Modelling dual-carriageway traffic behaviour as a complex system: A proposal for discussion.

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Abstract

This paper outlines the initial developmental stage of a microscopic traffic system model incorporating driver behaviour. The model uses exponential and Gaussian distributions to assign each car its starting time headway and velocity characteristics respectively as expected in real-world traffic [1,2]. Each car may be in one of three distinct regimes (time headway windows), depending upon how close in time the car is to the car in front of it. These time headway windows are developed from previous work carried out by the Centre for Traffic Simulation at the Royal Institute of Technology, Sweden, and correlate with an actual traffic study [3]. The development for assigning time headways and velocities is complete and velocity and position data sets relative to time for both the single lane and multiple lanes for small numbers of cars have also been achieved.

1. Introduction

To reduce congestion, most road authorities are exploring new traffic-control strategies. Infrastructure improvements are very costly and each modification must be carefully evaluated for its impact on the traffic flow, computer traffic simulations form a cost-effective method for making those evaluations, a similar type of solution is also being used in other industries [4, 5].

The initial developmental stages of a microscopic traffic system model and the general definition of a microscopic traffic system model are outlined. In this traffic system model the behavior of vehicles and drivers are looked at in great detail, including interactions among vehicles, lane changing, response to incidents, and behavior at merging points. The microsystem model that has been designed is dual lane system with cars joining at the start of the system and at junctions spaced along the carriageway at distances similar to those of real world motorways.

This novel model with its assigned driver behaviours has a large amount of detail due to the nature of its interacting system, which became apparent when studying this system to achieve a satisfactory solution. Due to the intrinsically complex nature of this problem the question arose is the solution of this system in time a NP-hard problem.

There is no shortcut or smart algorithm that would lead to a simple or rapid solution of this system involving many interacting and communicating cars on a multiple lane motorway. The consensus is that the only way to find a global optimal solution, which is the spread of driver distributions to achieve the shortest global transit times, over many runs of the system, is a computationally-intensive, exhaustive analysis.

2. Complex system

It is far from trivial to come up with an all-encompassing definition of complex systems, indeed an entire edition of one major publication was dedicated largely to this, studying area as diverse as geology, the economy and biology [6]. In the physics community the accepted definition is that a complex system comprises a large number of elements, building blocks or agents, capable of interacting with each other and with their environment [3,7].

There are multiple interactions between many different components; the components have a large degree of freedom. The interaction between elements typically occurs only with nearest neighbours but in some models the interaction is between distant elements. The common characteristic of many complex systems is that they display organisation without any external organising principle being applied [7]. The search for and study of complex systems are among some of the most elusive and fascinating systems investigated by scientists and engineers nowadays [8].

3. Complexity classes P and NP

The association between the complexity classes P and NP remains an unresolved problem for computer science [9]. The relation between the set of problems of related complexity P and NP is studied in the branch of theoretical computer science that deals with whether and how efficiently problems can be solved on a computer and dealing with the resources required during computation to solve a given problem. The most common resources are time (how many steps it takes to solve a problem) and space (how much memory it takes to solve a problem), how this applies to the problem outlined, is in relation to maximising the data gathered for a real-world road system with its maximum capacity of cars. The class P is the complexity class that consists of all those question with a yes-or-no answer that can be solved on a deterministic sequential machine with an expression that is constructed from one or more variables, constants and mathematical expressions; the class NP consists of all those decision problems whose solutions cannot be completely verified in a algorithm[10]. When these distinct conditions are applied to our example it is very similar to the example of finding the composite number which becomes very resource dependent in terms of memory and time when the sample number is large.

Due to the large amount of steps in terms of time and space required to model accurately a modern motorway filled to capacity with a maximum number of cars, it is believed that this type of modeling would definitely fall into the classification of NP-hard problem.

4. Microscopic traffic system model

Traffic simulations can evaluate the improvements not only under normal circumstances, but also in hypothetical situations that would be difficult to create in the real-world. However, in this specific model novel strategies are being assigned to the individual drivers and the spread of these strategies is being compared to the global transit times for the model.

