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Seepage of Smaller Vehicles under Heterogeneous Traffic Conditions

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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 *seepage action*. As the name suggests, in congested part of links, smaller vehicles like motorbikes and bikes do not stop at the end of queue. Instead, they move continuously across the gaps between the stationary congested vehicles and come in front. 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 backward traveling holes is introduced. Thus, the congested branch of the fundamental diagram is modeled more realistic.

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Keywords: Seepage, Lane splitting, Lane sharing, Lane filtering, Mixed traffic, Agent-based modeling, Backward traveling holes

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1. Introduction

Traffic streams in most of the developing countries consist of a variety of vehicles which are differentiated based on their static (physical dimensions) and dynamic (speed and acceleration) characteristics. In absence of physical segregation, motorized and non-motorized vehicles use the same right of way and thus increase vehicular interactions and chances of conflicts. Additionally, lane discipline and car following methods are scarce and thus modeling such traffic is difficult when applying regular homogeneous traffic flow models. In an approach by Agarwal at al.[1], mixed traffic is modeled in an agent-based simulation framework where the state of the art *first-in-first-out* queue simulation approach[13,23] is replaced by an *earliest-link-exit-time* approach. This approach allows faster vehicles to overtake slower vehicles in uncongested regime. Due to acute size of smaller vehicles (motorbike, bike etc.), they are non-sensitive to the width of the road but they affect flow of other vehicles remarkably. Moving forward in the similar direction, the present paper investigates the behavior of smaller vehicles in capacity and congested regimes, it is sometimes called as 'seepage action'.[20,21] In congested regime (where queues build up) and/or at traffic

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signals, smaller vehicles can pass faster vehicles by moving continuously across the gaps between stationary congested vehicles and come in front of queues.[26] Fig. 1 illustrates the seepage behavior at a traffic signal. This behavior is a common praxis in developing countries.

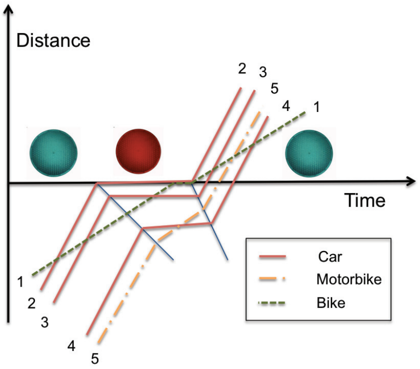

Fig. 1: Seepage of smaller vehicles at traffic signal.[26] The bike is not queued behind cars on red signal instead it is seeping continuously to come in front of the queue and then leaves first on green signal.

Seepage behavior is also known as lane filtering (passing between stationary vehicles)[12], lane sharing or lane splitting (passing between moving traffic)[12]. In a study in the Paris region, lane splitting is found to be a systematic practice.[2] 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. Recently in New South Wales, *under the Road Transport Legislation Amendment (Lane Use by Motor Bikes) Regulation 2014*, lane filtering is allowed legally[4] starting from July 1, 2014. This was done in order to reduce congestion and to avoid rear end collisions between motorbikes and cars. Some reports[12,14] state that lane splitting is safer due to increased visibility of motorbikes, on the contrary, some other studies[8,25,18] 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.)[21,12,14,25,11], the 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 effect of vehicle mix on saturation flow is examined by Oketch.[21] The authors found out that mixing 25% bikes and 25% motorbikes with cars enhances saturation flow by 22.7% and 16.2% respectively. In the past, investigations are made for lane filtering while keeping focus on road accidents safety. Its benefits are cited but value of benefits is rarely quantified. A related situation is the evacuation of large urban areas, e.g. in the case of tsunamis. As evacuees usually want to exit the affected area as fast as possible it is expected that seepage situations occur. Thus, existing simulation models that can deal with large evacuation problems[15] would benefit from seepage as well. Literature lacks of studies with focus on modeling traffic demand under mixed traffic conditions and allowing seepage action. Therefore, the present study aims to 1) develop a model to handle heterogeneous traffic conditions with seepage action and, 2) quantify the benefits of the model by comparing the travel times with and without seepage using a test example.

