Self-Organizing Three Lane Motorway Simulation to Analyze Vehicle behavior Using SimPy v.4

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***Abstract*— The objective of this research is to create an algorithm that enables self-driving automobiles to self-organize in order to mitigate the effects of lane closures After the design is complete, the method is tested using the SimPy v.4 simulation model. Understanding road driving habits is a difficult study. An appropriate traffic flow model is required to accurately characterize the speed, flow, and density of a multi-lane traffic flow. Unfortunately, models with complex behaviors usually require a long time to compute. Two speed-up techniques are presented in this study, which consider traffic cellular automation models. Instead of simulation, the first method uses an analytical response based on mean-field theory, which does not, however, coincide with the simulation resultant. In a high traffic condition, the second method considers 3-lane traffic to be reduced to 2-lane traffic. The computing time for various simulation circumstances is also presented in the case where a 3km section of highway that lowers from 3 lanes to 2 lanes after 2km according to the findings, a 2-lane simulation may be a realistic approximation of a 3-lane simulation with the identical simulation. Furthermore, in the best scenario, computing efficiency can be enhanced.**

Keywords: Simulation, SimPy, Traffic, density, multi-lane

I. Introduction

In the actual world, traffic flow is complicated by factors including acceleration, deceleration, idling, lane switching, and diverse driving behaviors. As a result, several models for single-lane traffic, multi-lane traffic, lane-changing behavior, and network traffic scenarios have been created. The essential traffic flow features are described by the traffic flow theory. Model consistency is two prerequisites for traffic flow modeling and simulation. In general, microscopic models agree well on these two features. One of the microscopic models is the traffic cellular automata (TCA) model. A road in TCA is represented as a series of cells, each of which is either vacant or filled with precisely one car. It is necessary to move by propagating down a string of cells, you may create a new location. Geometric design, various driving habits, different types of cars, weather conditions, land use, network topology, and other factors all have a role in traffic difficulties in everyday life. The study of traffic flow encompasses a wide range of issues. In the actual world, multi-lane traffic is very frequent. Simulating multi-lane traffic consist of several steps. Vehicle acceleration, deceleration, lane-changing, and passing consume a lot of processing time, especially in high-vehicle-density areas. However, to increase traffic control effectiveness, it is required to characterize and anticipate multi-lane traffic flow. Two speed-up techniques are presented and tested in this study. To begin, a TCA analytical solution is provided. The computation time will be saved if the TCA simulation result can be substituted by an analytical solution. Because lane-changing behavior happens in diluted traffic, a similar notion is used next. Vehicles are unable to change lanes when traffic is heavy, resulting in more than one car in the lane. As a result, multi-lane traffic might behave similarly to single-lane traffic. Single-lane traffic simulations are significantly faster than multi-lane traffic simulations. The following is a breakdown of the paper's structure. A basic overview of multi-lane traffic CA models is given. The analytical solution's speed-up strategy is presented. Then, a comparable technique is provided. Cities want to develop and deploy smart mobility technology to serve inhabitants and visitors with innovative services and improve the overall quality of life. Simulation is utilized in a wide range of disciplines. Model efficiency may be improved or optimized by using simulation with optimization.

Research Question

Analyze the computational time and density for simulation model by lane closure in self-driving cars using different density, travel time and Volume from 3km to 2km.?

II. Literature Review

We investigate basic two-lane cellular automata based on Nagel and Schreckenberg's single-lane CA. We highlight key criteria that determine the form of the basic diagram. Furthermore, we explore the significance of stochastic components in real-world traffic [1]. Modeling of multi-lane traffic is even less well understood. This is true not only for particle hopping traffic flow models but also for traffic flow theory in general. Queueing models are not genuinely multi-lane, but they simulate many lanes by altering the order of cars on one lane anytime a passing situation would occur in reality [2] Congestion has become a major issue today. The number of cars on roads, highways, and highways is growing every day, resulting in about one-third of all vehicular traffic taking place in crowded areas. According to studies, traffic congestion creates a six-tenths of a minute delay every kilometer traveled [3]. Traffic congestion have slowed the worldwide transportation system to the point that they are jeopardizing our country's economy and civilization. One of the factors is the increasing number of vehicles on the road. Another option is that there is a significant shortage of traffic supply. The most important cause, however, is that traffic planning and optimization did not correspond to contemporary telecommunications standards. [4].