4.1 Traffic Regimes

In this model, each car may be in one of three distinct regimes (time headway windows), depending upon how close in time the car is to the car in front of it.

The characteristics that need to be generated at the entry to the micro model are divided into vehicle/driver attributes such as vehicle speed and time headway, and model variables[11]. These micro characteristics are specific to each individual car with a good example being the cars assigned desired car velocity, which is the velocity the car will travel at if not interacting with any other cars. Attributes such as desired speed are generated independently based on the distribution of these characteristics in the general driver population got from an extensive study carried out and assigned to the micro model[12]. Model variables, such as the vehicle's speed and time headway to the vehicle in front need to be in accordance with the traffic situation upstream and downstream and, as such, are governed by the regimes outlines below. The variables that need to be assigned values at the entry of a vehicle into the micro models are usually: lane, time-headway to the vehicle in front and speed while this work is also looking at driver behaviour. The speed assigned to the vehicle is based on the following algorithm.

- Regime 1 (bound traffic): $t1 < th \leq t2$

  $V = V_{front}$

  (1)
- Regime 2 (partially bound traffic): $t2 < th \leq t3$

  $\alpha = (th - t2)/(t3 - t2)$

  (2)

  $V = \alpha V_{desired} + (1 - \alpha) V_{front}$

  (3)
- Regime 3 (unbound traffic): $th > t3$

  $th > t3$

  $V = V_{desired}$

  (4)

Where, *th*, the time headway is the time at which the car enters the model, *V* is the desired speed ($m s^{-1}$), V_{front} is the speed of vehicle directly in front of the car that is traveling along the motorway ($m.s^{-1}$) and $V_{desired}$ assigned desired speed ($m.s^{-1}$) of each car.

The above approach was proposed and tested with actual data by the Royal Institute of Technology, Sweden[3]. Measurements of speeds and time headways on an urban freeway in Stockholm show high correlation of speeds between consecutive vehicles on the same lane, in the case of small headways (*t*1 = 0.5 seconds, *t*2 = 2.5 seconds). This correlation decreases with increased time headways, and remains at a constant low level beyond *t*3 = 7.5 seconds. In almost all micro models including this model, an initial acceleration rate of 0 m/s^2 is assigned to the vehicles that enter the network.

5. Probability distributions

The assignment of each car its starting time headway and velocity characteristics as expected in real-world traffic is achieved using specific probability distributions, specifically exponential and Gaussian distributions. This exponential distribution is used for assigning time headway because the Poisson distribution gives the number of occurrences in a certain time period of an event, which occurs randomly but at a given rate, and the time between events that occur randomly but at a constant rate has an exponential distribution. An exponential distribution is often used to model the time between independent events that happen at a constant average rate. The distribution of car velocities is assumed to be Gaussian given the large number of independent variables (assumed to be random and uncorrelated) influencing the driver's desired velocity. The convergence of these processes to a Gaussian is due to the central limit theorem which states that the distribution of the mean of a sequence of random variables tends to a Gaussian distribution as the number of random variables increases indefinitely. The exponential distribution is used to assign the starting time headway as it is often used to model the time between independent events of a Poisson process, i.e. events that happen at a constant average rate, which can be achieved using several different methods for generating exponential variates[2] see [13] for a method of generating exponentially distributed random numbers. A Gaussian distribution is used to assign the starting velocity as many psychological measurements and physical phenomena can be approximated well by this probability distribution.

6. Results

The development for assigning time headways and velocities is complete and velocity and position data sets relative to time for both the single lane and multiple lanes for small numbers of cars have also been achieved. Below are graphs for both velocity and position of the single lane model initially with just two cars and secondly for a larger car number with the interactions for cars as they move from one time regime to the other included. In the Figure 1 and Figure 2, there are just two cars and the car in front is travelling at the slower speed of the two. The second car, when it enters regime 2 (what is this regime?) of our model, it begins to decrease in speed non-linearly according to the following equations (2) and (3).

