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Towards Simulating Non-lane Based Heterogeneous Road Traffic of Less Developed Countries

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Abstract

Microscopic traffic simulators have become efficient tools to conduct different analytic studies on roads, vehicles, behavior of drivers, and critical intersections, which lead towards a well-planned traffic solution. Devising a realistic and sustainable traffic solution requires replication of the real traffic scenario in a simulator. For example, to simulate the traffic streams of developing and under developed countries, we need to simulate non-lane based heterogeneous traffic stream, i.e., motorized and non-motorized vehicles, road traffic behaviors such as irregular pedestrian, illegal parking, violation of laws pertaining lanes, etc. However, most of the existing traffic simulators are unable to mimic the unstructured road traffic streams of less developed countries with their diversified behaviors. Therefore, in this work, we propose a new microscopic traffic simulator to handle non-lane based heterogeneous traffic stream and on road traffic behaviors that generally occurred in the road networks of cities in less developed countries. Our simulator receives network topology, traffic routes, and traffic demand flow rates as input, visualizes the traffic flows, and provides traffic statistics. To evaluate sustainability of our proposed simulator in real-life scenarios, we calibrate the simulator using real traffic data. Our evaluation reveals 99% accuracy in terms of travel time.

1 Introduction

Microscopic traffic simulation has become an effective tool for evaluating and developing road traffic management and control systems all over the world [1]. It facilitate different analytic studies on roads, vehicles, behavior of drivers, critical intersections to develop a well-planned traffic solution for both urban and rural areas. Consequently, traffic simulation over different real-life traffic scenarios allows us to foresee potential consequences of taking any measure at infrastructure level or at policy level. Hence, in recent times, usage of microscopic traffic simulators is increasing to investigate different transport planning and policy initiatives before actual field implementations.

However, in order to devise a realistic traffic solution, we need to model real-world traffic stream to the simulation environment, which varies from country to country. The traffic stream of less developing countries such as Bangladesh, India, etc., contain both motorized vehicles and human powered vehicles on same road way, which results in an unstructured traffic system, commonly characterized as non-lane based and heterogeneous traffic system [1, 2]. The fast moving motorized vehicles include bus, cars, auto rickshaws (Compressed Natural Gas), trucks, etc. On the other hand, the slow moving human powered vehicles include rickshaws, vans, and bi-cycles, which are different in driving behavior and exhibit lack of discipline following lane in particular. Furthermore, irregular road crossing by pedestrians and hawkers, illegal parking of vehicles, etc., are very common phenomena in the road networks of developing and under-developed countries.

In order to mimic the realistic outcome of any existing or future development on the road network of developing countries, we need to replicate the real traffic scenario of the developing countries in the simulator. However, existing traffic simulation tools such as VISSIM [3], MIT-SIM [4], etc. primarily focus on simulating structured traffic. Hence, we fail to use them to mimic diversified traffic scenario of developing countries. Besides, there exist some open source simulators [5, 6], which support only lane-based homogeneous traffic. However, we cannot extend them to support the real traffic scenario of less developed countries due to architectural differences.

As a remedy of the aforementioned problems in a sustainable manner, we propose a new microscopic traffic simulator, which simulates the non-lane based heterogeneous traffic stream and on road traffic behaviors that generally occurred in the road networks of less developed countries. Our simulator take network topology, traffic routes, and traffic demand flow rates as input, then it visualizes the traffic flows, and finally, provides traffic statistics such as average vehicle speed, total number of vehicles per road, and total number of accidents per road. Based on our work, we make the following set of contributions:

- We develop a traffic simulator to address non-lane based traffic by dividing a road into some thinner strips than lanes. Here, one vehicle can cover multiple strips and move along a random strip.
- Next, we incorporate irregular movement of pedestrians and hawkers such as crossing the roads, walking along the roads instead of foot-path, etc., in our simulator.
- We have collected traffic flow rate and average speed of vehicles in Dhaka using a data collecting module built with ultrasonic sensor (HC-001). We calibrate our simulator using this data to evaluate the performance of our simulator, which results in 99% accuracy in terms of travel time between two intersections of Dhaka city.

