Driver Behaviour and Traffic Modelling.
Are we Looking at the Right Issues?

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Abstract

Although much attention has been given to the simulation and modeling of driver behaviour, and comparison and testing of differing algorithms (such as car following) is now performed, there are several assumptions in use regarding micro-modeling that may not be correct. These could have important implications to our ability to model the impact of ITS (Intelligent Transport Systems), in particular, in-vehicle systems. In this paper we will examine four assumptions regarding car following models that may be in need of revision:

- i) *Drivers adopt constant time headways and use 'safe' following distances.*
- ii) *There is a lack of data against which to undertake calibration/ validation.*
- iii) *Short time steps allow more realistic simulations of dynamics*
- iv) *That there are important ' Chaotic patterns' ' in car following.*

1 Introduction

As micro-simulation has evolved we have seen steady improvements in our ability to describe how a driver controls the motion of a vehicle. This, combined with advances in computing has taken us from simple analysis of the dynamics of platoons of vehicles (1), through to modern simulation models capable of implementing the dynamics of thousands of vehicles under many differing conditions.

Although originally investigated for the purposes of understanding traffic dynamics, differing perspectives on the driving process have since been taken, eg control theory or using psychophysical states (2, 3). However, as each new perspective has added developments, so other features and techniques have fallen into dis- (and even mis-) use. Many of these have been discussed elsewhere (4), however it is the aim of this paper to present four topics for debate, which may until now have been viewed as the cornerstones of micro-modeling, but may no longer be valid starting points for research. In the following sections, each of these topics will be presented.

2 Time Headway and 'Safe' Distances

A common assumption about car following is that it can be described by the efforts of each driver to maintain a constant time headway, which at all times is 'safe'. That is, that if a preceding vehicle should brake at a maximum rate (b_{n-1}), then following a reaction time delay (τ), the following vehicle will, by using a deceleration less than a critical threshold (b_n), be able to slow down and avoid a collision by coming to a stop some small distance (s_0) behind it.

This assumption is one of the underlying principles of several well known car following formulations (5), however there is an increasing body of evidence pointing to this not being true. Several sources (eg. 6) not only report time headways generally being described by a $1/\sqrt{v}$ relationship but also that a large proportion of typical freeway headways measured may be ' unsafe' (48% of the headways measured were found to be under 1 second), a finding that has actually long been known (for example, anything from 36 to 68% (7)).

Additionally, the formulation of the models usually chosen is sometimes not well justified, with the majority of investigations using either the Gipps algorithm (5) or the 'General Motors' model (eg. 1) and few comparisons being undertaken between differing models (eg. 8).

A number of straightforward observations are possible of the models available, for example, the General Motors model contains a 'driving' term according to the relative speed (DV), which, if reaching zero results in zero acceleration regardless of following distance (DX). This is not the case with many other models, where for example the Gipps model contains a minimum separation term producing an equilibrium following distance of:

$$DX - s_o = v\ (1 - (v / 2b_n)\ (1 - 1/\gamma))\ \text{with}\ b_{n-1} = \gamma . b_n .$$

Gipps uses γ=0.875, meaning that it is anticipated that the lead drivers' maximum deceleration will be *less* than that of the following driver, an optimistic point of view which produces a headway of less than one second. Conversely a pessimistic driver with ã> 1, for example, 1.3, produces a headway of from 1 to 2.5 sec. (Fig. 1).

Alternative formulations have also been researched in other fields, for example physics based approaches to traffic flow modeling, and have included the 'Optimal Velocity Model' (9), relating acceleration (a) to following distance, speed and v_{DES}, the desired speed.

$$a = \{ (v_{DES}/2) [\tanh (DX - s_0) + \tanh (DX_0)] - v \} / \tau$$

Reducing to, and giving a stable following distance (for v<16.8, shown in Fig. 1) of:

$$14.4 + 5.8 \ln [(16.8 + v) / (16.8 - v)]$$

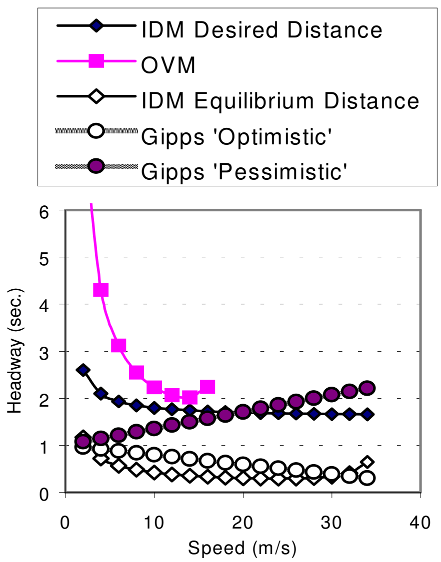

Figure 1: Comparison of Desired/ Equilibrium Following Distances.