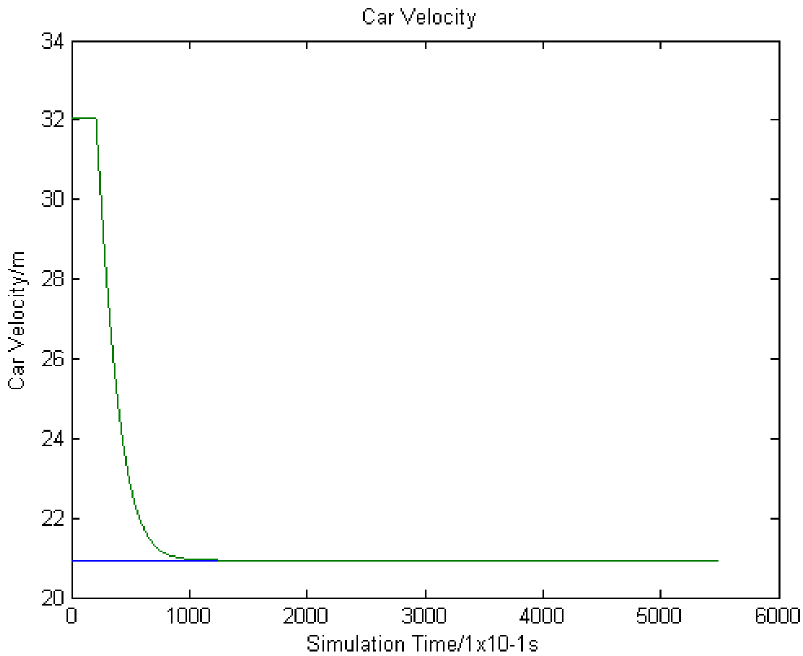

Figure 1, The velocity of two cars on a single way as the preceding car progress through the respective regimes

In Figure 1, the leading car A, is travelling at 21 m/s, followed by car B, initially travelling at 32 m/s. This abrupt velocity change is a result of the car A, entering regime 2, and the car changes from its desired velocity to the velocity of the car in front as the time to the car in front decreases from 7.5 seconds to 2.5 second, at which time, car B, in this instance is travelling at the same velocity as the car A.

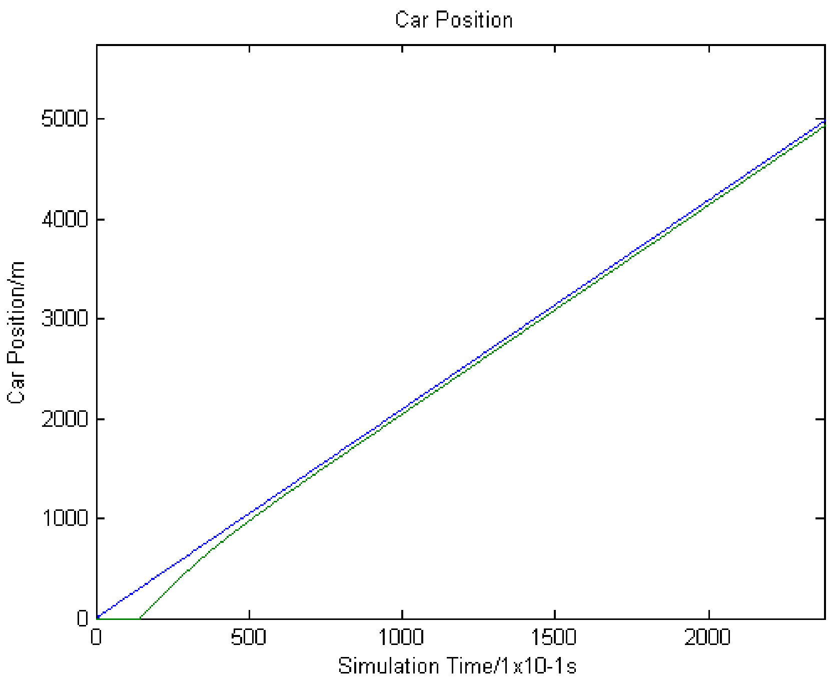

Figure 2, The position of two cars on a single way as the preceding car progress through the respective regimes

In Figure 4 position and time for 15 cars are displayed with the resultant velocity variation in Figure 3 highlighting the number of interactions that take place and how many steps it takes to solve a problem in term of time and space (how much memory it takes to solve a problem).