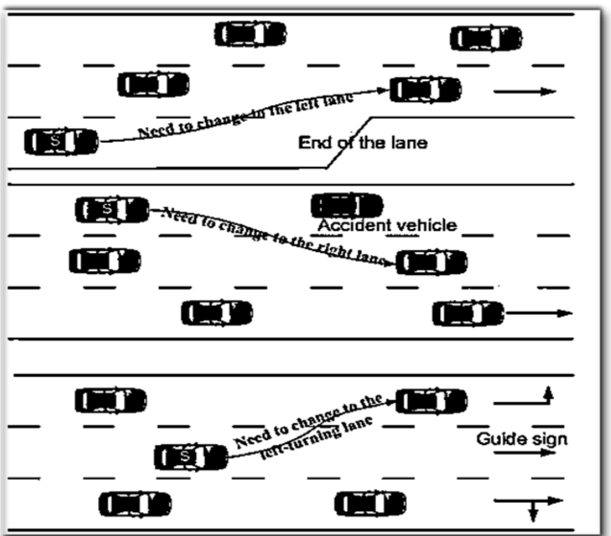

Fig. 1. When a motorist must change lanes

They discovered a link between the number of lanes shifts and two main factors: 1) the volume of traffic; 2) the type of traffic, and 3) The number of lanes that are available in any given direction of traffic. The traffic volume is proportional to the number of lanes available. To improve the safety of highway zones, dynamic lane merging systems (DLM) were created. They devised two types of lane merging strategies to advise and assist drivers on merging locations: early merge and late merge.

When people are driving, they commonly use motion signals including eye contact, reducing their speed, and altering their stance to indicate that they want to change lanes. Bansal et al. [5] created a novel mixed-autonomy traffic-driving technique in which a human-driven vehicle (HV) and an automated vehicle (AV) ride side by side. They tested this approach on a two-lane roadway. They put their technique to the test on a two-lane highway where HV and AV vehicles merge into each other's lane. They find that by fine-tuning a community incentive, it can adapt to human behavior. Figure 2 depicts the approach used to simulate an autonomous driving situation.

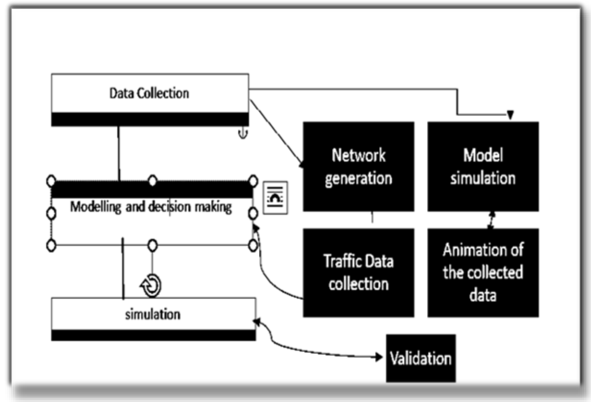

Fig. 2. A traffic simulation model for an autonomous driving scenario is shown below.

III. Methodology

The Methodology portion of any research is quite important. The main goal of our research is to use Python's SimPy simulation program to model traffic on a two-lane highway. To integrate all the components and entities necessary for simulation, several classes and objects are constructed. The Vehicle class is used to store data about the vehicle and its operations. The variables for the instance are defined in the constructor method, and the vehicle name is also saved in the data frame for gathering simulation results. For the 3km length of the motorway, the maximum number of cars is set at 1000.

The process method specifies the Vehicle procedure. First, the car enters the Entry highway entry point and waits for an empty lane. The assumption is that it will take a car 3 seconds to find an empty lane and then begin its journey. Various cases can be depicted with different parameters. The departure time is recorded in the simulation, and the current location is assigned as the variable. Surround is a data structure on the front, back, left, and right sides of a vehicle that links a number of properties and gives access to the following cars. left Lanes to the right and left Lane denotes the next available lane, whereas None denotes the absence of a lane to the left or right. The data is obtained from the data frame for each of the destinations, the cars enter the highway, and requests for an available lane are made. The car will proceed to enter the lane if it is not occupied. If not, the vehicle requests for another available lane, else it waits till the first lane is empty before it can proceed. It is somehow like the single server system trajectory. After 2 kilometers (2000m in code), the three lanes converge into two from 3. Vehicles, lanes, and the recorder are the three main items in the simulation.

