Modeling seepage behavior of smaller vehicles in mixed traffic conditions using an agent based simulation

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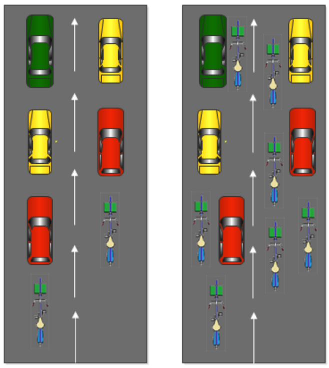
Abstract. In the direction of complex heterogeneous traffic modeling, the present study proposes a model to simulate the behavior of smaller vehicles in the congested regime, called as *seepage action*. As the name depicts, in the congested part of a link (road), smaller vehicles creep across the space between cars (or other vehicles) rather than standing at the end of the queue. This behavior is rarely modeled and quantified even though it is common praxis in most of the developing nations.
In order to facilitate this behavior, a state of the art queue model is modified to allow for seepage in congested regime. Furthermore, the concept of a simplified kinematic wave model is introduced in terms of backward traveling holes which make the congested branch of fundamental diagram is more realistic. A real-world scenario of Patna, India is presented for evacuation modeling under mixed traffic conditions with seepage behavior.
Keywords: Seepage, Lane splitting, Lane sharing, Lane filtering, Mixed traffic, Agent-based Modeling, Backward traveling holes, Evacuation

1 Introduction

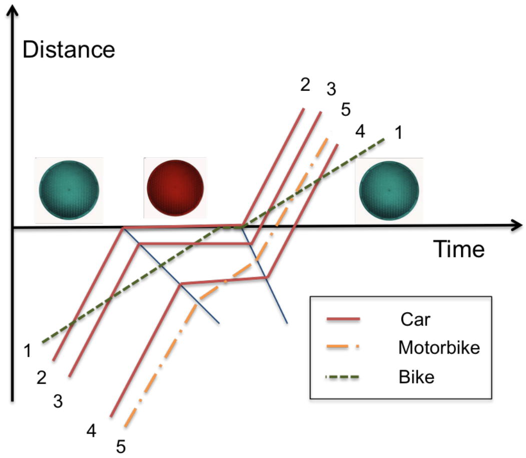
Modeling complex heterogeneous traffic is always a challenge to traffic planners since streets are full of variety of vehicles. These vehicles can be segregated based on their static (physical dimension) and dynamic (speed, acceleration, power *etc.*) characteristics. The traffic in industrializing nations is different to the traffic in industrialized nations for at least following reasons (a) absence of lane discipline (b) common road space for motorized and non-motorized vehicles. Motorized vehicles include car, bus, truck, motorbike (motorcycles), scooters and, three-wheeler motorized rickshaws. Non-motorized vehicles include bikes (bicycles), cycle-rickshaws *etc.* Travel behavior in such conditions is different than in homogeneous conditions. Thus, this paper investigates one of such so-called behavior *seepage* which predominantly exists in most of the industrializing nations.
Due to the acute size and great manoeuvrability of the smaller vehicles (motorbike, bike *etc.*), these vehicles are less sensitive to the remaining traffic but in turn, affect flow of other vehicles remarkably. Thus, during queue built up or at traffic signals, these vehicles move continuously across the gap between stationary congested vehicles and come in front of the queues. In literature, this behavior is known as 'seepage action' [1, 2], lane filtering (passing between stationary vehicles) [3], lane sharing or lane splitting (passing between moving traffic) [3].

Figure 1a shows seepage of motorbikes and bikes at a traffic signal in India and Figure 1b shows the basic difference between passing and seepage behavior. Figure 1c depicts the schematic of seepage of bike and motorbike at traffic signal. A bike (green dashed line) is not queued at the end of cars on red signal instead creeping continuously across the available gaps to come in front of the queue and leaves first on green signal [1, 4]. Similarly, a motorbike (in orange dash-dot line) also seep across the gap and come in front of the queue. This behavior is a common praxis in the developing nations.
There are limited studies which focus on the modeling of such traffic behavior but many studies cited pro and cons of this behavior. In a study by Aupetit et al [6] for Paris region, lane splitting is found to be a systematic practice. Findings are derived by monitoring trips made by 11 motorbike riders for about a month on entire Paris network accounting for 9662 *km* cumulative distance. In New South Wales, *under the Road Transport Legislation Amendment (Lane Use by Motor Bikes) Regulation 2014*, lane filtering is allowed legally [7] starting from July 1, 2014. This was done in order to reduce congestion and to avoid

(a) Seepage of smaller vehicles at traffic signal [5].



(b) Passing and seepage.