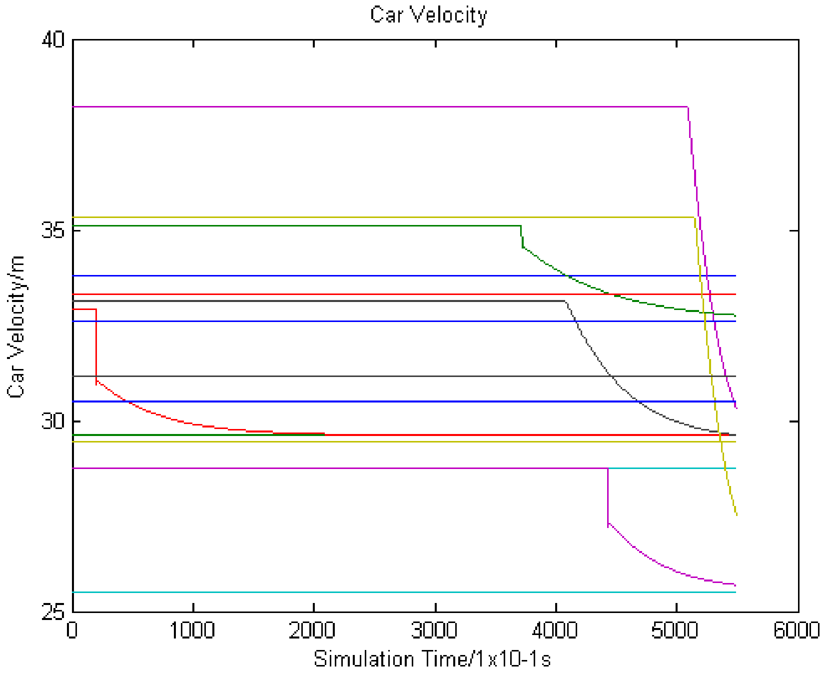

Figure 3, The velocity of 15 cars on a single way as cars progress through the respective regimes

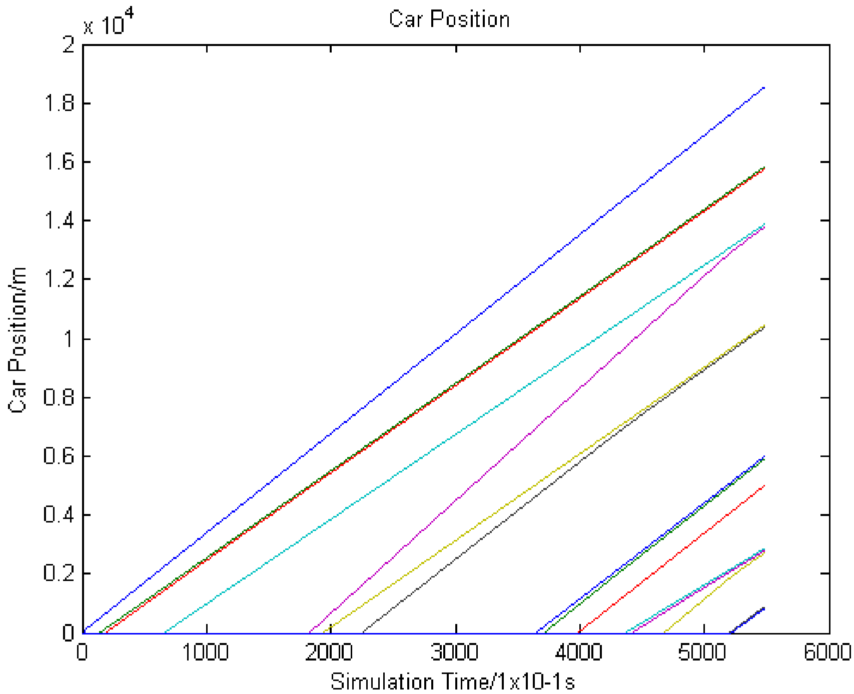

Figure 4, The position of 15 cars on a single way as the preceding car progress through the respective regimes