2 Related Work

Microscopic traffic simulation tools are increasingly being used around the world to test different transport planning and policy initiatives before their actual field implementations. For effective planning over a road network of a particular area, we need a simulator that meets the diverse behaviors of road traffic of that area.

There exist several simulators in literature and over the year they are updated to mimic the real-world traffic. Ferrer et al. [7], propose an interactive microscopic simulator (AIMSUN) for urban and non-urban networks. The latest version of AIMSUN [8] includes mesoscopic and microscopic simulators and dynamic traffic assignment models based on either user equilibrium

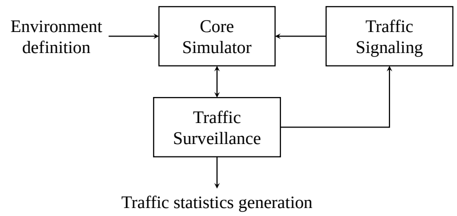


Figure 1: Modules of our proposed microscopic traffic simulator

or stochastic route choice. However, it supports only lane-based homogeneous traffic. Yang et al. [9] propose a microscopic traffic simulation model (MITSIM) that evaluates the impacts of alternative traffic management system designs, traveler information systems, public transport operations, and various ITS strategies at the operational level and assists in their subsequent refinement. However, MITSIM supports lane-based homogeneous traffic only. Although an open-source version of MITSIM is available from 2004 [10], we cannot extend it to support non-lane based heterogeneous traffic due to the architectural difference. Fellendorf et al. [11], propose a microscopic behavior-based multi-purpose traffic simulator (VISSIM) to analyze and optimize traffic flows. It offers a wide variety of urban and highway applications, integrating public and private transportation. It is the ideal tool for state-of-the-art transportation planning and operations analysis [2]. The latest version of VISSIM supports heterogeneous traffic that follows lane-based discipline. It also models car parking, moving pedestrian, etc. in a structured manner.

To fill the gap in literature, we propose a new simulator, which can handle non-lane based unstructured traffic scenario of less developed countries with their on road behaviors such as irregular pedestrians on road, unwise parking on road, mobile market, etc. in a sustainable manner.

3 Our Proposed Methodology

Our proposed simulator consists of three modules such as core simulator, surveillance, and signaling. We delineate the modules and their interactions in Figure 1. At first, we define the simulator environment, which describes the road network such as junctions and links, traffic flow rate, and routes and feed the definition to the core simulator. After that, the core simulator creates the environment according to given definition and generates heterogeneous traffic including pedestrians, motorized vehicles, and human-powered vehicles. Then, it simulates the traffic using their real-world behavior.

While running the simulation over the user defined environment, the surveillance module collects data of current traffic from different parts of the road network and forwards it to signaling module, which imposes traffic signals to the simulator. When simulation time is over, surveillance module generates different statistics on simulated road network such as average number of vehicles, average speed of vehicles, accident count, etc. for each link. We describe the detail architecture of our proposed simulator in the next section.