(c) Schematic of seepage at traffic signal. Reproduced after Oketch(2000) [1].

Figure 1: Seepage action (not to scale).

rear end collisions between motorbikes and cars. Some reports [3, 8] state that lane splitting is safer due to increased visibility of motorbikes, on the contrary, some other studies [9, 10, 11] find that this behavior makes motorcyclists more vulnerable and one of the other causes of motorbike accidents.

Although, it is a matter of debate to chose between safety and benefits (congestion and emission reduction, increased capacity, increased travel time reliability *etc.*) [2, 3, 8, 10, 12]. But, objective of the present study is limited to develop a heterogeneous traffic model which is able to handle existing seepage behavior and to quantify some of the benefits. The author Oketch [1] made an attempt to study this behavior using lateral movement model. A multi-class 'porous model' is presented by Nair et al [13] to allow seepage where speed of each vehicle class is determined by the availability of pores. In another study [5], authors Asaithambi et al addressed the issue of seepage of motorbikes at traffic signals. The authors used exclusive stopping space for motorcycles (ESSM) in front of the queue at intersections and found it beneficial for all modal split except when share of cars is dominant in traffic composition. Similarly, in recent studies by the authors Fan and Work [14, 15], a creeping model is developed as a multi-class generalization of the cellular transmission model. The models in the above studies are highly detailed models but in the present study, the authors wish to develop a heterogeneous traffic flow model which is computationally efficient for simulating large scale scenarios in an agent based simulation framework. Therefore, in the present study, a multi agent travel demand simulator MATSim [16] is used which is computationally faster than other available simulators [17].

A related situation is the evacuation of large urban areas, e.g. in the case of tsunamis[1]. As evacuees usually want to exit the affected area as fast as possible it is expected that seepage situations occur. The existing simulation framework is able to model the large evacuation problems [19, 20] in homogeneous

[1]See, e.g. [18] for a detailed overview of problems that arise when planing the evacuation of whole cities.

traffic conditions. To the authors knowledge there exist no studies on the simulation of seepage behavior under the highly dynamic conditions observed in real-world traffic in general and in particular in case of evacuations. But, with the help of the proposed approach, it is possible to simulate large scale evacuation scenario under mixed traffic conditions and allowing seepage behavior. It is assumed that evacuation model would benefit from seepage as well. The results are quantified with the help of a real-world scenario of Patna, India.

The present study aims to (1) develop a model to handle heterogeneous traffic conditions with seepage action and suitable for large scale scenario simulation and (2) quantify the benefits with the help of appropriate example.

Section 2 illustrates the travel demand simulator and seepage queue model. Validation of the proposed model is done in Section 3 with the help of space time trajectories and fundamental diagrams. A simplified concept of Kinematic Wave model is presented with the help of backward traveling holes. Further, a real-world scenario is presented in Section 4. In the Section 5, some additional aspects are discussed and finally, the study is concluded in the Section 6.

2 Modeling

2.1 Travel Demand Simulator - MATSim

The multi-agent transport simulation framework, MATSim [16] is used for all simulation experiments. Detailed information about the software has been published in several studies for e.g. [21, 22, 23, 24]. The minimal inputs are physical boundary condition (the road network) and daily plans of individual travelers as an initial condition. This is an time discrete simulator and therefore state of each agent is updated in every time step (1 *sec*).

In this framework, every person is considered as an agent who learns and adapts within an iterative process that is composed of following three steps: (1) Plans execution: selected plans of all agents are executed simultaneously using predefined mobility simulations in physical environment. A time step based queue simulation approach [25, 26, 27] is used for mobility simulation which is further modified in order to allow seepage. (2) Plans evaluation: In order to compare two plans, executed plans are evaluated using a utility function. In this study, MATSim standard 'Charypar-Nagel' scoring function is used [28]. (3) Re-planning: A new plan is generated for some agents by modifying an existing plan's attribute (departure time, route) using so called innovative strategies. The old plans are kept in the agents' memories and can be selected by so-called non-innovative strategies later on. The new plan then is executed in the next iteration. By repeatedly performing the steps above, an iterative process is initiated. Innovation is used until a certain iteration and in the end few more iterations are run with non-innovative strategies only (i.e. plan selection) which finally results in stabilized simulation outputs.

