Modelling Motorway Traffic using Microscopic Techniques

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We implement the intelligent driver model (IDM) combined with the model, minimizing overall braking induced by lane change (MOBIL) to create a microscopic simulation of traffic on multi-lane motorways. The simulation environment features stochastic vehicle generation based on real life data from the UK Government to make it as realistic as possible and the ability collect data from almost any metric related to the vehicles on the road making it very versatile. In the future this environment will be used to investigate and evaluate whether two parallel two lane motorways are better or worse for traffic flow than one four lane motorway.

Contents

1. Introduction

The program uses two independent driving models to compute the movement of vehicles. The first, the intelligent driver model (IDM) [2] calculates the acceleration of the vehicle according to the vehicle it is following, from the acceleration it is then possible to work out velocity and position of that vehicle. The second minimizing overall braking induced by lane change (MOBIL) [1] works by using the acceleration data collected by MOBIL on the vehicles in front and behind in both the current lane and potential lanes the car could move and then works out an incentive criterion. The incentive criterion determines whether a lane change is safe, positively impacts the driver and does not negatively impact the drivers in other lanes too much.

2. The Intelligent Driver Model

1. *Introduction*

The intelligent driver model [2] is a function which calculates the acceleration of the vehicle a_i, according to three dynamic variables, the current velocity on the vehicle v_i, the distance to the vehicle in front Δs_i, and the difference in velocity to the vehicle in front Δv_i. It ensures that cars behave naturally and is crash free. The acceleration function is:

$$a_i(v_i, \Delta s_i, \Delta v_i) = a\left(1 - \left(\frac{v_i}{v_{\max}}\right)^{\delta} - \left(\frac{s^*(v_i, \Delta v_i)}{\Delta s_i}\right)^2\right) \tag{1}$$

Where $s^*(v_i, \Delta v_i)$, which controls the ideal distance to the car in front is:

$$s^*(v_i, \Delta v_i) = s_0 + v_i T_i + \frac{v_i \Delta v_i}{2\sqrt{ab}} \tag{2}$$

2. *Constants*

The intelligent driver model contains a large number of constants which can be changed to fine tune the model. In future sections we will investigate which are dominant and which have the most influence over the model and in each particular situation.

Symbol	Quantity	Typical Value
a	Max Acceleration	2 ms^{-2}
b	Comfortable Declaration	3 ms^{-2}
δ	Acceleration Exponent	3
s_0	Minimum Separation	2m
$v_{\max}$	Max Velocity	$<$ 31 ms^{-1}
T_i	Reaction Time	0.67s

TABLE I: Table of all constants used in the intelligent driver model

Depending on how the model is set up some of these quantities can be universal meaning they are the same for all vehicles and some can be individual for each car generated. Currently a, b, δ and s_0 are universal and $v_{\max}$ and T_i are individually generated according to normal distributions.

3. Understanding the Model

The intelligent driver model works as a function of two main terms, the clear term and the traffic term such that:

$$a_i(v_i, \Delta s_i, \Delta v_i) = a\left(a_{\text{clear}} + a_{\text{traffic}}\right) \tag{3}$$

Each term dominates in a different situation. When the vehicle is not following another vehicle it's acceleration will be dominated by the a_{clear} term:

$$a_{\text{clear}} = 1 - \left(\frac{v_i}{v_{\max}}\right)^{\delta} \tag{4}$$

and when the vehicle is following another vehicle it's acceleration will be impacted by a_{traffic} such that:

$$a_{\text{traffic}} = -\left(\frac{s^*(v_i, \Delta v_i)}{\Delta s_i}\right)^2 \tag{5}$$

Most of the time the when the vehicle is in traffic it will be impacted upon by a combination of both terms but usually one will dominate. We observe by inspection that the heavier the traffic, the slower the velocities and the smaller the separation distances of the vehicles, the more a_{traffic} will dominate. Conversely the lighter the traffic, the higher the velocities and larger the separation distances of the vehicles the more a_{clear} will dominate.

3. Minimizing Overall Braking Induced by Lane Change (MOBIL)

1. Introduction

The model MOBIL[1] is be used as an extension to IDM [2] to make a single lane simulation extend to a multi-lane system with relatively little complexity. MOBIL [1] makes use of the IDM's [2] ability to calculate the acceleration of vehicles following each other in a line. As the acceleration of the vehicle is a function of the separation distance, $\Delta s_i)$ and the difference in velocities $\Delta v_i)$ we can use the acceleration of the vehicles to make decisions about whether a lane change is both safe and desirable. MOBIL's decision making process uses two basic criterion: the safety criterion, which determines whether a lane change is safe and the incentive criterion, which determines whether a lane change is desirable for both the car in question and it's followers and leaders.

