increases but the passenger count also increases. The difference between the mean number of trips for Policy 1 (88.85 trips) is huge compared to that for Policy 5 (19.2 trips). The difference in average passenger count is not that high (127.15 vs. 96) because the CNGs following Policy 5 carries more passengers in a single trip. Because of this, as the threshold value increases, the fuel efficiency increases almost linearly. However, it is not completely linear because even after a CNG gets its threshold number of passengers, it waits a few more seconds to pick more passengers.

The optimal policy for highest profit turns out to be Policy 3. However, the high variances in the data and low differences in the mean values indicate a small confidence level.

Confidence levels according to t-distribution,

$P[I_3 > I_1] = 84.7011\%$

$P[I_3 > I_2] = 63.7894\%$

$P[I_3 > I_4] = 54.8382\%$

$P[I_3 > I_5] = 58.5781\%$

VI. Conclusion

By running the simulation, we can conclude that the policy of 'minimum 5 passenger per trip' which the CNG drivers follow at the moment not only wastes the passengers' valuable time, but also not optimal for gaining profit. The 'minimum 3 passenger per trip' is an optimal policy for both passengers and CNG drivers.