2. Modeling

MATSim. The multi-agent transport simulation framework, MATSim[19] is used for all simulation experiments since it is computationally faster than other available simulators.[17] The minimal inputs are physical boundary condition (the road network) and daily plans of individual travelers as an initial condition. 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 model[13,23,5] capable of simulating large scenarios[3] 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.[7] (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. 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. The steps above are repeated iteratively. 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.

Seepage in MATSim. The traditional queue simulation is modified in order to allow for passing.[1] In the present study, the queue simulation is further modified to allow for passing of faster vehicles by slower vehicles in capacity and congested regime. The earliest link exit time in passing approach is defined using free speed travel time of the link which only allow vehicles to pass in free flow state whereas the following steps are necessary to allow seepage in congested state. The general approach for seepage functionality is as follow:

```
Data: define seep vehicle
for all links do
    if vehicles queued 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;
            end
        end
    else
        go to next link
    end
end
```

Algorithm 1: Introduction of seepage in MATSim framework

(1) A seep mode (smaller vehicles like bikes, motorbikes) is defined. Passing is allowed on the link. (2) If the flow on a link exceeds its flow capacity, a queue appears. (3) Now, 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, the front vehicle (seep mode) leaves the link depending on the flow and storage capacity of the link. (5) If no seep mode is found, flow dynamics remain unaltered i.e. first vehicle in queue leaves the link if flow and storage capacity of the link is not violated. Seepage is not allowed between two vehicles of same type.

3. Application

In this section, applications of seepage are illustrated. Car, motorbike and bike travel modes are used in the experiments. Passenger car units (PCU) and speeds of these modes are taken as 1, 0.25, 0.25 and, 16.67, 16.67, 4.17 m/sec respectively (same values as in the past study[1]).

Spatial plot. Fig. 2 shows the comparison of passing and seepage at bottleneck situation using space time trajectories. These plots are generated using a simple network with two links (origin and destination links) and a bottleneck link in between. This situation occur due to flow capacity restriction on the middle link. Fig. 2a and Fig. 2b show spatial-temporal plots for passing and for seepage of bikes in bottleneck situation respectively. Initially, in Fig. 2a, cars (in black) are passing bikes (in red) and therefore, after queue formation, no seepage occurs[1] and vehicles follow lane

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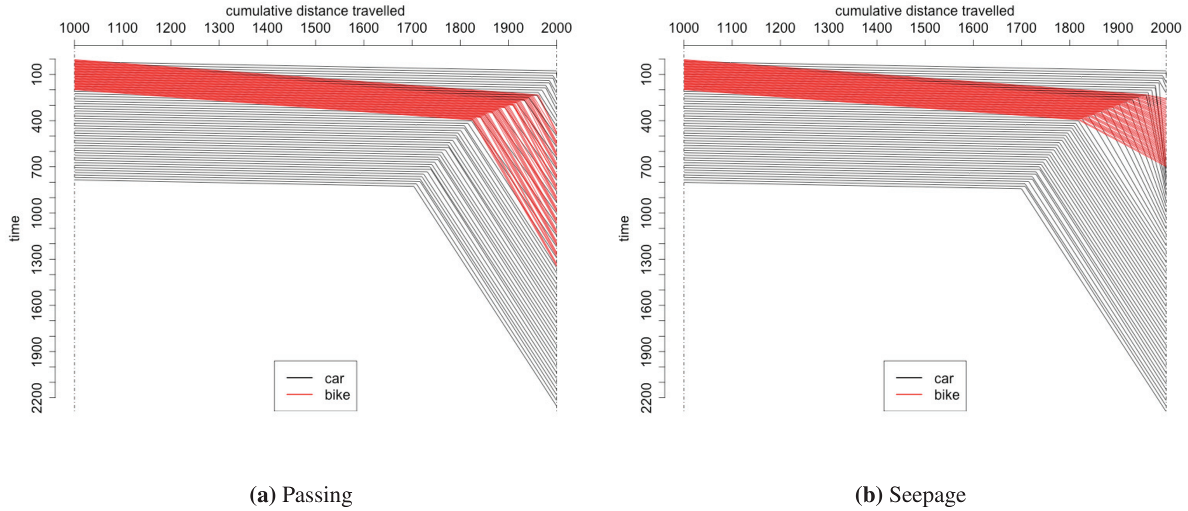
[1] Queue simulation in MATSim provides link enter and leave time events only and thus queuing positions are interpolated. Since, positions of vehicles in the queues are not in the same order as they leave the link[1], overlapping of trajectories of cars and bikes in congested regime is observed (see Fig. 2a).