Several classes and objects are created to combine all the components and entities required for simulation lane:

Lane Class: The construction of lanes for motorway traffic in the lane class is the first and most important part of the methodology. This class contains all the vehicles enter and exit lane events. It indicates that either the traffic should go to left or right lane for merging. Lanes can be built in two different ways.The highway has two lanes: the left lane and the right lane. Because cars utilize the left lane of the highway more frequently than the right lane, the left lane is referred to as the' **slow lane**,' while the right lane is referred to as the '**fast lane**' For merging lanes and segments, several functions have been used in the code:

i. **attachLeft():** This function attaches a parallel lane to the left of the existing lane.
ii. **attachRight():** This function attaches a parallel lane to the right of the existing lane.
iii. **widenLeft():** Attaches a lane segment to the current lane's left.
iv. **widenRight():** Attaches a lane segment to the existing lane's right side.

Vehicle Class: The Vehicle class determines how vehicles behave on highways in the code. This class considers all possible vehicle actions, such as overtaking, collision, and emergency braking. Vehicles are moving objects that traverse lanes. They have characteristics like as velocity, power source, and vehicle type. The vehicle type identifies the type of vehicle.

5108	100	511.62	22.33986	0.006518	625	0	-1	511.62	timer	car
5109	100	483.56	22.30894	0.005034	325	6	-1	483.56	timer	electric car
5110	100	448.16	22.23707	0.000951	626	0	-1	448.16	timer	HGV
5111	100	437.61	22.32569	0.007179	25	3	-1	437.61	timer	car
5112	100	424.19	22.32901	0.007173	326	6	-1	424.19	timer	electric car
5113	100	377.02	22.33836	0.008986	26	3	-1	377.02	timer	car

Fig 3. Type of vehicles

Surround Class: This lesson looks at the cars that are currently in use. It allows a vehicle to reach another vehicle from the vehicle's top, front, back, and sides. The many functions of the Class are listed below. (Fig 3).

Recorder Class: This class is responsible for keeping track of all simulations. It keeps track of everything that happens during the simulation's run period. For all the sub-events that occur, such as emergency braking, lane change, crashing, and any car reaching the simulation's finish, we built separate Python frameworks.

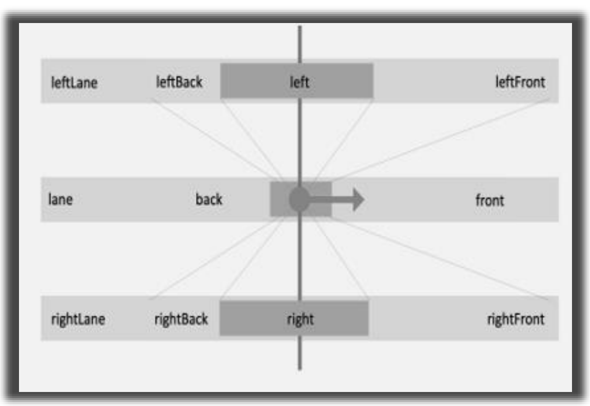

Fig. 4. Surrounding class depiction.

IV. Simulation Models

Simulating traffic flow necessitates considering a variety of factors. It lets us to observe the outcome of an experiment without having to carry it out physically. This reduces the number of physical resources and time required to set up the experiment. The notion is unique in that it may be used in a variety of circumstances.

Following the definition and construction of all classes, multiple simulation models are run, each with its own set of parameters and components:

Requirement for Simulation: The requirement specifies a specific simulation setup that must be investigated. This comprises a 3-kilometer stretch of highway that decreases from three to two lanes after two kilometers. This may be described as three different lanes, one of which is 2 kilometers(2000m) long and the other two of which are each 3 kilometers(3000m) long. To offer the needed configuration, these three lanes are stacked one on top of the other.

Model for Traffic Generation: For all simulation models, four quantities are measured and assessed. These values provide information on how our input parameters impact the simulated models. *Travel Time (Average)*: The average travelling time of any vehicle is the time taken by the vehicle to reach the end of the motorway. In this study, the car that will get to the end of the highway We estimated the average travel time by calculating the difference between the entering lane and end lane events of cars that successfully reached the end of the highway. These timings are then averaged based on the number of cars involved. The time used is IAT (Inter ArrivalTime) of three cases for simulation represented below optimal speed represented with different cases.

