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Proxy-Lane Algorithm for Lane-Based Models to Simulate Mixed Traffic Flow Conditions

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Abstract Simulation modelling of road traffic flows had been a proven tool to evaluate the impacts of traffic engineering and management solutions, before such solutions are implemented in field. There are several traffic simulation software programs available in the market. These programs are based on models formulated for lane-based homogeneous traffic conditions that prevail in developed countries. In recent years, there is an increased interest among researchers across the world to model mixed or heterogeneous traffic that prevails in developing countries. In this paper, a new algorithm is proposed to add a unique functionality to lane-based models and enable the latter to model mixed traffic flow conditions. The algorithm is demonstrated for its ability in mimicking mixed flow queue formations as observed in a road section surveyed in the city of Chennai, India.

Keywords Proxy-lane algorithm, simulation modelling, traffic simulation, mixed traffic, heterogeneous traffic

1. Introduction

Simulation modelling of traffic flow on urban roads had been a proven method for evaluating new strategies related to congestion management. It started with simplified macroscopic treatment of traffic flow of cars on single lane road sections. Traffic flow basic theories were developed as early as eighty years ago [1]. In the past thirty years, models have evolved significantly using ever increasing processor power and graphics capability of personal computers. Sophisticated traffic simulation software packages with 3D animation are now available in the market. Examples are: PARAMICS, VISSIM and AIMSUN [2-4]. They model traffic at microscopic level, focussing on the movement of an individual driver-vehicle unit. Origin-destination vehicular flow demand matrices are inputs for these models while route choice is handled internally. Some programs even treat traffic at what is referred to as nanoscopic level, focussing on travel decisions made by an individual person or trip maker in the simulation environment [5]. Even mode choice is handled by these models with specification of costs of travel as input. However, majority of the simulation models fall under the category of ‘microscopic’ type.

In a microscopic simulation setup, network of roads is described in terms of nodes (junctions or key spots along a road) and links (roads or road sections). Selected links or nodes are specified as origins and destinations (while there are also many other ways of specifying where vehicles should start and end their journeys). Demand in terms of vehicular flow is specified between the origins and destinations. Shortest (or even quickest) paths between origins and destinations are calculated by the program as and when required. Path is a series of links for a vehicle to traverse to reach its destination. During every timestep of the simulation, the program updates the position of every vehicle on every link. Three important algorithms are used to update a vehicle’s position. They are namely the car following, lane changing and gap acceptance algorithms. Car following algorithm is used to make decisions related to speed, depending upon the current vehicle’s proximity to the vehicle in front. Lane changing algorithm is used to decide if there is a need to change lane for avoiding a slow moving vehicle in front or to make a turn at the end of the current link. Gap acceptance algorithm is used to assess whether it is safe to initiate a lane changing process and reach an adjacent lane.

Models and algorithms discussed so far are based on a common assumption that vehicles adheres to lanes and nature of traffic is homogeneous. It is a condition where majority of vehicles have similar size and speed characteristics. It is also a situation where drivers tend to follow vehicles in front rather than forming haphazard queues. This is common in developed countries. On the contrary, traffic in developing countries is made of a variety of vehicles that significantly vary in static and dynamic characteristics. The traffic situation is so heterogeneous that lane-based models cannot be used to describe it in a realistic way (as they are not meant to describe so).

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Researchers in India and other developing countries created innovative methods to describe mixed traffic conditions. However, such works focussed on isolated and short road sections only (reviewed in detail in the next section).

In this paper, a new algorithm is proposed and tested to model mixed traffic conditions. It is named as proxy-lane algorithm. First, a brief review of mixed or heterogeneous modelling efforts is presented.

2. Literature Review

The terms 'mixed traffic' and 'heterogeneous traffic' are often used to mean the same. The intensity of heterogeneity however might vary from a simple combination of cars and cyclists to as complex combination of several slow and fast moving modes as seen in countries like India.

Treiber *et al* extended theoretical speed-flow-density traffic models to include what they called 'inhomogeneous' traffic situations [6]. The scope was nevertheless at a macroscopic level.

Deo, in her doctoral thesis work focused on modelling heterogeneous traffic movements [7]. This was one of the early works dedicated to heterogeneous traffic in detail. However, the study focussed on western or developed world only (according to author's own words). This fact rules out the possibility of directly applying the algorithms to study traffic situations in developing countries.