concept. Whereas, in Fig. 2b seepage is allowed and therefore, during congested regime bikes are creeping through congested cars and leaving the link before cars. Average link travel times for car are 847 and 955 *sec* for passing and seepage cases respectively; same for bike are 808.5 and 376 *sec*. Clearly, average travel time for bike is reduced considerably. Since car mode vehicles are staying behind bikes in the queue, average travel time for cars is increased marginally but total link travel time of cars and bikes is reduced by 24%. These findings are in line with literature.[12,11]

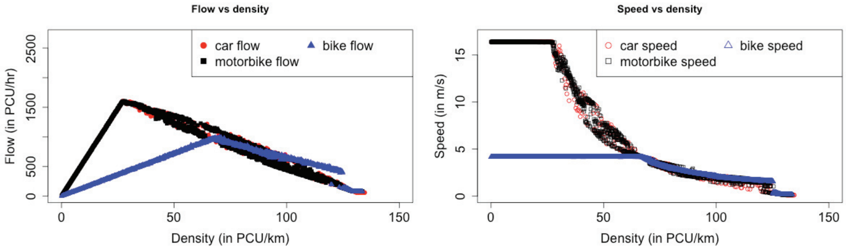


(a) Passing **(b)** Seepage

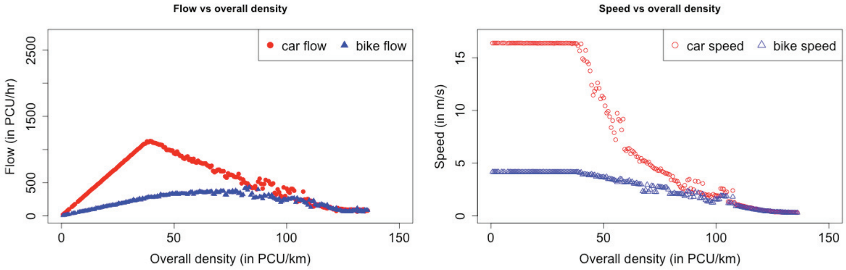
Fig. 2: Space time plot for (a) passing and (b) seepage of smaller vehicles at bottleneck.

Fundamental diagrams (FDs). In order to validate the proposed model, traffic fundamental diagrams (FDs) are necessary and therefore presented here. To overcome the limitation of unclear dynamics in jammed regime of FDs[1] and to generate more realistic dynamics of congested links the concept of backward traveling holes is introduced in the queue simulation. By applying the backwards traveling holes approach the model mimics the Kinematic Wave Model (KWM).[16,22] However, a true consistency with the theory is unclear since mixed-traffic and seepage is beyond the "classical" KWM. The basic idea behind the backward traveling holes approach is that during jammed regime, if a vehicle leaves the downstream end of link, space will not available instantly on the upstream end of link. Instead, it will take some time for the free space to reach the upstream end of link.[6,9] The holes effectively introduce an inflow link capacity, in addition to the already existing outflow link capacity. The queue model without holes typically has a horizontal section in the fundamental diagram, corresponding to the outflow capacity,[24] which comes together with a nearly vertically downward sloping congested branch. After introducing backwards traveling 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. In consequence, the overall capacity of a link can now be smaller than the outflow capacity.[10] Each hole corresponds to the PCU which is equivalent to the leaving vehicle's PCU. Each hole also has precomputed times of arrival on upstream end of link. In the present study, the backward traveling hole speed is assumed to 15 km/hr. This corresponds to a time gap of about 1.8 *sec* between to subsequent vehicles.