Traffic Generation: The Vehicle entity in the simulation is a real-world object that interacts with the Lanes. Each vehicle's length and kind of power source, as well as its velocities and timings, characterize it. Surround is a class that maintains track of the surroundings of a vehicle. We may also examine the several graphs below, which depict various aspects of the vehicle's movements.

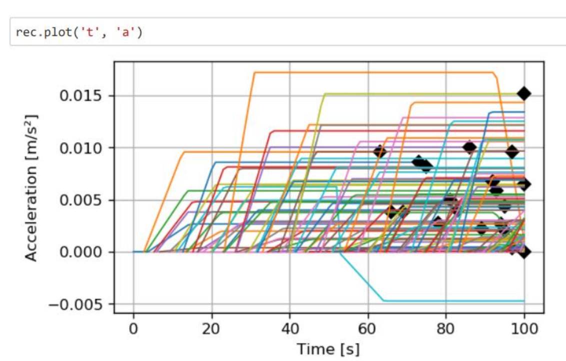

Fig.5. Before merging the simulation graph for 120kmperhour IAT 3sec

Case I: In this Simulation model, Values for *the traffic volume/density/travel time of vehicle at 120 km/h after 3000m and 2000m given below Fig .6. Number of vehicles in this model are 1000 and* IAT is 3seconds.With 20%Cars,35% heavy vehicles and 45% mix traffic.

```
Case 1

1000 Vehicles, 300 in left Lane, 400 in center lane and 300 in Right Lane

Inter-Arrival Time Distributions = 3 sec for each lane

Traffic Mix = 45% of "Car", 20% of "Electric Car", 35% of " heavy goods vehicles"

Motorway speed Limit Setting = 120Km/h = 120/3.6 m/s

 **************************** After 2000m (***************************

 The traffic Volume at 2000m the left lane :  1264.86
  The traffic Volume at 2000m the right lane : 1164.71
  The traffic Volume at 2000m the centre lane 1200.0

  The traffic Volume at 2000m in all lane 3629.5699999999997

  --------------------------------------------------
 The traffic density at 2000m the left lane :  10.0
  The traffic density at 2000m the right lane : 10.0
  The traffic density at 2000m the centre lane 10.0

 The traffic density at 2000m in all lane 30.0

  --------------------------------------------------
 Average Travel travel at 2000m the left lane : 8.96
 Average Travel travel at 2000m the right lane : 9.09
 Average Travel travel at 2000m the centre lane : 9.02

 Average Travel travel at 2000m in all lane : 9.023333333333333

  --------------------------------------------------
 Average speed at the 2000m the left lane : 120.54
 Average speed at the 2000m the right lane : 118.81
 Average speed at the 2000m the centre lane : 119.73
 Average speed at the 2000m the all lane : 119.69333333333334

***************************** After 3000m (*************************

 The traffic Volume at 3000m the right lane : 1200.0
 The traffic Volume at 3000m the centre lane 1028.57

 The traffic Volume at 3000m in all lane 2228.5699999999997

 --------------------------------------------------
 The traffic density at 3000m the right lane : 0.0
 The traffic density at 3000m the centre lane 0.0

The traffic density at 3000m in all lane 0.0

 --------------------------------------------------
Average Travel travel at 3000m the right lane : 29.67
Average Travel travel at 3000m the centre lane : 29.67

Average Travel travel at 3000m in all lane : 29.67

 --------------------------------------------------
Average speed at the 3000m the right lane : 121.33
Average speed at the 3000m the centre lane : 121.33
Average speed at the 3000m the all lane : 121.33
```

Fig. 6. traffic volume/density/travel time for vehicle at 120km/h

Case II*: 100 km/h after 3000m All the traffic volume/density/travel time is 0.0.*

```
**************************** After 2000m (**********************

The traffic Volume at 2000m the left lane :  1252.17
 The traffic Volume at 2000m the right lane : 1145.45
 The traffic Volume at 2000m the centre lane 1200.0

 The traffic Volume at 2000m in all lane 3597.62

 --------------------------------------------------
The traffic density at 2000m the left lane :  13.33
 The traffic density at 2000m the right lane : 13.33
 The traffic density at 2000m the centre lane 13.33

The traffic density at 2000m in all lane 39.99

 --------------------------------------------------
Average Time travel at 2000m the left lane : 10.62
Average Time travel at 2000m the right lane : 10.75
Average Time travel at 2000m the centre lane : 10.67

Average time travel at 2000m in all lane : 10.68

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Fig.7. traffic volume/density/travel time for vehicle at 100km/h

Case III*: 80 km/h after 3000m All the traffic volume/density/travel time is 0.0.*