Huang and Wu proposed an activity-based traveller agent behavioural model for simulating mixed traffic flow [8]. The study focussed on simulation of cyclists' behaviour at an isolated intersection in Beijing.

Luuk Erik in his thesis described how shared space approach could be used to model mixed traffic flow at un-signalized intersections [9]. It was also a study focussing on an isolated intersection.

Japanese researchers Shiomi *et al* attempted to develop a microscopic model for traffic flow with cars and motorcycles as seen in the city of Hanoi, Vietnam [10]. Behaviour of not following lane marking is considered. Discrete choice modelling is applied to model decision making behaviour. The look-ahead distance for a vehicle is limited to the vehicle in front. Vehicle-following behaviour was considered but not the lane-changing behaviour.

Hustim and Ramli derived relations for space mean speed analysis of light vehicles and motorcycles in the town of Makassar in Indonesia [11]. This was a macroscopic speed distribution study rather than microscopic a study.

Lu *et al* applied 'personality trait model' to model heterogeneous traffic behaviour of road users [12]. Though the title has the phrase 'heterogeneous', the article does not reveal much details about the degree of traffic mixture. Psychological factors such as aggressive, egocentric, active, risk-taking, tense and shy behavioural components are included.

In India, Arasan and Koshy made early efforts on simulating heterogeneous traffic for the purpose of deriving standards specific to urban roads [13]. Individual vehicle movements were simulated and their positions were determined within a traffic stream (instead of updating vehicles treated as a queue). 2D animation output was provided to visualize traffic flow. Scope of the study was limited to small sections of one-way roads with divided carriage way. Intersections were not covered.

A strip-based modelling method was proposed by Mathew *et al* [14]. The approach is to consider portions of traffic queues instead of regular main lane queues. Lateral movements are modelled to reflect non-lane based movement of vehicles.

Other notable works are as follows. Mallikarjuna and Rao developed analytical models pertaining to heterogeneous traffic modelling [15]. Macroscopic simulation was adopted though. Arasan and Dhivya developed a simulation and animation tool for microscopic simulation of heterogeneous traffic at a small scale [16]. Praveen and Arasan investigated how Passenger-Car Unit (PCU) values can be derived in a better way when traffic condition is heterogeneous [17]. Ramadurai and Mohan modelled heterogeneous traffic flow using macroscopic simulation [18]. The methodology was applied and tested for a 0.9km section of road in Chennai. Mullakkal *et al* modelled motorcycle movements using an innovative method of perception lines (from point of view of drivers modelled) [19]. This is a unique work in the area of two wheeler research but limited to a small section of a straight road. Traffic junctions, curved roads, rider behaviour and pavement conditions are not covered.

For most of the works reviewed, the spatial and the temporal scope were limited. Issues at a network level such as shortest paths, signal operations and coordination, flow variations, input and output data management are usually left out of scope. This was the motivation behind adding functionality to an existing full-fledged simulation model so as to mimic mixed traffic situation. In this way, network level issues are by default handled by the simulation program itself.

3. Proxy-Lane Algorithm

Simulation programs essentially have a simulation engine that processes vehicle positions every timestep (which is usually set to a value of 0.5 seconds or lower). The engine will process all links, one link at a time (in a usual non-parallel simulation setup). Within a link, it will process all lanes, one lane at a time. Within a lane, it will process every vehicle on the lane, starting from the first vehicle leading a queue (if any).

Processing work mainly involves finding the new position or location for the vehicle under consideration. The first vehicle on a lane will have the freedom to proceed without a leader in front. Other vehicles will follow one after another at a safe distance. For the first vehicle, the need for slowing or stopping for a sign, signal or link transfer is checked. For other vehicles, the basic law of car-following is used to find how much movement should be applied for the vehicle. Displacements required in both directions, along and across the road are calculated. Movement across the road will be necessary only when the vehicle is undergoing a lane changing process. The need for lane changing will occur if the vehicle needs to overtake a slow moving vehicle in front or if the vehicle needs to change to an appropriate lane to proceed straight or to turn left or right at the end of the road. As long as there is no need for a lane changing manoeuvre, a vehicle will continue along its lane.