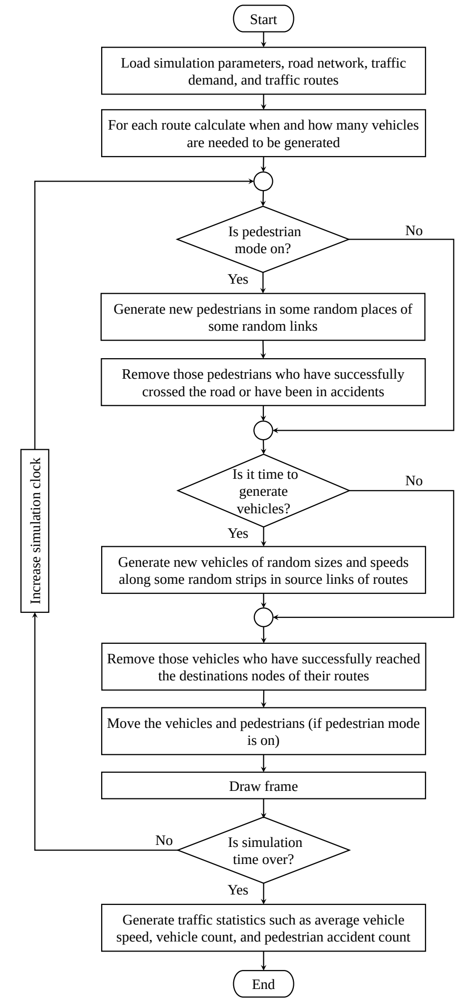


Figure 2: Flow chart of our proposed microscopic traffic simulator

4 Simulator Implementation

We implement our simulator in Java language and we visualize the simulation using Swing library of Java. At first, we create the simulation environment by using some configuration files. Then, we simulate the non-lane based heterogeneous traffic stream with their on road behavior in a loop until simulation time is over. The logical flow chart of our simulator is showed in Figure 2. Now, we describe the main components of our simulator in detail.

4.1 Modeling Road Network

Our simulator loads the simulator environment from five configuration files, which describe the information of junctions, links, traffic demand, routes, and some configuration parameters of the simulator. Since the road network is represented as a graph data structure in the simulator, the

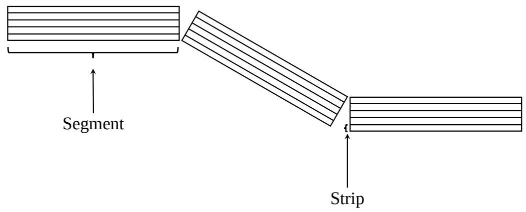


Figure 3: Strip arrangement of a curved road (link)

```
21
0 0 0 16 18 17 14
1 317 26 4
2 436 20 19
3 675 14 20
4 990 0 18
5 1204 95 17
6 1138 413 13
7 955 767 22
8 643 750 0
9 428 766 6
10 126 760 2
11 55 419 1
12 0 0 15 14 13 12
13 0 0 10 15 11
```

(a) Format of the junction file

```
23
0 8 16 1
0 618 730 591 567 10
1 11 18 1
0 67 403 161 409 10
2 10 18 2
0 110 735 134 656 10
1 137 647 175 440 10
3 18 19 1
0 185 410 289 260 10
4 19 1 1
0 295 225 293 46 10
5 19 15 2
0 356 257 469 358 10
1 484 368 563 377 10
```

(b) Format of the link file

```
12
11 9 1 21 6
9 11 6 21 1
1 10 4 3 2
10 1 2 3 4
7 4 22 12 14 18
4 7 18 14 12 22
8 3 0 8 9 20
3 8 20 9 8 0
6 1 13 15 10 5 4
1 6 4 5 10 15 13
2 5 19 16 17
5 2 17 16 19
```

(c) Format of the route file

```
12
11 9 1800
9 11 1800
1 10 1500
10 1 1500
7 4 1200
4 7 1200
8 3 2000
3 8 2000
6 1 3600
1 6 3600
2 5 1000
5 2 1000
```

(d) Format of the demand file

```
SimulationSpeed 100
SimulationEndTime 10000
PixelPerStrip 3
PixelPerFootpathStrip 3
PixelPerMeter 6
EncounterPerAccident 1
StripWidth 0.5
FootpathStripWidth 0.5
MaximumSpeed 50.0
PedestrainMode Off
```

(e) Format of the parameter file

Figure 4: Different input configuration files of our simulator

junctions are nodes and links are edges of the graph. Therefore, junctions and links define the road network. Besides, traffic route and demand describe the traffic flow rate for a particular path in the road network. We create a road using a link, which can be subdivided by some segments to represent the curvature of a road. Each segment is further divided laterally into some thin strips, which act as virtual lanes for non-lane based heterogeneous traffic stream. A vehicle occupies a number of strips based on its type. Each link is sandwiched by a foot-path on each side which also occupies some strips. Figure 3 demonstrates the arrangement of strips in a curved road. Now, we describe the input configuration files briefly.

4.1.1 Junctions

Junctions represent the intersections of the roads. In the configuration file of junctions, we describe a junction with its unique id, Cartesian co-ordinate, and a list of adjacent links. The input configuration file of junctions is showed in Figure 4a. The first line denotes the number of junctions of the given road network.