Calculation of the likely accelerations to be achieved however (Fig. 2 - upper) shows that the model allows high valued solutions in excess of those practically attainable all too quickly away from a small target headway band. Further developments have seen the formulation of the 'Intelligent Driver Model' (10), which counters elements for vehicle deceleration in order to maintain distance, with a 'driving' term to produce vehicle acceleration to a free speed:

$$a = a_0 [1 - (v / v_{DES})^{\delta} - (DX_{DES} / DX)^2]$$

$$DX_{DES} = s_0 + T.v + (v.DV / 2\sqrt{(a.b)})$$

Typically with s_0=2m, a_0=0.73m/s^2, δ=4, T=1.6 sec. and $\sqrt{(a.b)}$~1.1 s^2/m. However, the desired stable following distance (2 + 1.6.v, shown in comparison to other models in Fig. 1) is not equivalent to the equilibrium distance where all the 'forces' cancel each other (see Fig. 2 - middle). Although with higher magnitudes of deceleration at more extreme values (high speed and low following distance), the IDM in many respects produces a similar response surface to that of the Gipps model shown in Fig. 2 - lower.

The use of alternative approaches to model formulation therefore has clear advantages, with both the OVM and IDM models producing a desired/equilibrium headway similar to that encountered empirically (OVM ~$1/v^{0.6}$, equilibrium IDM, ~$1/v^{0.4}$). While the OVM does not produce realistic accelerations the IDM compares well with existing approaches while avoiding the concept of a 'safe' headway. (An 'optimistic' Gip ps model could produce headways of less than a second, which although technically 'safe' would not be described as such by most drivers).

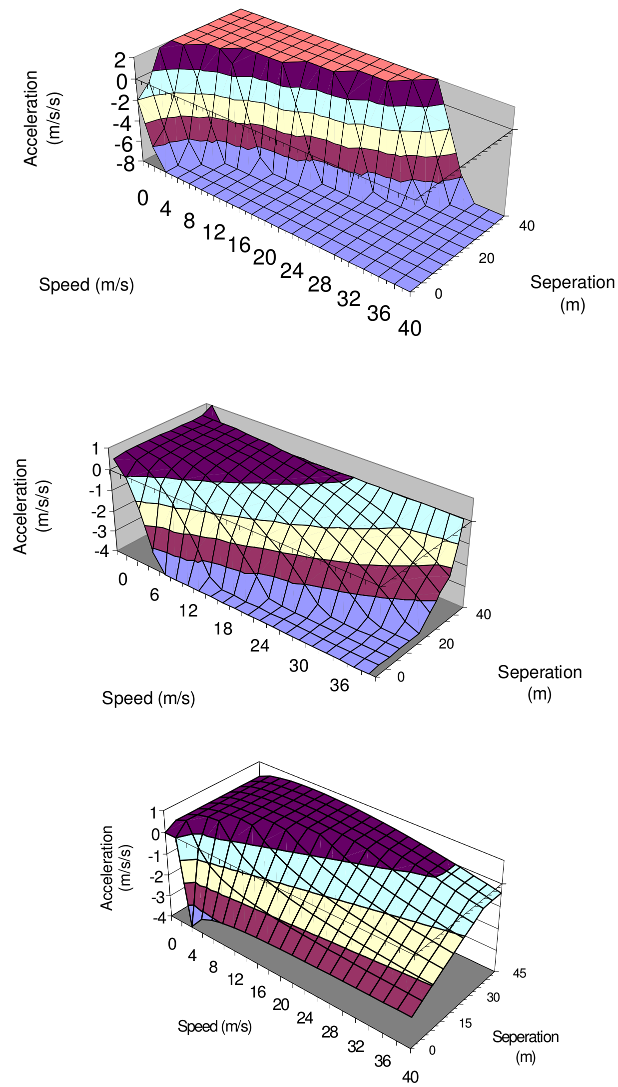

Figure 2: Response Surfaces for the OVM Model (Upper), the IDM Model (Middle) and the Gipps Model (Lower).

3 Calibration & Validation Data

One of the oft-cited problems with engineering a suitable behavioural model is the lack of available data against which to undertake assessment. Until the mid 1990s this was true with the primary set of data against which to gauge models (data collected on real roads where the drivers were unaware they were being observed) being that collected through helicopter observation of sections of freeway (11). One of the advantages of this database is the fact that aerial observation allowed the motion of many consecutive vehicles to be observed, allowing a lot to be learned regarding platoon dynamics. However, inaccuracy in photogrametric processing and the limited nature of the data set (each vehicle/ platoon only remaining in-view for a few minutes) restricts its usefulness. (A comparison of this method with others given below, is given in Fig. 3).