2.2 Seepage in MATSim

The state-of-the-art *first in first out* (FIFO) queue model [25, 26] is modified by an *earliest-link-exit-time* approach by Agarwal et al [29, 30]. The earliest link exit time ($t_{earliest}$) on a link is given by Equation 1 where ℓ is length of the link, $v_{\ell,max}$ is maximum speed allowed on the link and $v_{v,max}$ is maximum speed of the vehicle. The vehicles on the link are sorted based on the earliest link exit time and afterwards leave the link accordingly. Thus, this approach allows faster vehicles (lower $t_{earliest}$) to overtake (pass) slower vehicles (higher $t_{earliest}$) in uncongested regime. Hereafter, this model is referred as "passing queue model".

$$t_{earliest} = \frac{\ell}{min(v_{\ell,max}, v_{v,max})} \tag{1}$$

The passing queue model is further modified in order to allow passing of faster vehicles by slower vehicles in capacity and congested regime which is referred as seepage behavior as explained in Section 1. Thus, this paper presents "seepage queue model" which allow passing of slower vehicle by faster vehicles in uncongested regime and vice versa in congested regime. The general approach for seepage functionality is shown in Algorithm 1 and explained next.

(1) A seep mode (vehicle) is defined. Since, in the free flow regime, faster vehicles can overtake slower vehicle and therefore, passing is also allowed on the link. (2) If the flow on a link exceeds its flow capacity, a queue appears. Thus, in the simulation framework, if at time step (t), the actual exit time (t_{actual}) of an

