Gaps, Kinematics and Drivers Behaviour

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Abstract: Based on data from sophisticated traffic detectors in roads a study of car-following behaviour of drivers has been carried out. The study revealed that a significant proportion of drivers drive very riskily, i.e. the gaps between them and the vehicle in front are far too short in relation to the speed at which they are driving. A simple kinematical model was developed with three different progressions of deceleration during the vehicle braking event to determine the criteria for "risky driving". With statistical analysis it was thereafter determined if the definition of "risky driving" holds. The results can be used to help transportation authorities in their pursuit to improve drivers' behaviour in traffic streams.

1. Introduction

One of the most common types of car crashes is rear end collisions. The reason for many of these crashes is that drivers drive dangerously, i.e., the gap between their car and the car in front is far too small in relation to the speed they are driving and therefore they are not able to avoid a crash if the vehicle in front brakes suddenly. But when is a gap too small? From a kinematical analysis of a car in a traffic stream it is possible to define what gaps are sufficient from a safety standpoint. The gap between two vehicles in a stream needs to be large enough so that if the vehicle in front suddenly starts to brake, the second vehicle should be able to come to rest before it collides with the vehicle in front. Based on this requirement, a criterion can be set up where the two vehicles speeds, the reaction time of the second driver as well as the braking characteristics of the two vehicles are the input parameters.

Traffic detectors on roads collect an enormous quantity of data which reveals the drivers' behaviour, including vehicles gaps and speeds (Erlingsson et al., 2006). It is therefore possible to estimate the proportion of drivers in the "risky drivers" category. This information can be used by transportation authorities in their effort to improve driving behaviour in traffic streams.

2. The Braking Process

Through the years, the braking process of cars has been studied (Neptune et al., 1995). The typical progression of the deceleration of a vehicle during braking is shown in Figure 1.

Figure 1a) shows how the deceleration speeds up in the beginning and reaches its maximum value, and then falls slightly and becomes almost constant until the vehicle has stopped. Figure 1b) shows three simple models of the deceleration over time during braking. The first model

(M1) assumes a constant deceleration of the vehicle from the moment the vehicle starts to brake. The second model (M2) assumes a constant jerk throughout the whole braking process where the jerk is defined as the derivative of the acceleration (Leutzbach, 1988). Finally model three (M3) is a combination of the other two models where a constant jerk is assumed in the early stage of the braking event. Thereafter the deceleration is assumed to be constant until the vehicle comes to a complete stop.

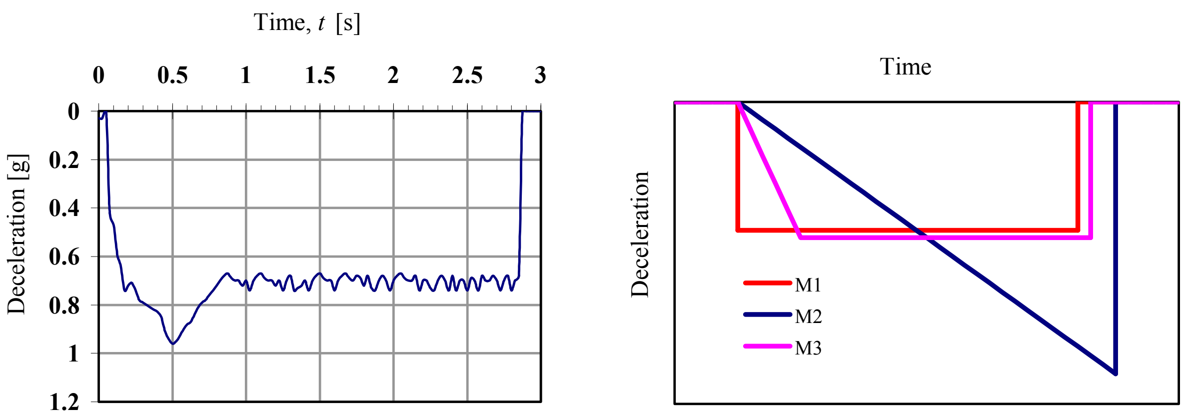

Fig. 1 a) Typical deceleration vs. time result of a skid-to-rest test. b) Three models (M1, M2, M3) are used to simulate the deceleration vs. time during braking.

Based on the different models and knowing the initial speed of the vehicle, the vehicle speed as well as its position can be estimated at any given time during the braking process. Figure 2 shows one example of this where the deceleration, speed and position over time, as well as speed vs. position, are given for a single vehicle during the braking process.

