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
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.
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Load simulation parameters, road network, traffic demand, and traffic routes.

For each route calculate when and how many vehicles are needed to be generated.

Is pedestrian mode on?

No

Generate new pedestrians in some random places of some random links.

Remove those pedestrians who have successfully crossed the road or have been in accidents.

Is it time to generate vehicles?

No

Generate new vehicles of random sizes and speeds along some random strips in source links of routes.

Remove those vehicles who have successfully reached the destinations nodes of their routes.

Move the vehicles and pedestrians (if pedestrian mode is on).

Draw frame.

Is simulation time over?

No

Generate traffic statistics such as average vehicle speed, vehicle count, and pedestrian accident count.

End

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
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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

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

Figure 4: Different input configuration files of our simulator
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 sim-
ulation 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 pro-
viding geographical road network and real survey data of traffic demand, routes, accident prob-
ability, 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.
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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.
Figure 6: Format of the simulator log files describing the state of pedestrians and vehicles for each simulation step

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:

\[ x_1 \ x_2 \ x_3 \ x_4 \ y_1 \ y_2 \ y_3 \ y_4 \]

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.
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 of the vehicles 20 km per hour (kph), and accident probability of 0.1%.
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![Graphs showing traffic statistics for original map and modified map](image)

(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

![Road maps showing real GIS and simulated road maps](image)

(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 underdeveloped 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 behavior, 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.

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