

Traffic Flow Simulations Based on Microscopic Models

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ABSTRACT

Microscopic car-following models are widely used to generate traffic flow simulations. In some cases visualization on macroscopic scales (both spatial and temporal) are required to provide relevant feedback to researchers. Recent studies have indicated that the life time of highway traffic jams is severally influenced by temporary deviations of the driving style of individual motorists. The most influential parameters are the longitudinal acceleration and the headway distance produced by car drivers soon after leaving a congestion situation. To study the effects of acceleration profiles on the life times of congestions it is crucial to generate traffic flow simulations which can be viewed at highly varying spatial and temporal scales. The influence of adaptive cruise control (ACC), for example, is one of the factors that can be forecasted using traffic flow simulations.

Keywords

Traffic flow simulation, microscopic driving model, feedback to researcher

1. INTRODUCTION

Queues of highway traffic cause time delays for the passengers involved but are also known to reduce the highway's capacity. The discharge flow from a bottleneck is commonly at a lower rate, for which several reasons have been hypothesized. It could be explained by a memory effect, in response of drivers after being trapped in a jam. As a reaction, once they leave a jam, they adapt only slowly to an almost free road ahead of them and will accelerate in a lazy style [Treiber 2003]. This deteriorates the dissipation of the traffic jam. However, the opposite effect has also been observed: the discharge flow following a capacity drop often recovers to a higher rate for a short period of time before returning to the "normal" rate [Kim 2012, Laval 2006].

In this paper we analyze the effect of changing driving styles using simulations based on a dedicated microscopic traffic flow model, which is a modified version of the Intelligent Driver Model (IDM)

(Treiber 2000).

2. MAXIMAL ACCELERATION AND RELAXATION TIME

To analyse the effects of change of driving style of individual chauffeurs we need a model that permits behaviour parameters to be dependent on time. Further, the parameters can be different for different drivers and dependent on the specific traffic situation. As a modelling scheme we therefore chose microscopic car following. In this study we focus on the longitudinal driving behaviour of highway traffic on a single lane, discarding lane change and ramp inflows/outflows. The specific, time dependent driving styles can be modelled by a simple extension of the IDM. The IDM itself is suited for our analysis purpose as its parameters are measurable, intuitive and extendable (Kesting 2008).

The single-lane version of the IDM describes the positions of N cars as a function of time. The acceleration $a(s, v, \Delta v)$ of a car is modeled as function of the net distance s to the nearest vehicle in front, the velocity v and Δv , the velocity relative to the car in front. The IDM is expressed as

$$a(s, v, \Delta v, t) = a_{\max} \left[1 - \left(\frac{v}{v^*} \right)^4 - \left(\frac{s^*(v, \Delta v)}{s} \right)^2 \right],$$

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where a_{\max} is the maximum acceleration that could occur in the model. In most simulations a_{\max} is a constant, *e.g.* set to 1.5m/s^2 but in our study we will make it situation dependent. v^* is the speed a driver would like to achieve on an empty road, often set as a constant. s^* is the distance to the leading car that a driver would like to achieve. In the IDM

$$s^*(v, \Delta v) = s_0 + \max\left(0, vT + \frac{v \Delta v}{2\sqrt{a_{\max} b_{\max}}}\right),$$

where s_0 is the minimum net distance that should ever occur between two consecutive cars even at zero speed; vT a velocity dependent net safety distance that should at least be maintained to the preceding car. The time gap, or time headway T is typically set between 0.5s and 1.5s in simulation runs, either as a constant for all cars or according to some distribution model (Hoogendoorn 1998). b_{\max} is the maximum comfortable deceleration.

We have adapted the model slightly by allowing any positive acceleration a to change to a higher or lower value at time t_{out} and then to gradually returns to the “normal” function during the time span $[t_{\text{out}}, t_{\text{out}} + T_{\text{relax}}]$. t_{out} is the point in time that a particular car gets out from a traffic jam. T_{relax} is the relaxation time, that is the time it takes for the driver to “forget” the jam in which he or she was stuck. We have defined the modified acceleration function a' as

$$a'(s, v, \Delta v, t) = \begin{cases} F(t)a(s, v, \Delta v, t) & \text{if } a(s, v, \Delta v, t) > 0 \\ a(s, v, \Delta v, t) & \text{if } a(s, v, \Delta v, t) \leq 0 \end{cases} \quad (1),$$

where

$$F(t) = \begin{cases} \frac{a_{\text{out}}}{a_{\max}} + \frac{t - t_{\text{out}}}{T_{\text{relax}}}\left(1 - \frac{a_{\text{out}}}{a_{\max}}\right) & \text{if } t_{\text{out}} \leq t \leq t_{\text{out}} + T_{\text{relax}} \\ 1 & \text{elsewhere} \end{cases}.$$

