MOTORWAY MADNESS

Introduction

As you drive along a motorway, you often find that cars in front of you slow down, then just as inexplicably accelerate a short time later, only to slow again. As you keep adjusting to the speed of the car ahead, you sometimes find a clump of vehicles closely packed in front of and behind you and at other times there are only a few vehicles in sight.

From a physicist's point of view, traffic flow can be regarded as a "many-body system of strongly interacting bodies" Such systems can show wavelike behavior and abrupt transitions from one state to another – one can compare the change from freely moving to jammed traffic to a phase transition from gas to solid.

A simplified model

In our simulation, the traffic state at a given time is characterised by the positions, velocities, and the lane of all vehicles (though we will start with just a single lane). The decision of any driver to accelerate or to brake depends only on his or her own velocity, and on the vehicle immediately ahead. Lane-changing decisions, however, depend on all neighboring vehicles.

We simulate accelerations and decelerations using the Intelligent-Driver[1] Model (IDM). In this model, the acceleration $\mathrm{d}v/\mathrm{d}t$ of a given driver depends on velocity v, on the distance s to the vehicle in front, and on the velocity difference Δv (taken to be positive when the cars are approaching each other):

$$\frac{\mathrm{d}v}{\mathrm{d}t} = a\left\{1 - \left(\frac{v}{v_0}\right)^4 - \left(\frac{s^*}{s}\right)^2\right\},$$

where

$$s^* = s_0 + v\left(T + \frac{\Delta v}{\sqrt{ab}}\right).$$

Thus the acceleration is divided into a "desire" acceleration $a(1 - (v/v_0)^4)$ on a free road, and braking decelerations induced by the vehicle in front. The acceleration on a free road decreases from the initial acceleration a to zero when approaching the desired velocity v_0. The imposed deceleration increases with

- decreasing distance to the front vehicle (one wants to maintain a certain "safety distance");
- increasing own velocity (the safety distance increases);
- increasing velocity difference to the front vehicle (when approaching the front vehicle at a too high rate, a dangerous situation may occur).

The IDM has the following intuitive parameters:

- desired velocity when driving on a free road, v_0;
- desired safety time when following other vehicles, T;
- acceleration in everyday traffic, a;

[1] Many, especially cyclists and pedestrians, would argue that this was an invalid concept.

- “comfortable” braking deceleration in everyday traffic, b;
- minimum bumper-to-bumper distance to the front vehicle, s_0.

Typical values that would be used in the simulation are $v_0 = 120\ \mathrm{km/h}$ (you would choose, say, $50\ \mathrm{km/h}$ for city traffic), $T = 1.8\ \mathrm{s}$, $a = 1\ \mathrm{m/s^2}$, $b = 3\ \mathrm{m/s^2}$, $s_0 = 2\ \mathrm{m}$. In general, every “driver-vehicle unit” can have its individual parameter set. For example, lorries are characterized by low values of v_0, a and b, careful drivers choose a long safety time T whereas aggressive drivers are characterized by a low T in connection with high values of v_0, a and b. Often two different types are sufficient to show the main effects.

Lane changing

An extension to the model would include several lanes of traffic, most simply treated by allowing all types of vehicles to drive and overtake on either lane. Lane changing is governed by two criteria that have to be fulfilled simultaneously:

- The incentive criterion is fulfilled, if the driver anticipates being able to drive more freely on the new lane (own advantage), and does not force other drivers to brake too hard (disadvantage of others). We translate the meaning of “driving more freely” into a number and compare it with the hindrance exerted onto other drivers by calculating (with the IDM or other single-lane model) the anticipated acceleration after the lane change and comparing it with the actual acceleration.
- The safety criterion implies that lane changes leading to accidents or forcing other drivers to make emergency braking manoeuvres should be forbidden in the model.

It may be useful to visualise the effects of allowing lane changes by starting with different colours of car in each lane, and seeing how much they mix.

The project

Set up a computer program to apply the IDM to a series of vehicles: start with a one-lane version. You could have an open system, in which you feed a series of vehicles in at one end at random times selected to give an average traffic density, or you could set up a periodic system (think of it as cars going round in a loop). You will integrate the equations numerically. Some careful thought at the start about the best way to set up the problem for a varying number of cars will be essential. Then experiment with different densities of traffic, different mixtures of traffic (e.g. a fraction of lorries mixed with cars), and describe the types of behaviour you see. Consider drawing out the distribution of vehicles, and even animating it.

If you have time, extend the model to deal with several lanes.

A.H. Harker
October 2003