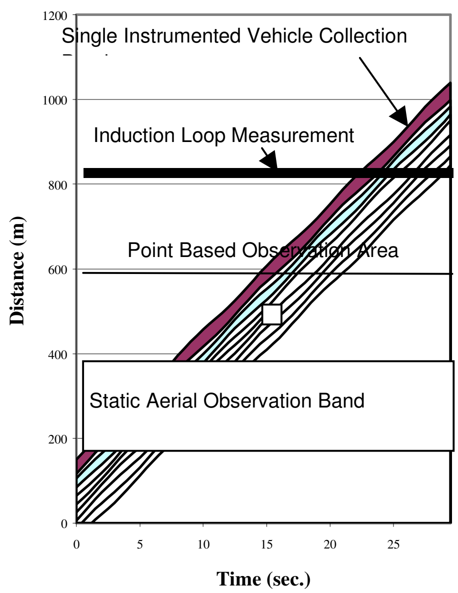

Figure 3: Functional Areas of Differing Data Collection Methods

With the coming of the 1990s however, and more particularly the increased investment in driver assistance systems such as ACC (Adaptive Cruise Control) automotive distance sensors became more readily available allowing their use in research tools such as instrumented vehicles, in-turn allowing studies to be undertaken in real traffic, observing the dynamics of pairs of vehicles, with a high accuracy and over a long time scale (eg. 12).

Instrumented vehicles however are not the sole future source of information on real driving processes, and are not without weaknesses. One solution has been to use GPS in order to define a vehicles' position, and if units are used in consecutive vehicles then differential calculations can give separation, speed and relative speed of vehicles in a platoon (13). Although the accuracy of such units is now increasing, cost of appropriate units (eg dGPS with cm accuracy) is still high (~$15k each), and hence studies are restricted. A recent indication of the degree to which the method can be used however are the studies undertaken by Gurusinghe et. al. (14), where eight vehicles equipped with dGPS were driven as a single platoon, allowing data to become available on platoon dynamics for the first time perhaps since the 70' s. Although of high accuracy such a method does have restrictions, with each car having to form part of a consecutive sequence, hence restricting trials in real traffic.

One problem with both of these techniques is the measurement of driver behaviour at fixed positions, eg. junctions, where one may wish to model acceleration at on-ramps for example. In these cases any method based on a single (or set of) vehicles will experience difficulties, as although measurements will be possible, the vehicles concerned will then have to finish their collection run past the area of interest, and turn about ready for another pass through the section being monitored. Although yielding data, the fraction of time spent collecting useful information is quite small, and hence a method is needed that allows the measurement of many different vehicles as each one passes through the area of interest. It is in cases such as this that aerial measurements have the advantage, although easier systems are now available, for example the System for Assessment of the Vehicle Motion Environment (15) developed by NHTSA. This system matches images from neighboring video cameras mounted high above the installation of interest, and through the use of image processing is able to compile accurate vehicle trajectories.

4 Time Step

Although seemingly a topic that has more in common with the computing efficiency in simulation (smaller times steps mean a greater update frequency and hence a larger computing overhead) the time step, or update rate, is a key part of the validity of any model.

Micro-simulation models in general use time steps of between 0.1 and 1 second, typically 0.5 sec, and the more frequent the update rate, the easier it becomes to implement decision process's. For example if a drivers' reaction time is 0.68 sec., and a time step of 0.5 sec. is used, interpolation will be required to account for this change in 'driver state' between steps. If a step of 0.1 second is used, interpolation may still be necessary but errors introduced through non-linearity in the driver models will be less.

These issues aside however, it is a common mistake to update the following algorithm at each time step, and the faster this is done, the greater the chance of the following vehicle being able to exactly track the motion of the preceding vehicle. In reality the driver does not always modulate the throttle and brake on such a fine time scale, and hence in a sense, errors need to be ‘introduced’ by using a ‘coarse enough’ time step.

A second issue that reinforces this suggestion is the fact that a driver will not constantly observe the preceding vehicle, and will have to look away from the scene directly ahead in order to look at road signs, vehicle controls, into the rear view mirror etc, and will indeed look slightly ‘off target’ to see what is happening in neighboring lanes. The result of this constant scanning process (accuracy of perception aside) is that drivers will rarely have ‘up to date’ information on the dynamics of the vehicle in-front (Fig. 4).