```
**************************** After 2000m (***************************

The traffic Volume at 2000m the left lane :  1028.57
 The traffic Volume at 2000m the right lane : 1200.0
 The traffic Volume at 2000m the centre lane 1028.57

 The traffic Volume at 2000m in all lane 3257.14

 --------------------------------------------------
The traffic density at 2000m the left lane :  16.67
 The traffic density at 2000m the right lane : 13.33
 The traffic density at 2000m the centre lane 16.67

The traffic density at 2000m in all lane 46.67

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Average Time travel at 2000m the left lane : 13.0
Average Time travel at 2000m the right lane : 13.33
Average Time travel at 2000m the centre lane : 13.39

Average time travel at 2000m in all lane : 13.24

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```

Fig. 8. traffic volume/density/travel time for vehicle at 80km/h

Case IV*: 60 km/h after 2000m and 3000m, All the traffic volume/density/travel time is 0.0.*

```
**************************** After 2000m (**********

The traffic Volume at 2000m the left lane :  0
 The traffic Volume at 2000m the right lane : 0
 The traffic Volume at 2000m the centre lane 0

 The traffic Volume at 2000m in all lane 0

 --------------------------------------------------
The traffic density at 2000m the left lane :  0.0
 The traffic density at 2000m the right lane : 0.0
 The traffic density at 2000m the centre lane 0.0

The traffic density at 2000m in all lane 0.0

 --------------------------------------------------
Average Time travel at 2000m the left lane : 0
Average Time travel at 2000m the right lane : 0
Average Time travel at 2000m the centre lane : 0

Average time travel at 2000m in all lane : 0.0
```

Fig.9. traffic volume/density/travel time for vehicle at 60km/h

Evaluation of the results obtained from the variable speed in the simulation can be obtained by Comparing the simulation values, it shows that as the speed is reduced the traffic on the lane reduced from 120 Km/h to 60 Km/h it varies in a continuous manner refer the above values in Fig 6 to Fig 9.The average speed reduced from 121.33 to 0 for the first scenario till the last , where the vehicle is going with the IAT of 3 seconds from 3Lanes to 2 Lanes but the density increase dramatically for first 2km from 120km/h to 100 km/h from 0.0 to 39.99 and for 80 km/h 46.67 till 2km but as the traffic reduced over the lane then the 3000m lane values decreased and become 0.0

- ***Case V****:* The IAT for this case increased from 3seconds to 10sec and the speed was like Case 1. The traffic simulation in this case shows that the traffic density decreased from 30.0 to 6.66 at 2000m

```
**************************** After 2000m (***************************

The traffic Volume at 2000m the left lane :  720.0
 The traffic Volume at 2000m the right lane : 0
 The traffic Volume at 2000m the centre lane 400.0

 The traffic Volume at 2000m in all lane 1120.0

 --------------------------------------------------
The traffic density at 2000m the left lane :  3.33
 The traffic density at 2000m the right lane : 0.0
 The traffic density at 2000m the centre lane 3.33

The traffic density at 2000m in all lane 6.66

 --------------------------------------------------
Average Time travel at 2000m the left lane : 8.67
Average Time travel at 2000m the right lane : 9.0
Average Time travel at 2000m the centre lane : 8.75

Average time travel at 2000m in all lane : 8.806666666666667
```

Fig. 10. traffic volume/density/travel time for vehicle at 120km/h for 10sec IAT.