4.1.2 Links

Links define the actual roads or corridors in the simulation environment. In the configuration file of links, we describe a link with its unique id, id of two adjacent nodes, and number of constituent segments. After each link description, we describe the information of all segments that belong to a link. We describe a segment with its unique id, Cartesian co-ordinates of two end points, and width of the segment. Figure 4b shows the format of a link file. The first line denotes the number of links of the given road network.

4.1.3 Traffic Routes

Traffic routes are the paths between source and destination nodes in the graph. We describe a traffic route with the source node, destination node, and the list of links. We demonstrate a route file in Figure 4c. Here, the first line denotes the number of routes in the file. We use bidirectional traffic, hence, each entry is repeated in reverse direction. Traffic generates from source node and starts from the first link of the route. Conversely, it arrives at the last link of the route and enters into destination (sink) node.

4.1.4 Traffic Demand

Traffic demand represents the traffic flow rate of a route between a source and sink pair of nodes in the network. We describe traffic demand of each route with its source node, sink node, and flow rate in vehicles per hour. Figure 4d shows a demand file. Here, the first line denotes the number of demand entries in the file. As we use bidirectional traffic, each demand entry is repeated in reverse direction.

4.1.5 Simulation Parameters

We provide some additional simulation parameters to customize the environment such as simulation speed, simulation end time, pixel per strip, pixel per footpath strip, pixel per meter, encounter per accident, strip width, footpath strip width, maximum speed of the vehicles, and state of pedestrian mode. Here, one unit linear distance is equivalent to one meter and one simulation step is equivalent to one minute. Besides, encounter per accident is the probability percentage of being an accident. Figure 4e shows the parameter file. These parameters can also be given as input from GUI.

After creating simulation environment, we calculate when and how many vehicles are needed to be generated from a probability distribution. We can mimic a real road environment by providing geographical road network and real survey data of traffic demand, routes, accident probability, maximum speed of vehicles, etc. We can also add time dependency on these parameters to make the environment more realistic.

4.2 Modeling Pedestrians

After modeling road network, we have to model the pedestrians and their behavior in our simulator. In developing country, pedestrians move across the roads from anywhere. Besides, a pedestrian may have an accident with a running vehicle while crossing the road. We generate new pedestrians in some random places of random links and the probability distribution of pedestrian generation is completely uniform. We remove those pedestrians who have successfully crossed the road or have been in accidents. Note that, our simulator has an option to turn off the pedestrian model, which we provide as input during road network modeling.

Actually, we create the pedestrian as a generic object to provide additional functionality to make the simulator more realistic. For example, we can make some static pedestrians on the border sides of a road to mimic the street hawkers, crowds around mobile markets, etc., on the footpaths.

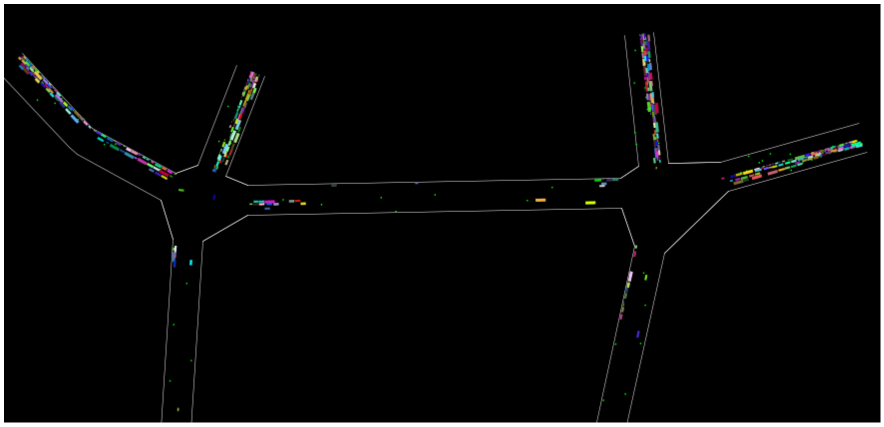


Figure 5: Visual representation of our simulator (colored rectangles are vehicles, green dots are pedestrians)