If a traditional lane-based homogeneous traffic simulation model (or software) is used to simulate a traffic mix of big and small vehicles, queues will be generated as shown in Figure 1.

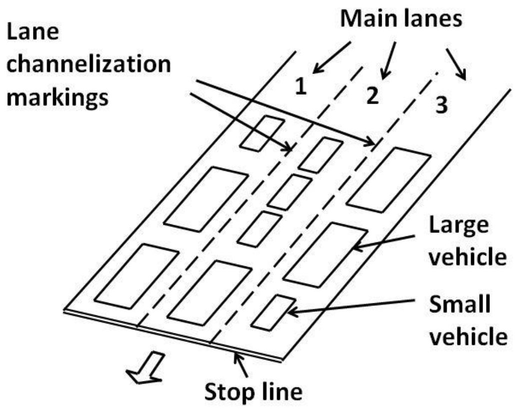

Figure 1. Lane-based homogeneous model used for mixed traffic

A fast moving small vehicle will have to follow a slow moving big vehicle if there is no gap on the adjacent lanes. In the Figure 1, lanes are marked as 1, 2 and 3. If the second vehicle on lane 2 (assuming it is a fast moving small vehicle) needs to overtake the big vehicle in front, it cannot initiate a overtaking or lane changing process as there is apparently no space on adjacent lanes 1 or 3. In developing countries, drivers of small vehicles such as motorcycles or auto-rickshaws tend to use the space between the lanes. This is the basis for the new proxy-lane algorithm proposed.

The working of proposed proxy-lane algorithm can be explained with the help of Figure 2. Besides the main lanes numbered as 1, 2 and 3, the delineation lines or lane markings are also considered as virtual lanes and marked as A and B, only for the use of small vehicles. No large vehicle can use these lanes A or B. Small vehicles can perceive them as lanes in addition to main lanes. These portions along the road are referred to as proxy-lanes.

When the simulation engine processes a position update for a small vehicle that is currently positioned on a main lane, space availability on adjacent proxy-lanes will be checked (instead of adjacent main lanes), if there is a need for lane change. If a vehicle is already travelling on a proxy-lane, and if a lane change is needed, the space available on adjacent main lanes will be checked. For instance, a small vehicle on lane 2 in the Figure 2 can look for gap on proxy-lanes A or B. In another case, a small vehicle on proxy-lane A can look for a gap on lanes 1 or 2. Similarly a vehicle on proxy-lane B can look for gap on lanes 2 and 3.

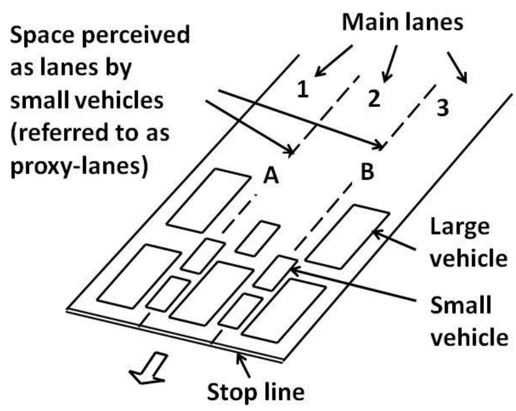

Figure 2. Proxy-lanes in between main lanes

A small vehicle can prefer to stay on a main lane or it can prefer to continue travelling on a proxy-lane. Because, for a small vehicle, the perceivable number of lanes includes both main lanes and proxy-lanes. Simulation engine will process for vehicles on main lanes first, and then process for vehicles on proxy-lanes. Same car following and lane changing principles are applied, except that there are more number of lanes available for smaller vehicles; main lanes and as well as proxy-lanes.

The new algorithm was implemented in traffic simulation software called TrafPlus, originally developed as a lane-based model for simulating homogeneous traffic [20]. The source code was updated to include this feature. A new user setting was added to switch on or off to specify whether a particular vehicle type can use proxy-lanes. In this way, user can have the discretion of setting a particular vehicle type to be suitable to fit in the space between reasonably large vehicles expected to travel on the main lanes.

4. Use of Proxy-Lane Algorithm

The main difference expected between using a lane-based model and using the same with addition functionality of proxy-lane algorithm is to find if there is any significant difference in the way queues are formed. The best traffic condition to test will be a level of flow neither too low nor too high. Extremely low flow conditions will not form queues at all. Extremely high flow conditions will affect results by virtue of interactions arising out of congested conditions that are known to be unstable. Therefore, it was decided to model a service level that provides free flow capability for vehicles and yet results in forming of queues if stopped at say, a pedestrian crossing with signal, without any spillbacks at junctions upstream.