Case VI: The IAT for this case increased from 10 seconds to 20 seconds and the speed was like Case 1 and Case 5. The traffic simulation in this case shows that the traffic density decreased from 6.66 to 3.33 exactly half at 2000m by increasing the IAT twice the initial value.

```
**************************** After 2000m (***************************

The traffic Volume at 2000m the left lane :  327.27
 The traffic Volume at 2000m the right lane : 0
 The traffic Volume at 2000m the centre lane 0

 The traffic Volume at 2000m in all lane 327.27

 ---------------------------------------------------
The traffic density at 2000m the left lane :  0.0
 The traffic density at 2000m the right lane : 0.0
 The traffic density at 2000m the centre lane 3.33

The traffic density at 2000m in all lane 3.33

 ---------------------------------------------------
Average Time travel at 2000m the left lane : 8.67
Average Time travel at 2000m the right lane : 9.0
Average Time travel at 2000m the centre lane : 9.0

Average time travel at 2000m in all lane : 8.89

 ---------------------------------------------------
```

Fig. 11. traffic volume/density/travel time for vehicle at 120km/h for 20sec IAT.

The first part of our simulation study is simulating a three lane highway to calculate all of the parameters and quantities measured in the previous section, and the second part is integrating the free motorway Speed() function into the model to calculate the velocities of all the vehicles in the flow.

- **Model for Behavior of Human Drivers**: Simulation of the behavior of the human drivers is done using the below components:

```
if d < d_behaviour:
  behaviour = 'normal'
elif d > d_behaviour:
  behaviour = 'drunk'
else:
  behaviour='rash'
```

Fig.12. Human behavior in the simulation of traffic flow

Uniform Distribution: In this sort of distribution, the python random. uniform () method is used, which provides a random floating-point value between any two functions. Uniform Distribution is a distribution made up of these floating-point numbers.

– Expovariate Distribution: In this sort of distribution, the python random.expovariate() function is used, which provides pseudo-random integers between any two functions. It is possible to determine the random numbers generated by this function. Expovariate Distribution refers to a distribution made up of these random numbers.

Data Collection and simulation data gathered

The simulation itself entails setting up the parameters correctly, adding randomization, and documenting all fine-grained changes in the system.The behavior of five vehicle entities is monitored to achieve optimal traffic flow. The full simulation parameter values as seen and documented by the simulation recorder. Inter arrival time (**IAT**) is computed in our study using both a Uniform and an Expovariate distribution. The second task is an extension of the previous model for imitating human driving behavior. We utilized the free motorway speed () function, which is supplied in the traffic generating file's class that leads to the vehicle's speed. Data collected the csv file from simulation for different speed and IAT. Multiple cases can be formed with multiple variations like change in number of vehicle, lane etc.

Data_x20192037_priyanka_simulation1_60kmperhour
Data_x20192037_priyanka_simulation1_80kmperhour
Data_x20192037_priyanka_simulation1_100kmperhour
Data_x20192037_priyanka_simulation1_120kmperhour (1)
Data_x20192037_priyanka_simulation1_120kmperhour_10...
Data_x20192037_priyanka_simulation1_120kmperhour_20...

Fig. 13. Simulated data from cases tested on the 1000 vehicles.

V. RESULTS AND INTERPRETATION

When comparing the simulation data, when the speed is lowered, the traffic on the lane decreases with the speed and the density increased with the reduced number of vehicles till the end of 3km lane. The comparisons of simulation in the code is reflected with the case numbers and the resultant csv files are stored for future analysis of the work by other researchers to reduce the lanes in the circumstances where the number of vehicle is uniform whereas the speed and the Inter Arrival time varies for the vehicle also the behavior of the driver plays a vital role in the simulation. By increasing the IAT twice the initial amount, the traffic density fell from 6.66 to 3.33 exactly half at 2000m, according to the traffic simulation. The driver can be depending on the type of the vehicle and the mental and physical state of the driver.

VI. REFLECTION AND FUTURE WORK

In this paper, we modelled many features of a three-lane highway in our study. Three distinct simulations were built for different values of parameters such as inter-arrival time and speed distribution are used in the models. For each simulation, throughput, average trip time, average speed, and traffic density were calculated. The first simulation model, which uses a uniform speed distribution function, achieves a top speed for of 1000 vehicles. Traffic forecasting is an important element of transportation system management modernization. Accurate traffic parameter forecasting findings can assist traffic control centers in transportation systems in reducing traffic congestion and increasing mobility. Models will have more intrinsic features that mirror real-world circumstances in the future to generate sophisticated simulations with various surfaces, driving circumstances, and lighting settings, among other things whether its day or night. Also, Weather conditions, gender, age can be included in the future work of this traffic simulation study. Proper simulation studies can provide the much-needed evidence for various vehicle options. This demonstrates the value of simulation in guiding key commercial and social choices in the correct direction.

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