4.3 Modeling Vehicles

This component is the core part of our simulator. In developing countries, different types of vehicles run in the roads such as motorized and non-motorized, i.e., human powered. As they are different in terms of width, length, speed, etc., they cannot maintain a lane structure while moving along the roads. We model these non-lane based heterogeneous traffic by using different size of vehicles with different speeds. We model the real-world drivers behavior by using car following model and moving the vehicles along any strip of the roads. According to traffic demand, we generate different types of vehicles on different source nodes of the routes. As soon as the vehicles reach the destination nodes of their routes successfully, we remove them from the network. In order to mimic the parked vehicles on the roads, we can create some static vehicles on the border sides of some roads.

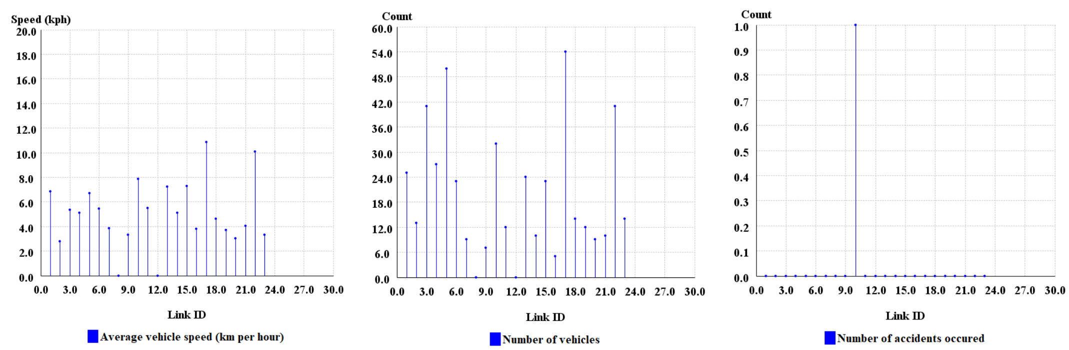
4.4 Graphical User Interface

The usability of a traffic simulator depends on interactivity. Hence, in order to make our simulator more user friendly, we provision for graphical interactions along with the configurations files. Our simulator visualizes the simulation in a graphical user interface (GUI). One such simulation is illustrated in Figure 5. Here, the colored rectangles and green dots represent the vehicles and pedestrians respectively. We can see that different sizes of vehicles are congested in the three source links. They are waiting for green signals from traffic signaling module. We can also see that the vehicles are highly congested in the middle of the roads and the congestion decreases with the increase of lateral distance across the road. There is no lane-structure in the roads and vehicles try to move everywhere when they get spaces. Hence, this scenario delineates the real non-lane based heterogeneous traffic stream, which resembles a common scenario in the road networks of cities in developing and underdeveloped countries.

Since GUI mode consumes much CPU and memory, we provide an option to simulate the traffic in console mode. The console mode is faster than GUI mode. Consequently, at the end of simulation, diverse traffic statistics are generated.

```
start
object
4692 8365 false
4944 7675 false
vehicle
933 984 931 983 4847 4851 4868 4871
4782 4731 4808 4757 9098 9010 9083 8995
3669 3670 3693 3694 583 653 583 653
1351 1367 1371 1387 8728 8676 8734 8682
11124 11120 11140 11136 8887 8856 8885 8854
11772 11775 11781 11784 152 177 151 176
7414 7405 7434 7426 8727 8676 8723 8673
7853 7841 7867 7856 395 425 401 430
13209 13158 13209 13158 4784 4784 4805 4805
3684 3685 3705 3706 567 622 567 622
5665 5700 5650 5685 312 350 326 364
13874 13853 13876 13855 1083 1088 1089 1095
end
```

Figure 6: Format of the simulator log files describing the state of pedestrians and vehicles for each simulation step



(a) Average vehicle speed in km per hour over all links (b) Total number of vehicles over all links (c) Total number of accidents over all links