4.1. Data Collection

A three lane road section in the north of Ambattur area in

Chennai was chosen to count vehicles and their types during off peak hour just before congestion starts building in the evening on a working day. The mode split is shown in Figure 3. The proportion of two-wheelers is little more than 60%. The area is a sub-urban area accommodating middle income group families mostly. It is reflected in the high proportion of two-wheelers (motorcycles).

The modal shares to be used for modes such as cars, motorcycles and autorickshaws (later considered in analysis), will be as follows: 12%, 62% and 4% respectively.

Some of the terms used in the Figure 3 are explained. The term auto-rickshaw is a three wheeled intermediate public transport service vehicles operating between passenger specified origins and destinations. Share-autos are other intermediate public transit vehicles that are getting popular in urban areas of Chennai and other cities in India. They are four wheeled van-like vehicles providing transit service on pre-defined routes like buses. However, passengers can board and alight at any spots along the route by hand flagging. Originally it began as shared auto-rickshaws when passengers were willing to share seats and fare for common origins and destinations. Later, dedicated vehicle services began and evolved into what is now still referred to as 'share-autos'. The category 'others' include modes like mini-vans, mini-trucks etc. Cycles refer to non-motorized two-wheelers. They are not modelled since they travelled along kerb side of the road without causing any interference to other traffic when observed in the field.

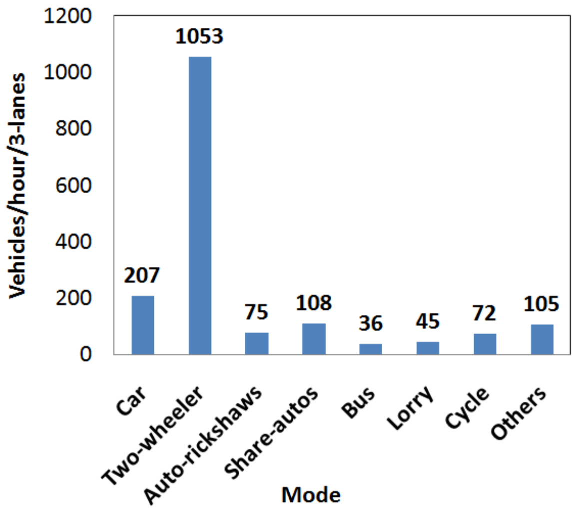

Figure 3. Mode-wise flow observed in field

In addition, average speeds were measured for cars, motorcycles and auto-rickshaws as 39, 54 and 35 km/hr respectively. A mixed traffic situation was seen in field. Motorcycles were seen to manoeuvre between cars and other large vehicles and hence, they show a higher mean speed.

For simulation, a one-way three-lane road with a pedestrian signal is modelled as shown in Figure 4. Nodes 0 and 4 are to represent origin and destination respectively. Node 2 is where a pedestrian signal is modelled. Nodes 1 and 3 are just random intermediate nodes added for gathering more link-level statistics.

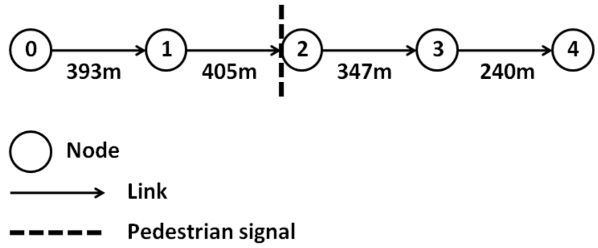

Figure 4. Node-link diagram for road modelled

4.2. Queue Formation Analysis

Snapshots of TrafPlus simulation without and with implementation of proxy-lane algorithm are presented as Figure 5 and Figure 6 respectively. The first scenario is where motorcycles and auto-rickshaws were set to use main lanes only, to mimic a homogeneous lane-based model. The second scenario is where both the modes were set to use any space available between the main lanes, using the proxy-lane algorithm explained earlier. Motorcycles and auto-rickshaws were chosen for this setting as they were the notable modes seen on field often using the space between main lanes.