Here we have assumed a linear “return to normal” during relaxation time T_{relax} . The precise interpretation of the relaxation time and its quantification remain speculative. In the literature, values of 1 minute up to 10 minutes have been suggested. As mentioned in Kesting (2008), typical values for a_{\max} and b_{\max} are 1.4 and 2.0m/s^2 , respectively, whereas ranges between 0.3 and 3.0m/s^2 have been suggested as well. If we set $a_{\max} = 1.5\text{m/s}^2$ as the “normal” value, then the range $a_{\text{out}} = 0.3\text{m/s}^2$ to 3m/s^2 would correspond to $F(t_{\text{out}}) = 0.2$ to 2.0.

t_{out} is itself a function of t and can be defined as the latest moment prior to t for which $v < v_{\text{delay}}$:

$$t_{\text{out}}(t) = \max(\{u \in [0, t] \mid v(u) < v_{\text{delay}}\} \cup \{-T_{\text{relax}}\}),$$

assuming that the simulation starts at $t = 0$. v_{delay} is the maximal velocity that is perceived by a driver as uncomfortable or causing delay. Both v_{delay} and T_{relax} serve to model the degree of the drivers’ motivation to react promptly on the behaviour of cars ahead.

3. THE EFFECTS OF v_{delay} , a_{out} AND T_{relax} ON TRAFFIC FLOW

Using the adapted IDM of equation (2) for simulations we have analysed the behaviour of cars that leave a jam. The parameters of the IDM were set as $T = 1.5\text{s}$, $v^* = 33.3\text{m/s}$ or 120km/h , $a_{\max} = 1.5\text{m/s}^2$, $b_{\max} = 2.0\text{m/s}^2$ and $s_0 = 2\text{m}$. We designed an initial, simple scenario to simulate the development of a row of $N = 200$ cars, each having a length of $l = 5\text{m}$, driving on a single lane of a straight road without on- or off-ramps. At $t = 0$, all cars drive in the positive x -direction, equidistantly at constant speed $v_i(0) = 2.778\text{m/s}$ or 10km/h for $i = 1, \dots, N$.

The scenario prescribes that at $t = 60\text{s}$ the leading car accelerates with $a = 1.111\text{m/s}^2$ during 25s, thus linearly increasing its speed from 10 to 110km/s . The simulated behaviour of the following cars is governed by equation (1) and will depend on the values of a_{free} and T_{relax} unless the speed of all cars would exceed v_{delay} . If we set $v_{\text{delay}} = 0\text{km/h}$ then $a' = a$ and equation (1) reduces to the original IDM. We refer to the setting of $v_{\text{delay}} = 0$ as the D0 condition. The velocities of car 1, 2, 100 and 200 obtained during the 20 minutes of simulated time in the D0 condition is depicted in Figure 1.

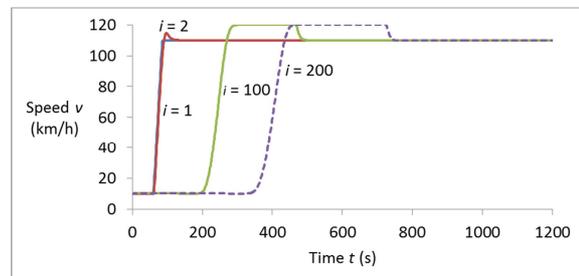


Figure 1. Results of simulations in condition D0. Development of speeds of cars indexed 1, 2, 100 and 200 in the specified scenario, using the IDM.

At $t \approx 350\text{s}$ the 200th car begins to accelerate, about 4½ minutes later than the first car did. At $t = 405\text{s}$ car 200 reaches an acceleration of 0.45m/s^2 , the largest during the simulation, significantly less than the maximal accelerations exhibited by cars 1 to 10 (between 1.0 and 1.1m/s^2). This is in line with the fact that the gaps between cars increase with growing speed, which damps the accelerations. In general, the cars catch up with their predecessor and reach a speed of $v^* = 120\text{km/h}$ and then decelerate to 110km/h to adapt to the platoon. The length of the row of cars increases from 2.2km at $t = 0$ to 11.3km at $t = 432\text{s}$ and then stabilizes to 10.4km from $t =$

740s onwards, where the cars form a stable platoon with $s = s^* = 10.4\text{km}/199 - l = 48\text{m}$. We define the delay d_i of car i due to the fictive jam by the time loss

$$d_i = \int_0^{1200} \frac{v^* - v_i(t)}{v^*} dt$$

which amounts to 161s for the leading car, up to 408s for the final car.

If we change the condition by setting $v_{\text{delay}} = 30\text{km/h}$, the accumulated delay of each car (except the leading one) increases. The final car experiences an extra delay of 52s up to 414s, depending on the settings of a_{out} and T_{relax} . For $v_{\text{delay}} = 60\text{km/h}$ the extra delay of the 200th car can get as large as 482s in the simulation. The length of the row increases to 26.1km.