Figure 7: Traffic statistics for each link during simulation time

4.5 Simulator Log

We save the attributes of the pedestrians and vehicles for each simulation step in a log file to replay the simulation. A typical log file is shown in Figure 6. For each step, the log starts and ends a simulation step with a *start* and an *end* keywords respectively. The information about pedestrians and vehicles is started with an *object* and a *vehicles* keywords respectively. The log describes the information regarding a pedestrian with the co-ordinate of the pedestrian and status of the pedestrian whether (s)he is in accident or not. On the other hand, the information regarding the a vehicle is described with the co-ordinates of four corner points as following format:

$$x_1 \quad x_2 \quad x_3 \quad x_4 \quad y_1 \quad y_2 \quad y_3 \quad y_4$$

Here, (x_1, y_1), (x_2, y_2), (x_3, y_3), and (x_4, y_4) represent the top-left, top-right, bottom-left, and bottom-right corner points of the vehicle.

4.6 Statistics Generation

In order to simulate the surveillance system, we place one sensor in a random place of per segment. The sensors gather data of the number of vehicles that have passed over the sensor

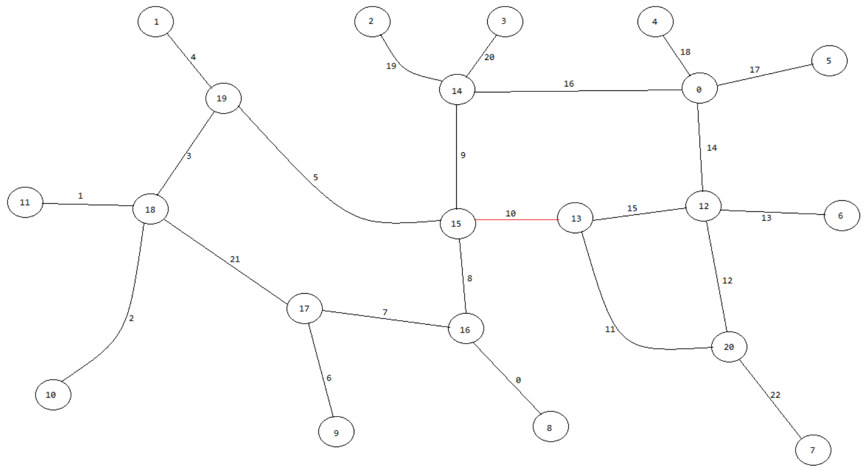


Figure 8: Sample map of a road network used in analyzing link effects by removing the red colored link

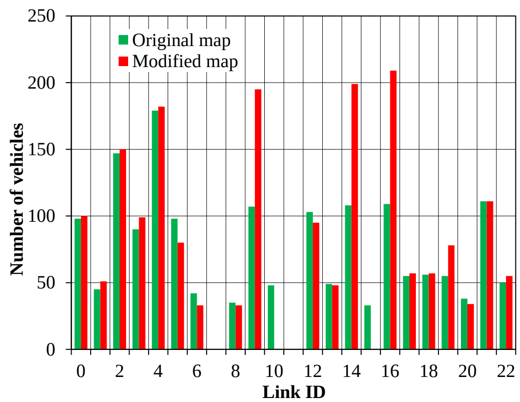
and measure the speed of the passed vehicles. It also collects accident information on every segment. When the simulation time is over, the surveillance module plots the graphs of average number of vehicles, average speed of vehicles, and average accident count for every link using JMathPlot library of Java [12]. The traffic statistics of a small road network is shown the Figure 7. Here, we use traffic demand of 100 vehicles per hour (vph), maximum allowable speed of the vehicles 20 km per hour (kph), and accident probability of 0.1%.

5 Experimental Evaluation

In this section, we present some preliminary results of our simulator. We evaluate our simulator in both virtual and real-world experiments. In virtual test, we analyze the effect of a particular link over the whole network. Moreover, we also measure travel time of the simulated vehicles and compare it with real data. We use a Windows PC to evaluate our simulator, which has four Intel Core i5-3470 (3.20 GHz) cores and four GB physical memory.