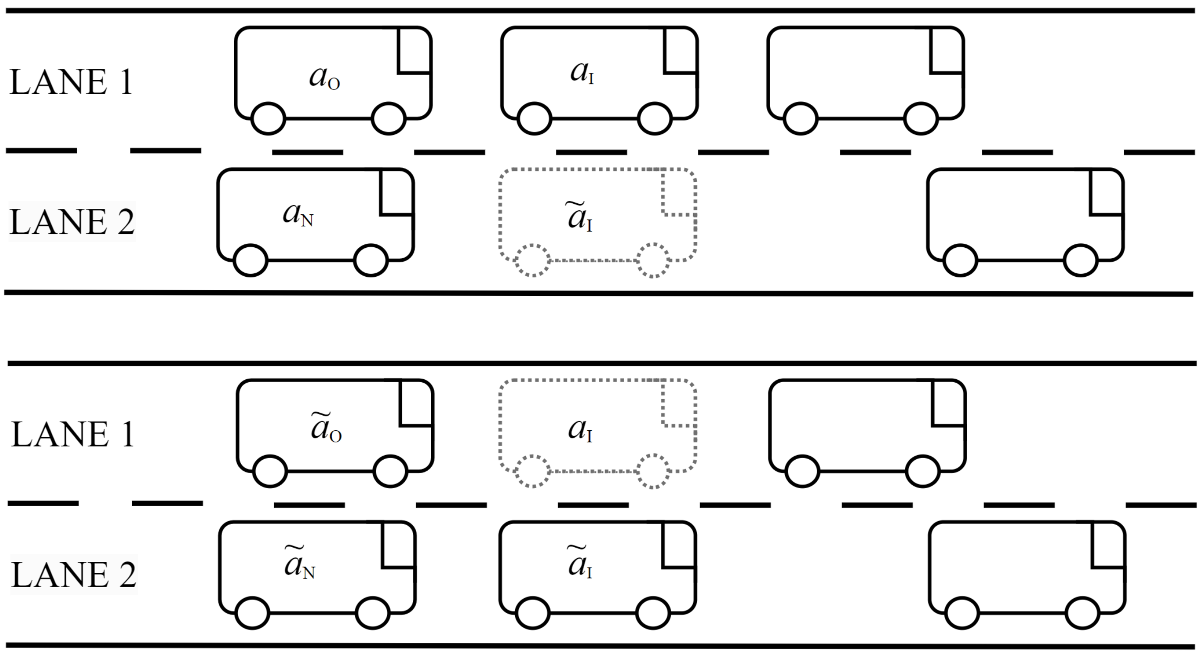

FIG. 1: Diagram of the 2 lane motorway. The upper figure is depicting the vehicle situation and accelerations before a prospective lane change. The lower figure is depicting the vehicle situation and accelerations after the lane change has occured.[1]

In the initial model we have a 2 lane road with vehicles in both lanes which are both behind the car of interest. The car of interest with acceleration a_{I} is in lane 1 being followed by the old follower with acceleration a_{O} and is considering moving to lane 2 where it would have a new follower with acceleration a_{N}. The model works by calculating a comparing the accelerations the cars would have if they switched lanes. We will denote these calculated accelerations by $\tilde{a}_{\mathrm{I}}$, $\tilde{a}_{\mathrm{O}}$ and $\tilde{a}_{\mathrm{N}}$ respectively.

2. *Safety Criterion*

The safety criterion checks whether moving into a new lane would cause the new follower to have to break dangerously effectively avoiding . As the acceleration is a function of separation distances and velocity differences comparing accelerations will contain all information we need to know to work out whether a lane change is safe. Mathematically the criterion written out is:

$$\tilde{a}_{\mathrm{N}} \geq b_{\mathrm{safe}} \tag{6}$$

Where b_{safe} is the maximum deceleration of the vehicle which is safe. According to MOBIL [1] this is approximately 1G or 9.8ms^{-2}.

3. *Incentive Criterion*

The incentive criterion is logic which decides whether a lane change is advantageous for the vehicle of interest and compares this with the impact it will have on the follower vehicles in the new and old lane. Mathematically the criterion written out is:

$$(\tilde{a}_{\mathrm{I}} - a_{\mathrm{I}}) + p\left((\tilde{a_{\mathrm{N}}} - a_{\mathrm{N}}) + (\tilde{a}_{\mathrm{O}} - a_{\mathrm{O}})\right) > \Delta a_{\mathrm{th}} \tag{7}$$

Where p is the politeness factor.

Unpacking the meaning of equation 7 the equation can be thought of as three terms: the difference of the vehicle of interest's, new follower's and old follower's current and potential acceleration did the lane change take place. The terms are then compared against a lane changing threshold, Δa_{th} and if the threshold is passed then the lane change will take place. It should be noted the new and old follower's acceleration differences are also multiplied by a politeness factor, p which will be greater for more considerate drivers and lower for more selfish drivers. It should also be noted that when p = 1 and Δa_{th} = 0 we have the condition that achieves minimal braking and increases overall model acceleration which is where the MOBIL model gets it's name from:

$$\tilde{a}_{\mathrm{I}} + \tilde{a}_{\mathrm{O}} + \tilde{a}_{\mathrm{N}} > a_{\mathrm{I}} + a_N + a_O \tag{8}$$

To generalise to more than two lanes we compute the criterion for both lanes and if it is above the threshold for both lanes then the change is executed to the lane with the higher incentive.

References

[1] Arne Kesting, Martin Treiber, and Dirk Helbing. General lane-changing model mobil for car-following models. Transportation Research Record, 1999(1):86–94, 2007.

[2] Martin Treiber, Ansgar Hennecke, and Dirk Helbing. Congested traffic states in empirical observations and microscopic simulations. Phys. Rev. E, 62:1805–1824, Aug 2000.