Another noticeable characteristic is, if the car that is joining the motorway and is immediately in the regime 2 window, then it can go through vivid changes in velocity. In this particular case the car joins the motorway with a gap of approximately 5.0s to the car in front and, it has to undergo a velocity change from 28.75 $m.s^{-1}$ to 27.20 $m.s^{-1}$, using a time step of 0.1*m.s*, causing the oscillatory instabilities that are observed due to deceleration of 15.5 $m.s^{-2}$. This oscillatory stability is clearly observed in Figure 5.

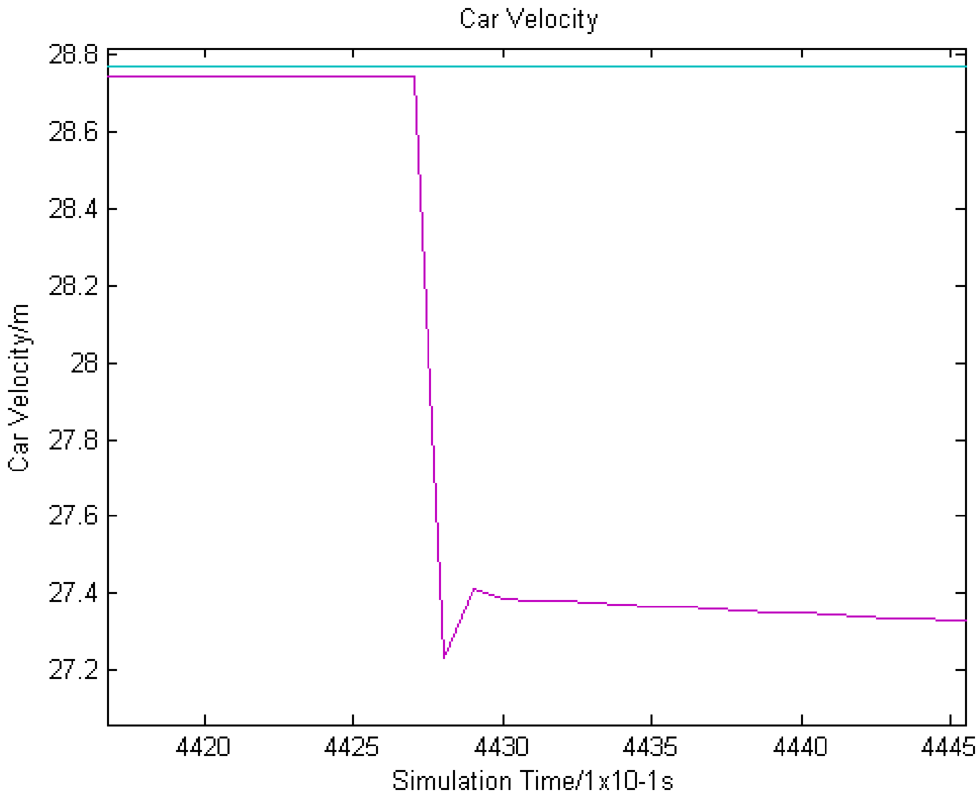

Figure 5, The velocity change of a single car leading to oscillatory instability

7. Discussion

When the initial investigation into both single lane and multiple lane models had been expanded out for a large number of cars, the question arose is the solution of this system in time a NP-hard problem After studying the results section, there seems to be no shortcut or smart algorithm that would lead to a simple or rapid solution of this system involving many interacting and communicating elements that would represent traffic with sufficient accuracy [14]. Instead, it is thought, the only way to find a global optimal solution which is the spread of driver distributions to achieve the shortest global transit times, over many runs of the system, is a computationally-intensive, exhaustive analysis. A global optimum solution as it refers to this model is the solution that would allow for all the cars to progress through the network at the shortest possible time. This is the time for a specific number of cars to travel through the network.

8. References

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