A significant difference in the formation of queues is seen in Figure 6 compared to Figure 5. Motorcycles stay on lanes when no proxy-lane algorithm is implemented (as in Figure 5). With the algorithm in operation, motorcycles occupy the space between main lanes (as in Figure 6). Three lanes roads are perceived as seven lane roads by motorcycles. As such, proxy-lane algorithm packs vehicles into a compact space and hence, queue lengths are shortened for the same number of vehicles.

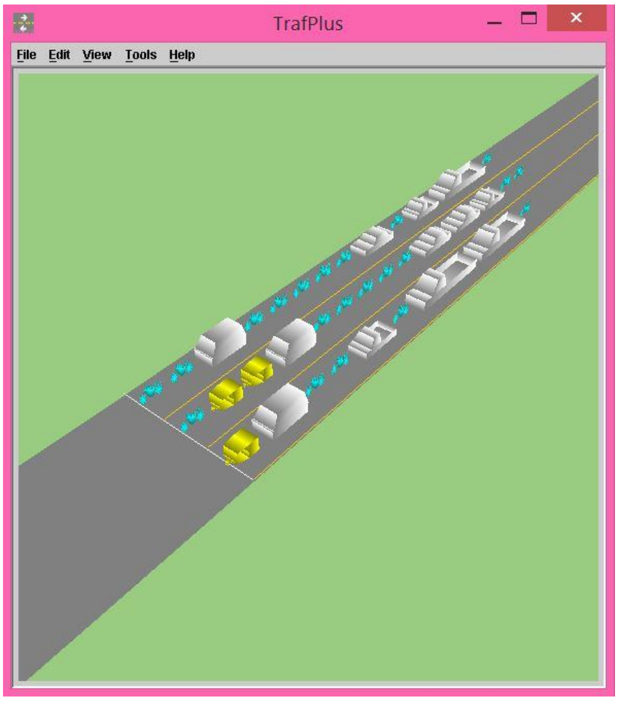

Figure 5. Queue formation before implementing proxy-lane algorithm

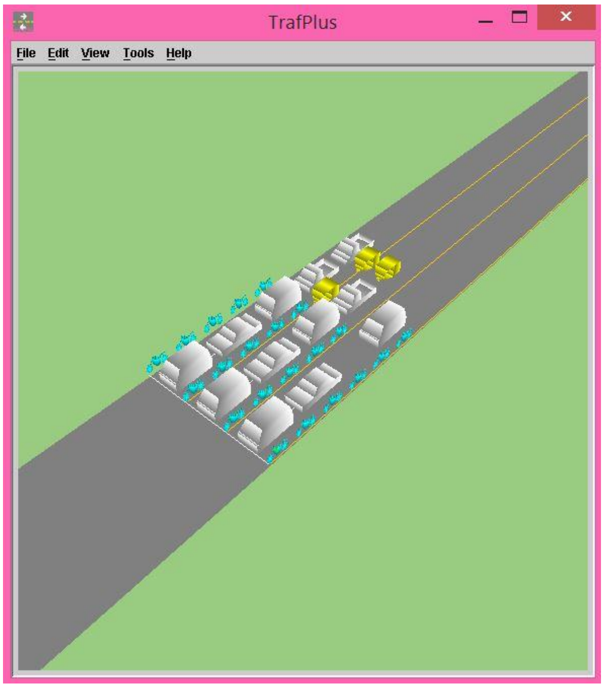

Figure 6. Queue formation after implementing proxy-lane algorithm

Undoubtedly, traffic safety is compromised when drivers tend to skip lane regulations and occupy gaps between other vehicles. This had been the situation for many decades in cities and towns of developing countries. With no sign of control or reduction in the growth of two-wheeler vehicles such as motorcycles and scooters, it can be assumed that mixed traffic situations will prevail for several decades in future too, until a drastic shift from personal modes of travel to mass transportation is achieved.

4.3. Mean Speed Analysis

From simulation, mean speed values for vehicles travelling on a link with no obstructions were used here for analysis. Link 3-4 in Figure 4 was chosen for this purpose. Mean speed values are presented in Figure 7 for different cases considered for analysis.

In Figure 7, each mode has three values of mean speeds: first bar showing data from lane-based simulation, second bar showing data from lane-based simulation with proxy-lane algorithm in operation, and the third bar showing what was observed earlier in field.