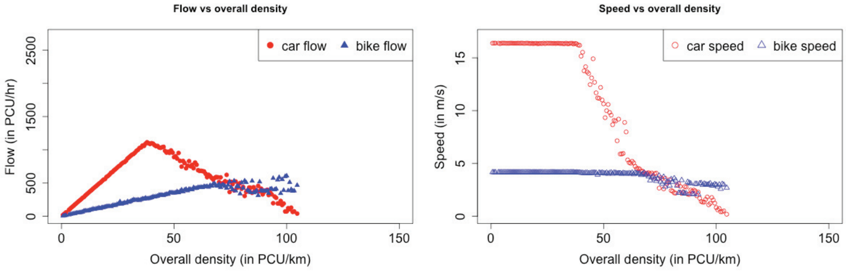
In order to plot FDs, a triangular race track network is used in the present study which was earlier used in the study by Agarwal at al.[1] Thus, it is shortly described here. Each link in network is 1000 m long. Maximum flow capacity and density of each link are 2700 PCU/hr and 133.33 PCU/km respectively. An equal modal split (in PCU) for cars and bikes is used for this experiment. Initially, FDs for only car, only motorbike, and only bike are plotted (see Fig. 3a) for comparison. Clearly, dynamics in jammed regime is more clearer now and as expected, the maximum flow is not achieved due to the underlined dynamics of holes.[10] Shapes of the FDs for car are supported by the diagrams in the past by Eissfeldt[10]. Interestingly, as in the previous study by Agarwal at al.,[1] FDs for car and FDs for motorbike look similar and maximum flow for bike is achieved at a higher density than for car and motorbike due to lesser maximum



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



(b) Car bike passing



(c) Car bike seepage

Fig. 3: Fundamental diagrams for (a) single modes simulations and, (b) passing and (b) seepage for car bike simulation

speed of bike. Fig. 3b and Fig. 3c show the FDs for passing and seepage behavior respectively. Branches of FDs in free flow regime in Fig. 3b and in Fig. 3c are same since, until the capacity regime is reached, slope of the flow density curve is given by minimum of allowed link speed and maximum speed of vehicle. After that, flow starts decreasing until the flow becomes zero thus capacity regime and jammed regime are together representing the link dynamics during congestion. In Fig. 3c, bike flow keeps increasing until a density of about 110 PCU/km. Reduction in speed for bikes is marginal but car flow and speed is approaching zero at lesser density than for passing behavior. In case of passing behavior, flow characteristics of bikes and cars are affected by presence of each other (see Fig. 3b). But, on the contrary, for seepage behavior, the flow characteristics of bikes are marginally affected by the presence of cars but flow characteristics of cars are significantly affected by presence of bikes (see Fig. 3c) 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 Fig. 3c, data points corresponding to densities higher than 110 PCU/km are not shown due to flow dynamics of holes at higher densities. Thus, capacity and jammed regime for bike flow has not been observed. Since, the seepage behavior is clearly depicted with the obtained data points and thus acceptable.

4. Conclusion and outlook

In order to develop a model to simulate heterogeneous traffic close to reality, this paper studies the commonly present seepage behavior of smaller vehicles. Due to easier manoeuvrability of motorbikes/bikes, these vehicles pass across the gaps between the stationary or almost stationary vehicles. Fundamental diagrams and space time trajectories are plotted to see the effect of smaller vehicles in traffic stream. In order to have clearer pictures in congested part of link, the concept of backward traveling holes is introduced. In future, the proposed model needs to be tested with more concrete data of a real world study and more important application like evacuations. 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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References