Algorithm 1: Schematic of seepage queue model.

```
Data: define seep vehicle
Input: A finite set of links L = {l_1, l_2, ..., l_n}
for at every time step until simulation ends do
    for all links (i.e. l_i ∀ i ∈ (1,n)) do
        if vehicle queued (i.e. t_actual > t_earliest) then
            for all queued vehicles do
                if queued vehicle = seep vehicle then
                    send queued vehicle to front of queue;
                    break and go to next link;
                else
                    go to next queued vehicle;
        else
            go to next link;
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agent on a link exceeds the precomputed earliest link exit time $t_{earliest}$ of the agent on the link, the vehicle is queued. (3) In the next step, just before a vehicle is about to leave the link, the vehicles whose earliest link exit time has passed (basically queued vehicle), are identified. (4) For identified vehicles, a seep mode is searched and if it is found then it is pushed to the front of queue and, afterwards, the front vehicle (seep mode) leaves the link depending on the flow capacity of the current link and the storage capacity of the next link. (5) If seep mode is not found in the queue, flow dynamics remain unaltered i.e. first vehicle in queue leaves the link if flow and storage capacities of the link are not violated. Seepage is not allowed between two vehicles of same type.

3 Validation

In this section, seepage queue model is validated with the help of space time trajectories (Section 3.1) and fundamental diagrams (FDs) (Section 3.2). Car, motorbike and bike travel modes are used for the mixed traffic experiments in the present study. For simplicity, the passenger car units (PCU) and speeds of these modes are taken from the previous studies [29, 30] and are shown in Table 1.

Table 1: Travel mode parameters.

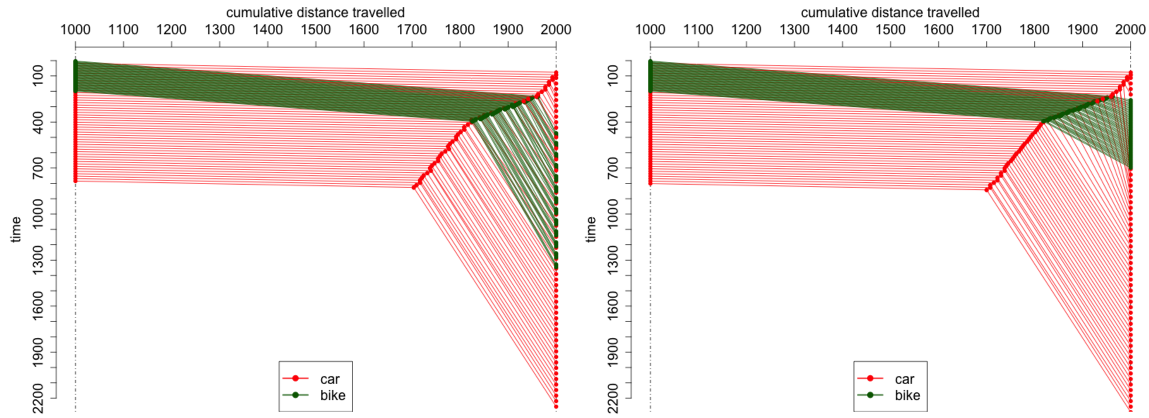
Travel Mode	PCU	Speed (m/sec)
Car	1	16.67
Motorbike	0.25	16.67
Bike	0.25	4.17

3.1 Spatio-temporal plot

Figure 2 shows the spatio-temporal plots for passing and seepage queue models at a bottleneck situation. These plots are generated using a simple 3 link network, in which two similar links (origin and destination links) are joined by a different link in between. The flow capacity of the middle link is less than the other two links and therefore, the middle link is a bottleneck link. Figure 2a and Figure 2b show spatial-temporal plots for passing and for seepage of bikes on bottleneck link respectively. Initially, in Figure 2a, cars (in red) are passing bikes (in green) until queue formation occurs and afterwards, vehicles leave link based on their position in the queue[2] i.e. vehicles follow lane concept. Whereas, in Figure 2b seepage is allowed

[2]Queue simulation in MATSim provides link enter and leave time events only and thus queuing positions are interpolated. Since, positions of vehicles in the queues are not in the same order as they leave the link [29], overlapping of trajectories of cars and bikes in congested regime is observed (see Figure 2a).

and therefore, after queue formation, in congested regime, bikes are creeping through congested cars and leaving the link before cars. One can clearly observe that green trajectories are stepper than red trajectories in congested regime which indicates that bikes (green) are overtaking cars (red). In this small experiment, average travel times for car are 847 and 955 *sec* for passing and seepage queue models respectively; the same for bike are 808.5 and 376 *sec*. Clearly, as expected, seepage results in significant reduction in average travel time of bike. Since car mode vehicles are staying behind bikes in the queue, average travel time for cars is increased marginally. Interestingly, total link travel time of cars and bikes is reduced by 24%. These findings are in line with literature [3, 12].



(a) Passing. **(b) Seepage.**

Figure 2: Space time plot for (a) passing and (b) seepage of smaller vehicles at bottleneck.

3.2 Fundamental Diagrams (FDs)