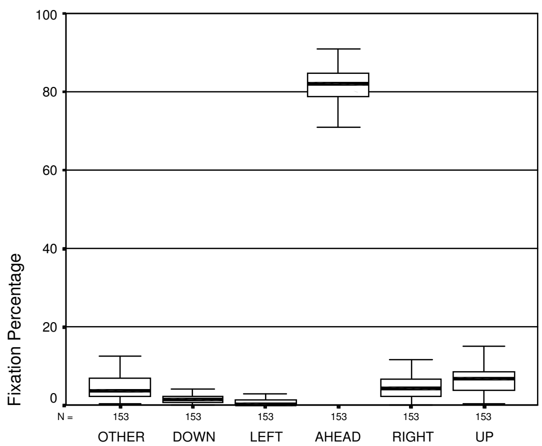

Figure 4: An illustration of the typical distribution of attention during motorway driving between 6 broad regions (taken from 16)

For example, everyday experience tells us that we may go a second or so between glances at the vehicle we are following and indeed studies have shown that this is so. For example Tijerina (17) has shown that a driver looks away from the forward view on average every 3.4 sec for around 0.6 sec. at a time, and that this is unaffected by typical car following variables. Thus, models that constantly update the dynamic state of each vehicle may not be realistic. Such an assumption however is nothing new and indeed may first have been incorporated (though now often neglected) explicitly by Helly (18) who stated that the car following model that he introduced should not re-assess/re-calculate the vehicles' acceleration until certain conditions are fulfilled. In this case, that spacing (DX) (or relative speed, DV) disagrees with a predicted value (assuming a constant speed), which will only occur after a set time, which reduces to:

$$t > (K. DX_{DES} / A. R - DX) / DV$$

With R a random number between -1 and +1, K, a scalar related to acceleration noise of the order of 0.25 and A, an observational accuracy.

5 Chaos and Asymptotic Behaviour

Another feature frequently cited regarding micro-modeling, is the issue of asymptotic stability, that is, the effect that the motion of the first vehicle in a long stream has on the motion of another many vehicles behind, or alternatively, the effect on the vehicle immediately following, after an extremely long time. The behaviour of the vehicles concerned are governed by the response of the model in its asymptotic limit, either in spatial iteration or time. Thus one can ask, will a disturbance die out in time/as it travels down a lane of vehicles, or will it build?

Such investigations are well known and are an integral part of the testing of any model, and indeed controlling the growth of such oscillations may be an important factor in traffic control (19). In recent times, such analyses have been given a new slant with the introduction of concepts from Chaos theory which may actually add a dimension of predictability to the propagation of oscillations (eg 20). What is often overlooked however is that the conditions under which such fluctuations are investigated (strings of a spatial or temporal extent, that allow chaotic patterns to be exhibited) almost never occur. For example, iterations over time periods of at least 300 seconds are commonly used in such investigations (5+ minutes), however the likelihood for any single pair following event to last that long in situations of ‘interest’ would be small. This would mean that any oscillations that may be building would be interrupted as vehicles move into/ out of any chain, introducing reactions that may not be described by the original algorithm. (Average lane change rates indicate that at high flows drivers usually choose to change lane roughly once every 4-5 Km (21), which assuming a speed of 20 m/s means every 200-250 sec.). Chaotic oscillations, at least of the type commonly modeled therefore, would rarely occur, although they could in principle be modeled by integrated models that incorporate the effects of spontaneous changes in headway and relative speed - caused by lane changes - smoothly into the car following process.

6 Conclusions

In this paper we have examined four assumptions regarding the simulation of car following that may now be in need of revision if we are to be able to accurately investigate the effects of ADAS:

i) Constant time headway and ‘safe’ following distance. Although used as a common starting point in model development it is likely that neither of these assumptions may be true, and that future models should attempt to avoid the use of the ‘safe headway’ concept.
ii) Calibration/Validation data. With the widespread use of instrumented vehicles and driving simulators in the design of driver assistance systems, there is now an abundance of new data available against which it is

possible not only to validate models, but also to refine and re-formulate.

iii) Time step. Although a small time step is needed in order to give flexibility in the processes being modeled, many human based control processes should perhaps be modeled at a coarser scale, in order to allow for driver error and the splitting of time/ resources between differing driving tasks in order for a 'realistic degree of error' to be introduced.

iv) Our understanding of the asymptotic behaviour of following processes may be lacking in realism, where, although important, models used would be better investigated if adapted to allow for real conditions, ie lane change, and shorter 'following strings'.

In addition to these four challenges to our current modeling paradigms we should also consider a *fifth* challenge – the statistical features of the behavioural processes. For example, even if the above four issues are addressed we do still face the question of 'when is enough data (calibration) enough?' Each driver for example *may* interact differently with differing vehicle types, in differing flow conditions etc. etc. There may also be a natural variability to the behaviour of any driver given *identical* conditions. Thus we must ask, how much data must be collected on a particular driver/behavioural process before it can be said to be representative of what is occurring in the real world? Although seeming an esoteric question, this last 'fifth element' to behavioural modelling is perhaps the final arbiter of how far driver modeling can go, and indeed how extensive the resources that need to be devoted to the topic, will finally need to be.

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