Motorcycles and autorickshaws were set to follow proxy-lane algorithm, to represent both faster and slower modes that normally do not stay on main lanes.

The largest difference in mean speed is seen for motorcycles when compared between before and after implementation of proxy-lane algorithm. This is encouraging because the new value of mean speed (61 km/hr) is closer to field observation (54 km/hr), a notable improvement from the case of lane-based simulation with no proxy-lane consideration (36 km/hr).

For auto-rickshaws, queue formations showed visual confirmation of autorickshaws to use proxy-lanes (earlier in Figure 6). However, they do not show a notable change in their mean speed, like motorcycles. This is probably because of their low mode share (which is only 4%).

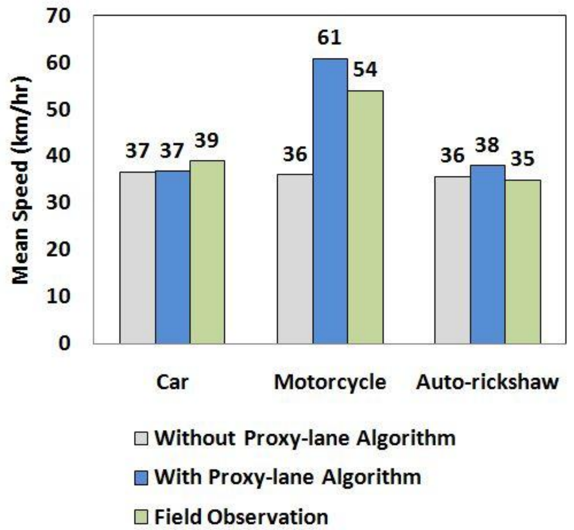

Figure 7. Mean speed comparison

Mean speed values for cars seem not to be affected by whether or not proxy-lane provisions are set to motorcycles and auto-rickshaws. Again this is probably because of their relatively lower mode share (which is 12%).

When fast moving small vehicles are allowed to occupy space between bigger vehicles, their mean speed gets closer to what is observed in the field. This indicates that proxy-lane algorithm works as expected to model mixed traffic situation compared to the direct use of traditional lane-based modelling approach, especially when the mix has a high proportion of small and fast vehicles, which accounts for the heterogeneity in the first place.

4.4. Summary of Analysis

Significant difference was shown in queue formation when proxy-lane algorithm was applied for selected modes; two-wheelers and three-wheelers. Speed analysis showed that speed measurements for fast moving small vehicles such as motorcycles show significant improvement when proxy-lane algorithm is applied to them.

The simulation performed using TrafPlus applies the same car following, lane changing and gap acceptance models as any other lane-based models do. The novelty here is the use of proxy-lane algorithm for vehicles that can accommodate themselves in the space between vehicles on main lanes. The purpose is not to model non-lane based simulation. The purpose is to improve lane-based simulation to reflect a degree of heterogeneity in the traffic being modelled. In the absence of a readily available mixed traffic simulation model, a better representation of mixed traffic is achieved by implementing the proxy-lane algorithm formulated.

5. Conclusions

Traffic in developing countries is comprised of a high and increasing proportion of two-wheelers like motorcycles and scooters. In city areas, there is predominant movement of three-wheelers too, like auto-rickshaws. This leads to mixed or heterogeneous flow condition. Models developed for lane-based and well-behaved driving conditions will not suit to simulate traffic situations seen in developing countries. Researchers show an increased interest to model vehicle movements in mixed state. Models are reported to have been developed from scratch. However, in this paper, a new algorithm is proposed as an added functionality to existing lane-based models to represent heterogeneity in the traffic conditions modelled. The space between lanes is set to be perceived as additional lanes by vehicle types chosen to perceive so. This space along the road is named as a proxy-lane. Small vehicles in developing countries are seen to occupy such space though it compromises safety regulations. The algorithm is implemented in TrafPlus, originally a lane-based simulation model. TrafPlus is then used to model two scenarios: with and without the implementation of proposed algorithm. Field data collected for a three-lane road section in Chennai (India) is used for this purpose. There is a significant improvement in the representation of mixed traffic condition when using the proxy-lane algorithm, judged by observing the queue formations as well as by comparing motorcycles' speed values with field observations.

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