In order to validate any traffic flow model, fundamental diagrams (FDs) are necessary and therefore presented here. The FDs for the FIFO queue model and passing queue model are presented in the studies by Agarwal et al [29, 30]. The dynamics in the jammed regime of these FDs is unclear as shown in Figure 3 (golden points), therefore, in the present study, to have more clearer and realistic dynamics of the congested links the concept of backward traveling holes is used in the queue model.

3.2.1 Queue model with 'holes'

The backwards traveling holes approach mimics the simplified Kinematic Wave Model (KWM) [31, 32, 33]. However, a true consistency with the theory is unclear since mixed-traffic and seepage is beyond the "classical" KWM.

During jammed regime, if a vehicle leaves the downstream end of the link, the space freed by the leaving vehicle is named as 'hole'. This space is not available instantly on upstream end of the link instead this space is first occupied by the following vehicle and this process continues until the space reaches on upstream end of the link. As a consequence, the space is not available instantly instead it takes some time for the hole (space) to reach to the upstream end of the link [34, 35]. Therefore, after a certain density, no vehicle can enter the link until free space reaches upstream end of the link and thus, the holes effectively introduce an inflow link capacity, in addition to the already existing outflow link capacity.

The comparison of the two approaches (with and without holes) is shown in Figure 3 for only car simulation. These plots are generated with simulation run from a race track network as described in the Section 3.2.2. In the free flow regime, primary relationship between the three fundamental variables of traffic flow ($q = \rho v$, where q is the traffic flow, ρ is density and v is the speed) holds for queue model with and without holes (Figure 3). In the queue model without holes, the free space corresponding to the leaving vehicle is available instantly and therefore, until the congested regime is reached, link outflow capacity is remain constant in capacity regime and therefore, typically has a horizontal section in the fundamental diagram corresponding to the outflow capacity as shown in Figure 3 [36, 29]. This horizontal section joins together with a nearly

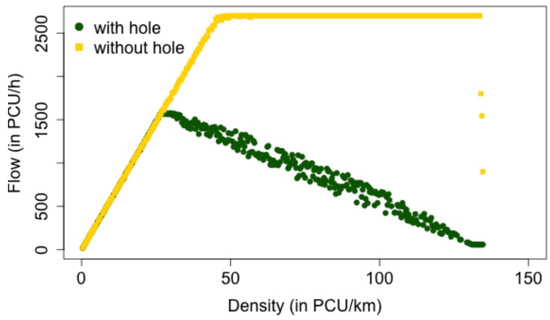


Figure 3: Comparison of FDs for car only simulation with and without holes.

vertically downward sloping congested branch (see golden points in Figure 3). After the introduction of the holes, the slope of the congested branch gets reduced to the speed of the backwards traveling holes, which corresponds to the speed of the backwards traveling kinematic wave. In consequence, the congested branch can now meet with the upwards sloping uncongested branch at a capacity below the outflow capacity. As shown in Figure 3, in consequence, the overall capacity of a link can now be smaller than the outflow capacity, this is in line with the literature [37].
To distinguish the holes corresponding to the vehicle type, two attributes are assigned to each hole in the simulation: (1) size of the hole which is same as the PCU of the leaving vehicle's PCU and (2) speed of hole which is a constant speed for all vehicle types. Thus, each hole has precomputed times of arrival on upstream end of the link. In the present study, the backward traveling hole speed is assumed to 15 km/hr which corresponds to a time headway of about 1.8 *sec* between two subsequent vehicles.

3.2.2 Race track experiment

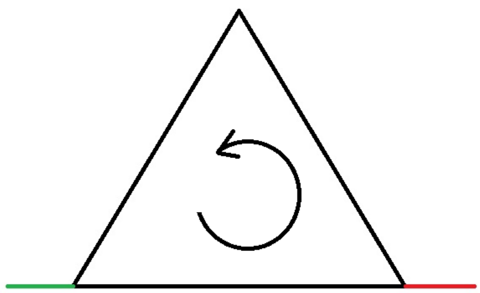
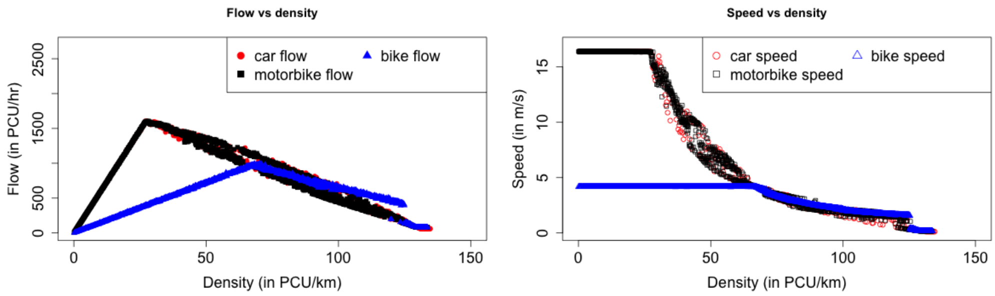


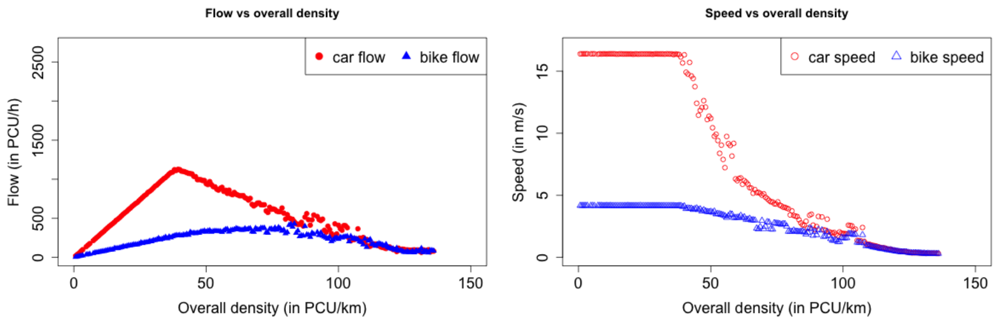
Figure 4: Triangular race track network.

In order to plot FDs, a simple triangular race track network is used as shown in Figure 4. The same race track network is used in the studies by Agarwal et al [29, 30]. Each link in network is 1000 m long. Maximum flow capacity and density of each link are 2700 PCU/hr and 133.33 PCU/km respectively. All agents depart from left and continue traveling on the track until stability is achieved and afterwards agents arrive on right.