The development of speed holds back for higher v_{delay} and decreasing a_{out} , as shown in Figures 2, 3 and 4 for the final car of the platoon. We now analyse another traffic scenario (referred to as scenario B), with a more varying behaviour of the leading car, see Figure 5. In the time interval $t = 60\text{s}$ to $t = 300\text{s}$ the leading car accelerates and slows down in alteration. The speed profile is designed to reflect the participation of the cars in busy traffic.

About the visualization modes of the traffic simulations we learned that the researcher calls for varying degrees of zoom and acceleration in order to gain initial understanding of the model and the conditions that could be experimented.

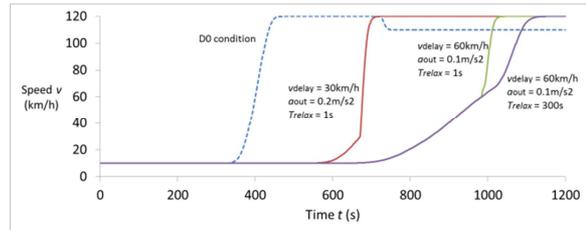


Figure 2. Speed development of car 200 conditioned by a_{out} , v_{delay} and T_{relax} .

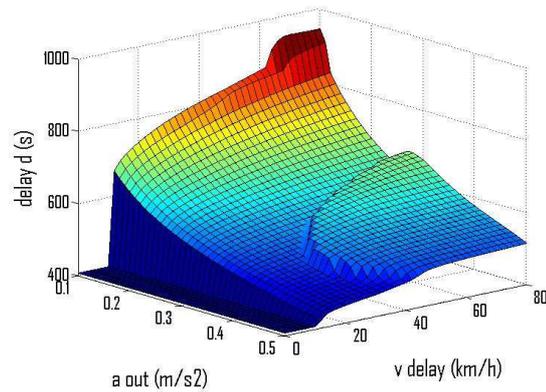


Figure 3. Delay of 200th car at $t=1200\text{s}$, plotted against a_{out} and v_{delay} . $T_{\text{relax}} = 1\text{s}$.

a) Condition D0



b) $v_{\text{delay}} = 60\text{km/h}$, $a_{\text{out}} = 0.1\text{m/s}^2$

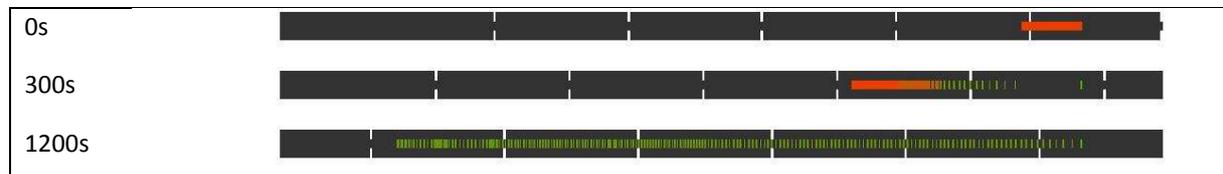


Figure 4. Abstract pictures of the road with row of cars at $t = 0\text{s}$, $t = 300\text{s}$ and $t = 1200\text{s}$ for a) D0 condition and b) $v_{\text{delay}} = 60\text{km/h}$, $a_{\text{out}} = 0.1\text{m/s}^2$, $t_{\text{relax}} = 1\text{s}$. The snapshots are taken from a simulation movie (see AVI files submitted to the conference). The cars are moving to the right; the distance between the white markings is 5km

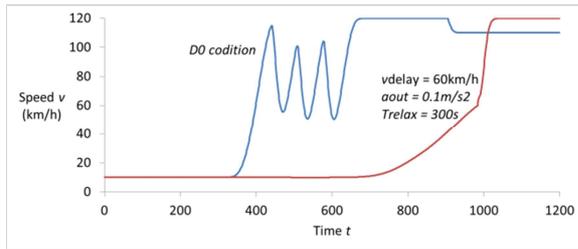


Figure 5. Speed development of car 200 in scenario B under two conditions defined by a_{out} , v_{delay} and T_{relax} .

4. CONCLUSIONS

We have proposed a modified version of the IDIM traffic simulation model which supports the control of parameters defining drivers' behaviour such as delayed acceleration, demotivation and relaxation time. These parameters are important if the effect of adaptive cruise control and/or the behaviour of human drivers are to be studied. We have designed two simple scenarios of road traffic and studied the effects of the parameters on journey delay, on the distribution of cars on the road and on jam formation and dissipation. Although the effects are significant and well quantifiable, their influence on a macroscopic scale can only be intuitively understood by presenting the space-time behaviour of the system on various scales: relaxation time is measured in seconds and a journey in hours; intervehicle distances are measured in metres and the road segment under study has a length of 25km. It appeared that simulation movies at variable playing speed could provide feedback to the researcher effectively.

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