5.1 Virtual Testing

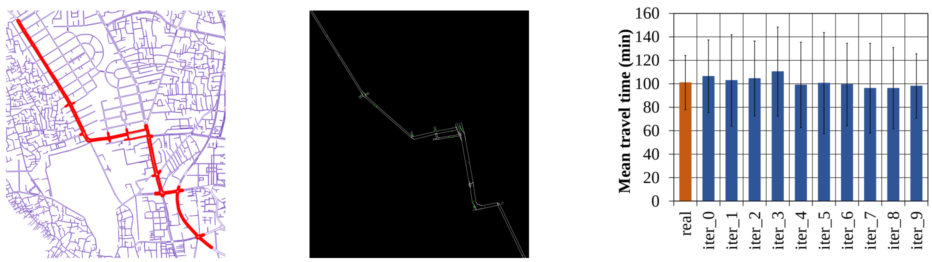
We consider a particular link of a road network and analyze its effect over the whole network. Figure 8 shows the map of the road network, which is used for testing purpose. We analyze the effect of the red colored link (link 10) by inclusion and exclusion respectively in two simulations. The traffic statistics of both simulations such as average vehicle speed and total number of vehicles are showed in Figure 9. We can see that the number of vehicles has increased significantly in some links such as link 9, 14, and 16 due to link 10 exclusion (Figure 9a). Besides, the average speed of these congested links have decreased (Figure 9b). In these experiments, we use demand flow rate of 100 vph, maximum allowable speed is 10 kph, and pedestrian mode is turned on with accident probability of 0.01%.



(a) Total number of vehicles over all links

(b) Average speed of vehicles over all links

Figure 9: Traffic statistics for original map and modified map



(a) Real GIS road map of Sankar to Palashi intersections (red colored)

(b) Simulated road map of Sankar to Palashi intersections

(c) Travel time measuring in simulator and real-world

Figure 10: Comparison between simulated and real average travel times

5.2 Real Testing

In addition to evaluation in virtual environment, we evaluate our simulator with real-world experiments. We compare the simulated travel time against real data in a real road network. We use the real road map of Dhaka city (capital of Bangladesh) and measure the travel time between Sankar and Palashi intersections in both simulation (Figure 10b) and real-world (Figure 10a). In the simulation, we use demand flow rate of 124 vph and maximum allowable vehicle speed of 17.3 kph in both intersections [2]. We also turn pedestrian mode on. Note that, we collect real data of bi-directional traffic including different vehicles, i.e., from Sankar to Palashi and vice-versa. We perform 10 iterations in simulation by creating same environment of real world and log travel time of different bi-directional vehicles. Then, we calculate average values with standard deviations. The resultant average real travel time and simulated travel time is showed in Figure 10c. We can see that our simulator closely mimics the real travel time (99% accuracy) from Sankar to Palashi and vice-versa.

6 Future Work

The purpose of this traffic simulator was to mimic unstructured, non-ideal road traffic scenarios present in the developing and under developed countries. Therefore, we used a simple model to realize these diverse behaviors. However, there are a lot of factors that we omitted for the sake of simplicity, such as, driver behaviour, vehicle characteristics, modal split etc. We envision to incorporate these factors in our future models. Moreover, owing to the lack of data, travel time between only a pair of points in the Dhaka city is simulated and verified. In future, we plan to cross check our results by collecting travel time data among different pair of points in Dhaka city to demonstrate efficacy of our simulator.

7 Conclusion

The presence of non-ideal conditions such as the mixture of human powered and motor powered vehicles, illegal parking, violation of rules pertaining lanes, etc., are worsening the traffic condition of less developed countries in the world. A traffic simulator addressing the above-stated issues could be a potential answer towards designing an effective and sustainable transportation system for these countries. However, none of the existing studies on traffic simulator mimics all the aspects of the road traffic behaviors of developing countries. Therefore, in this work, we design a simulator that meets the above-specified issues in a sustainable manner. We provide different calibration parameters that can be used to mimic the real-world scenario. We validate our simulator by some experiments involving real map and real data of Dhaka city, the capital of Bangladesh. We plan to incorporate autonomous vehicles in the simulator to analyze its sustainability by observing on road behavior while moving along the roads in the less developed parts of the world.

Acknowledgment

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