Figure 5 shows the different FDs for equal model split (in PCU) for car and bike. Initially, FDs for only car, only motorbike, and only bike simulations are plotted (see Figure 5a) for reference purpose. Clearly, dynamics in jammed regime is more clearer now and as expected. These FDs do not have flat portion in capacity regime as explained in the Section 3.2.1. In these FDs, left arm of the FDs depends on the free flow (maximum) speed of the vehicle and maximum allowed speed on the link (see Equation 1) and right arm corresponds to the pre-assigned hole speed. The maximum link flow is not achieved due to the underlined dynamics of holes as explained in the Section 3.2.1. The shapes of the FDs for car are supported by the diagrams in the past study [37]. The FDs for the car and motorbike look similar since these vehicle only

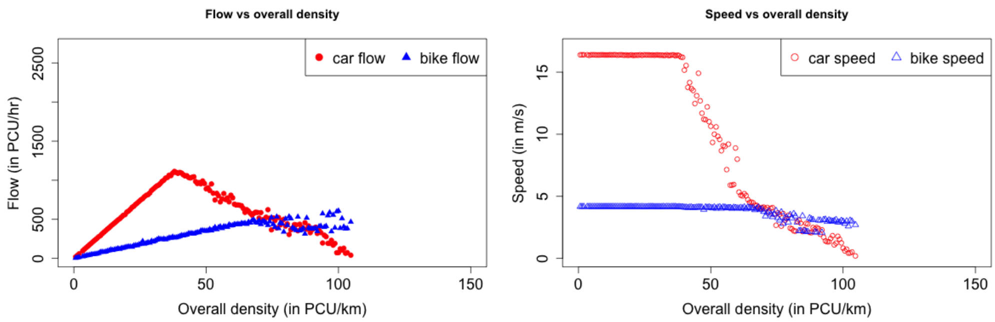
differ in their size. The FDs for only car and only motorbike simulations without holes implementation were also similar [30]. The maximum flow in the only bike simulation FD is achieved at higher density due to lesser maximum speed of the bike.



(a) Only car, only motorbike and only bike simulation.



(b) Car bike passing.

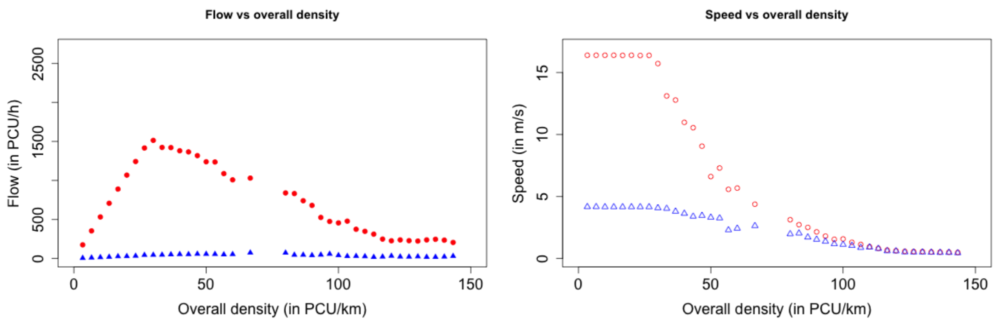


(c) Car bike seepage.

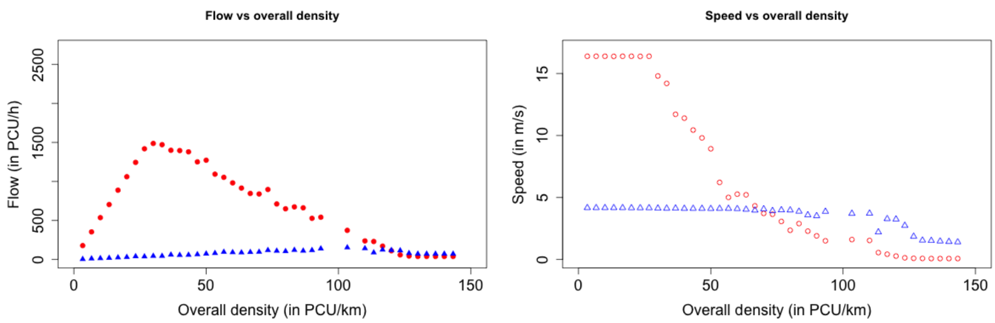
Figure 5: Fundamental diagrams for (a) single modes simulations and, (b) passing and (c) seepage for car, bike simulation.

Further, Figure 5b and Figure 5c show the FDs for passing and seepage queue models respectively. The branches of FDs in free flow regime in Figure 5b and in Figure 5c are same since, until the capacity regime is reached, the slope of the flow density curve is given by the minimum of maximum allowed link speed and maximum speed of vehicle (see Equation 1). After that, flow starts decreasing until the flow becomes zero thus capacity regime and jammed regime are together representing the link dynamics during congestion. The speed-density plot shows the variation in the speed of the vehicle over total density. In the free flow regime, speed of the car and speed of the bike are equal to their maximum speeds and decrease afterwards. From Figure 5c, it can be observed that bike flow increases until the density about 110 PCU/km and bike speed reduces marginally slightly after free flow regime. On the contrary, car flow and speed is approaching zero at a density lesser than in passing behavior. Clearly, in case of passing behavior, flow characteristics of bikes and cars are affected by presence of each other (see Figure 5b). But, in contrast to passing, in the seepage behavior, the flow characteristics of bikes is marginally affected by presence of cars but flow characteristics of cars is significantly affected by presence of bikes (see Figure 5c) and thus producing a behavior similar to what is observed in reality.

These results are in line with observations on traffic in developing nations where mixed traffic has smaller vehicles in abundance. In Figure 5c, data points corresponding to densities higher than 110 PCU/km are not available due to flow dynamics of holes at higher densities. Each data point is achieved after flow and speed stabilization for each mode. When a vehicle leave the base link, the corresponding stability is inspected. At higher densities, more bikes are in the queue and due to seepage behavior, only bike leaves the link and subsequently, car stability is not achieved. This explains the missing data points after a density of 110 PCU/km. Though the dynamics for seepage model is clear from the Figure 5c, still another simulation with lesser bike share is set up to get the data points in congested regime. To do that, in this simulation run, after every four bikes, first vehicle (car or bike) in the queue is allowed to leave. The resulting FDs are shown in Figure 6. Now, from Figure 6, it is more clear that, due to seepage bike flow and speed start decreasing at a density higher than in passing queue model. The speed of bike in seepage FDs, start decreasing at higher density whereas car speed approaches to zero at lower density.



(a) Car bike passing.



(b) Car bike seepage.

Figure 6: Fundamental diagrams for (a) passing and (c) seepage simulation. Modal split is 9:1 for car and bike in PCU.

4 Application

This sections compiles the application scenario of the seepage behavior. The proposed seepage queue model is applied to a real-word scenario of Patna, India. Therefore, in this section, evacuation modeling for heterogeneous traffic condition with seepage behavior is presented.

4.1 Real world evacuation