1. Agarwal, A., Zilske, M., Rao, K., and Nagel, K. Person-based dynamic traffic assignment for mixed traffic conditions. In *Conference on Agent-Based Modeling in Transportation Planning and Operations* (Blacksburg, Virginia, USA, 2013). Also VSP WP 12-11, see `http://www.vsp.tu-berlin.de/publications`.
2. Aupetit, S., Espié, S., S., and Bouaziz, S. Naturalistic study of riders' behaviour in lane–splitting situations. *Cognition, Technology & Work* (2014), 1–13.
3. Balmer, M., Rieser, M., Meister, K., Charypar, D., Lefebvre, N., Nagel, K., and Axhausen, K. MATSim-T: Architecture and simulation times. In *Multi-Agent Systems for Traffic and Transportation*, A. Bazzan and F. Klügl, Eds. IGI Global, 2009, pp. 57–78.
4. Centre for Road Safety. Transport for New South Wales, accessed 2014.
5. Cetin, N., Burri, A., and Nagel, K. A large-scale agent-based traffic microsimulation based on queue model. In *Proceedings of the Swiss Transport Research Conference (STRC)* (Monte Verita, Switzerland, 2003).
6. Charypar, D., Axhausen, K., and Nagel, K. Event-driven queue-based traffic flow microsimulation. *Transportation Research Record 2003* (2007), 35–40.
7. Charypar, D., and Nagel, K. Generating complete all-day activity plans with genetic algorithms. *Transportation 32*, 4 (2005), 369–397.
8. Clarke, D. D., Ward, P., Bartle, C., and Truman, W. In–depth study of motorcycle accidents. Tech. Rep. 54, School of Psychology, University of Nottingham, 2004.
9. Eissfeldt, N., Krajzewicz, D., Nagel, K., and Wagner, P. Simulating traffic flow with queues, 2006. See `http://www.vsp.tu-berlin.de/publications`.
10. Eissfeldt, N. G. *Vehicle–based modelling of traffic*. PhD thesis, Universitä zu Köln, 2004.
11. Ellis, T. Inquiry into managing transport congestion Victoria. *Motorcycle Riders' Associations (MRA)* (2006).
12. FEMA. A european agenda for motorcycle safety: The motorcyclists point of view. Tech. rep., Federation of European Motorcyclists Associations, 2009.
13. Gawron, C. An iterative algorithm to determine the dynamic user equilibrium in a traffic simulation model. *International Journal of Modern Physics C 9*, 3 (1998), 393–407.
14. Hurt, H. H., Ouellet, J. V., and Thom, D. R. Motorcycle accident cause factors and identification of countermeasures volume I. Tech. rep., Traffic Safecty Center, University of Southern California, Los Angeles, California, 1981.
15. Lämmel, G., Grether, D., and Nagel, K. The representation and implementation of time-dependent inundation in large-scale microscopic evacuation simulations. *Transportation Research Part C: Emerging Technologies 18*, 1 (2010), 84–98.
16. Lighthill, M. J., and Whitham, J. B. On kinematic waves. I: Flow movement in long rivers. II: A Theory of traffic flow on long crowded roads. *Proceedings of the Royal Society A 229* (1955), 281–345.
17. Maciejewski, M. Parametric calibration of queue-based traffic flow model in MATSim. In *VII Konferencja Naukowo-Techniczna "Systemy Transportowe – Teoria i Praktyka"* (2010).
18. MAIDS. *In–depth investigation of motorcycle accidents*. Association des Constructeurs Européens de Motocyles, 2003.
19. MATSim. MultiAgent Transport SIMulation webpage, accessed 2014.
20. Oketch, T. New modeling approach for mixed-traffic streams with nonmotorized vehicles. *Transportation Research Record: Journal of the Transportation Research Board 1705*, 00–0285 (2000), 61–69.
21. Oketch, T. Modeled performance characteristics of heterogeneous traffic streams containing non-motorized vehicles. Annual Meeting Preprint 03–0721, Transportation Research Board, Washington D.C., 2003.
22. Richards, P. Shock waves on the highway. *Operations Research 4* (1956), 42–51.
23. Simon, P., Esser, J., and Nagel, K. Simple queueing model applied to the city of Portland. *International Journal of Modern Physics 10*, 5 (1999), 941–960.
24. Simon, P., and Nagel, K. Simple queueing model applied to the city of Portland. Annual Meeting Preprint 99-0861, Transportation Research Board, Washington D.C., 1999.
25. Sperley, M., and Pietz, A. J. Motorcycle lane–sharing: Literature review. Tech. Rep. OR–RD–10–20, Oregon Department of Transportation Research Section, 2010.
26. Wang, J., Yang, J., Li, Q., and Wang, Z. The effect of nonstandard vehicle's special behavior on mixed-traffic modeling. *Applications of Advanced Technologies in Transportation Engineering* (2004), 589–594.