The following discusses the application of the proposed model a real-world evacuation scenario of mixed traffic with seepage behavior. The objectives of presenting this real-world scenario is to show and to quantify the influence of seepage for disaster management. The approach is useful for areas prone to tsunami and floods and in other emergency services during big events.

Inputs The initial scenario is taken from the study by Agarwal et al [29] and therefore described here briefly. The input network contains 3505 nodes and 7542 links. A disaster prone area is identified as evacuation area. The aim is to evacuate all the persons inside this area. The network is connected with some exit links which lead to a safer location.

The location and travel mode of the persons are taken from the Patna comprehensive mobility plan [38]. For simplicity, it is assumed that all persons starts evacuating simultaneously as soon as warning is announced and all persons starts evacuating from their home location.Thus in the simulation run, all persons inside the evacuation area is considered for evacuation. Assuming everyone start at once is a conservative assumption, since it would lead to a high initial load onto the network and thus to high densities resulting in a lower throughput (cf. fundamental diagrams in Figure 5) compared to a to widely distributed departure times. A study that investigates the influence of departure time distribution on the overall evacuation performance is presented in [39]. In absence of travel schedule for public transport (PT), PT mode is not considered in the simulation. The walk mode can not be simulated using regular vehicular traffic model and therefore skipped in the simulation. Thus, similar to the previous study [29], car, motorbike and bike modes are considered in the simulation. Overall about 1% sample size is taken.

Simulation set up Two simulation runs are considered here, each corresponding to passing and seepage behavior. Simulation is run for 100 iterations. Until the 75 iterations, 10% of agents are allowed to change their route and remaining agents until 75 iteration and all agents after 75 iteration, select a plan from their generated choice set based on multinomial logit model (see Section 2.1). In the 0^{th} iteration, basically the shortest path is assigned to each agent between its origin and destination. Afterwards, agents learns and adapts to the system as described in the Section 2.1. Finally, the outcome of the last iteration shows the routes corresponding to an approximately Nash equilibrium (NE). Therefore, based on the agents' behavior, results are also analyzed for two cases, namely (1) Shortest path (SP) (2) Nash equilibrium (NE).

Results Table 2 shows the comparison of average trip time from two simulation runs and for both cases. Clearly, as expected, the average trip time for shortest path is significantly higher than NE in both simulation runs. Interestingly, the effect of seepage behavior can be observed in the 0^{th} iteration only. For the shortest path case, the average trip time for bike with seepage bahavior is about 13% less than the average trip time with passing behavior only. Consequently, due to seepage of bike, the average trip time for car and motorbike is increased.

In the Nash Equilibrium, the average trip time for each mode is significantly less than the average trip time in shortest path case for both simulation runs. Furthermore, in the seepage run, bike can overtake car and motorbike in congested regime thus bikes are faster and therefore average trip time of bike is 17.6% less than the average trip time for passing run. As a consequence of seepage of bike mode, average trip time of car and motorbike is 38.5% and 40.5% higher than the average trip time for passing run respectively. Interestingly, in the end, the total clearing time to evacuate all agents stays the same when seepage is enabled.

Table 2: Comparison of passing and seepage evacuation runs for Patna.

Travel mode	Number of evacuee	Avg trip time passing [min]		Avg trip time seepage [min]	
		SP	NE	SP	NE
Car	168	301.94	123.42	368.42	170.91
Motorbike	1266	329.57	152.46	451.76	214.33
Bike	3921	382.73	178.47	333.47	147.00

Evacuation progress Figure 7 shows the evacuation progress for both simulation runs and for both cases. Since, only bike is allowed to seep, car and motorbike modes are combined together and referred as fast mode whereas bike is referred as slow mode. Firstly, as expected, Nash equilibrium (NE) is evacuating faster than shortest path for passing simulation runs and both types (slow and fast) modes. Slow mode of seepage run also show the same trend. This is in line with the literature [19]. In terms of policy making this would mean the shortest path solution does not take congestion into consideration and thus does not constitute a feasible solution. But, on the contrary, due to seepage of bike, fast modes are stuck and therefore, in the fast mode of seepage run, initially, number of evacuated persons for NE (solid orange circles) is slightly lower than SP (hollow red circles). Furthermore, seepage has led to higher rate of evacuation for bike mode and lower rate for fast modes (car and motorbike). In the afternoon hours, number of fast modes evacuated for seepage and passing runs become almost same and therefore, overall, seepage has no negative impact in terms of evacuation rate.

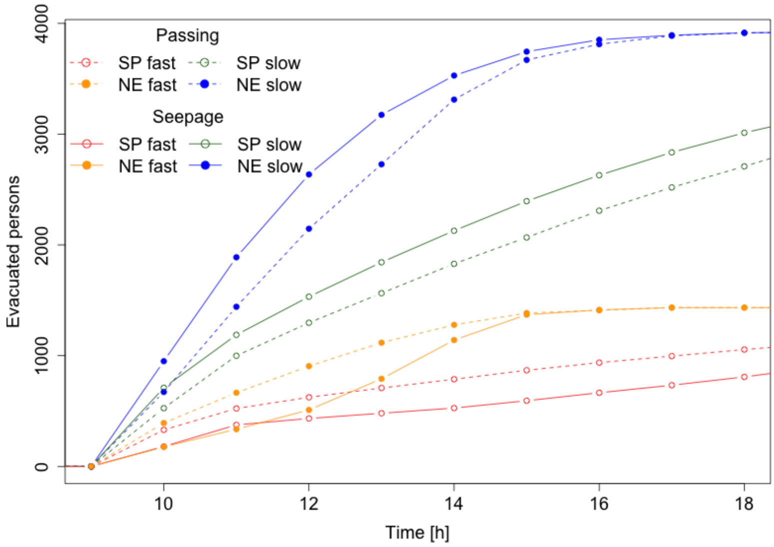


Figure 7: Comparison of evacuation progress. Fast refer to car and motorbike whereas slow refer to bike.

5 Discussion

In the present study, seepage of bike (bicycle) is studied. But, the same approach is applicable for any type of vehicle type across the world. Sometimes, car seep between the truck on a multi-lane highway. In most of the developing nations, not only bike but motorbike also show seepage behavior due to ease in manoeuvrability. Though, the same approach can be extended for multiple seep modes, the present study is restricted to seepage of bike mode. Seepage plays also an important role in situation where ambulance vehicles or other fire engines need to seep through large pedestrian crowds. This situation happens for example during large music festivals or other public events. In those situations the seep mode is not assigned to the smaller vehicle, instead the smaller "vehicles" (i.e. pedestrians) give space to the large vehicles (i.e. ambulances). Albeit those situations seem to be quite different from the seepage observed on road networks, it seems to be reasonable to apply a similar approach as the one that has been proposed in this contribution. The general applicability of queuing models to pedestrian traffic has been discussed in earlier works [40].

As shown in the Fig. 1b, during seepage in practical situations, bike (seep mode) do not occupy additional space instead use the space between the two cars in the same lane which in turn can relive the additional storage space. This additional relived space can enhance the saturation flow and overall result in lesser clearing time for evacuation scenarios. This functionality is not considered in the present study but this can be implemented in the future studies.

6 Conclusion and Outlook

In order to simulate heterogeneous traffic close to reality, this paper presented a so called "seepage" behavior in an agent-based simulation framework. This is a common praxis in most of the developing and some of the developed nations. Due to the smaller size and easier manoeuvrability, smaller vehicles (bike, motorbike) pass across the gaps between the stationary or almost stationary vehicles. Spatio-temporal plots and fundamental diagrams are demonstrated for the validation of the proposed model. The dynamics of the queue model in congested regime was unclear and therefore the concept of backward traveling holes is used which introduced a link inflow capacity implicitly. Furthermore, the proposed seepage queue model is then applied to a real-world scenario of Patna, India for evacuation modeling in mixed traffic conditions. The passing and seepage queue model are then compared for the scenario. Clearly, the seepage behavior resulted into the significant decrease in average trip time of the bike and increase in average trip time of car and motorbike. Overall, the total travel time went down for the seepage simulation run.

In future, the proposed model needs to be tested with regular traffic modeling and system optimum solution for evacuation modeling in heterogeneous traffic conditions. Research into the application of the KWM theory to mixed mode traffic with seepage will be a future topic as well.

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