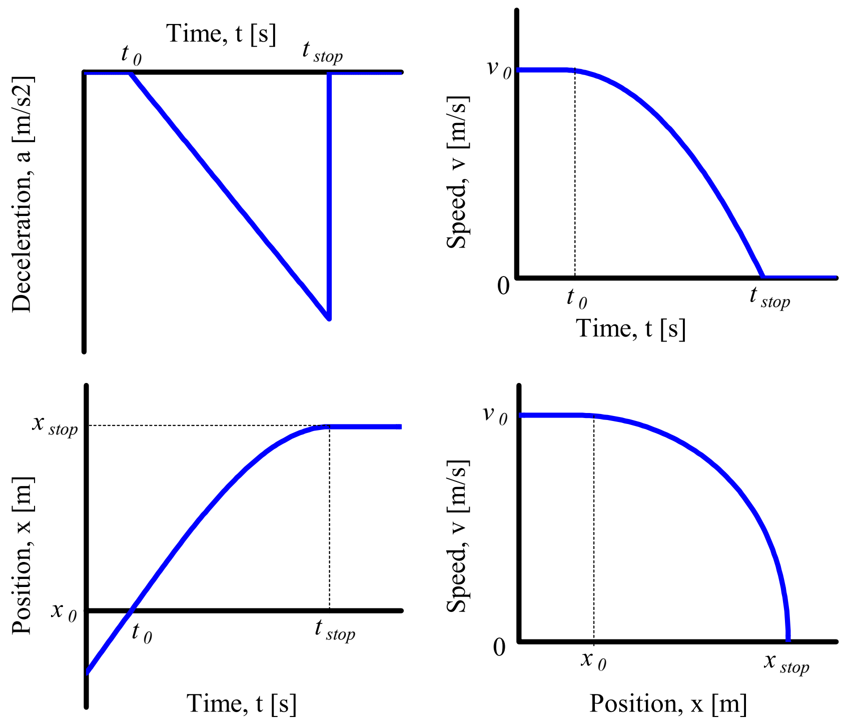

Fig. 2 Deceleration, speed and position of a single vehicle vs. time during braking process when model 2 has been assumed. The braking process starts at t_0 where the vehicle speed is v_0 situated at position x_0.

3. Minimum Gap

Taking two vehicles in a simple traffic stream, as shown in Figure 3, this analysis can easily be extended and positions of both vehicles $x_1(t)$ and $x_2(t)$ can be predicted. If the gap between them is known can be estimated whether or not a crash will occur if the leading vehicle suddenly starts braking. This is done by calculating the vehicles' positions relative to each other at any time during the braking process and checking whether at some point the position of the front bumper of the second car lands in front of the rear bumper of the first car. To avoid a crash the following inequality must hold during the entire braking process:

$$x_1(t) - x_2(t) \geq 0 \qquad 0 \leq t \leq t_{stop} \tag{1}$$

where $x_1(t)$ and $x_2(t)$ are the positions of the leading and the following vehicle respectively and t_{stop} is the elapsed time until both vehicles have come to a complete stop. The minimum gap needed to avoid a crash is therefore given as the gap which fulfils $x_1(t) - x_2(t) = 0$ during the entire braking process.

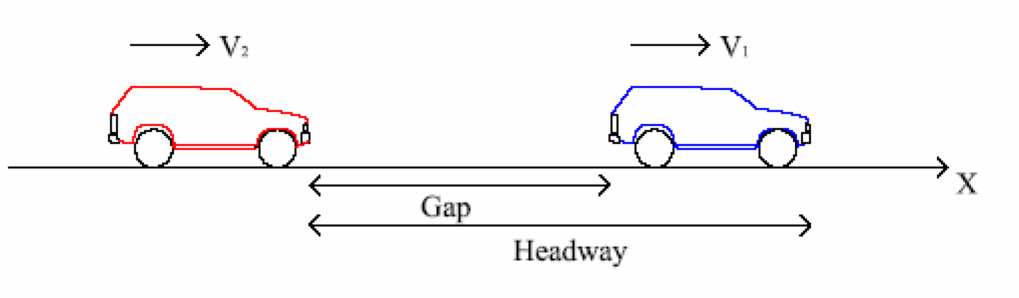

Fig. 3 Two vehicles travelling with at speeds v_1 and v_2 respectively, in a simple stream. Definition of headway and gap.

It is therefore possible to draw a surface in three dimensions showing the speeds of the two vehicles and the minimum gaps as co-ordinates that mark the boundaries between the two vehicles which would be sufficient to avoid a crash and those that would not be sufficient.
For the combined model (model 3) the equation for the minimum gap between the two vehicles becomes:

$$\begin{aligned} d = {} & \frac{\lambda_1 \Delta t_{1_a}^3}{24} - \frac{v_{1_0} \Delta t_{1_a}}{2} - \frac{v_{1_0}^2}{2\lambda_1 \Delta t_{1_a}} + \frac{\lambda_2 \Delta t_r^3}{24} - \frac{\lambda_2 \Delta t_{2_a}^3}{24} - \frac{\lambda_2 \Delta t_{2_a} \Delta t_r^2}{8} + \frac{\lambda_2 \Delta t_r \Delta t_{2_a}^2}{8} \\ & + \frac{v_{2_0}^2 \left(\Delta t_r - \Delta t_{2_a}\right)}{2\lambda_2 \Delta t_{2_a}^2 - 4\lambda_2 \Delta t_r \Delta t_{2_a} + 2\lambda_2 \Delta t_r^2} + \frac{v_{2_0} \Delta t_{2_a}}{2} + \frac{v_{2_0} \Delta t_r}{2} + \frac{v_{2_0}^2}{\lambda_2 \left(\Delta t_{2_a} - \Delta t_r\right)} \end{aligned} \tag{2}$$

where λ_1 and λ_2 are the jerks of the leading and following vehicle respectively, v_{1_0} and v_{2_0} are the speeds of the respective vehicles before they start to brake, Δt_{1_a} is the length of the time interval where vehicle 1 has a constant jerk, Δt_{2_a} is the time interval between the end of the vehicles 1 and 2 constant jerk period respectively, and Δt_r is the response time of the driver in car 2. Figure 4 shows such a surface according to M3 (Figure 1b).

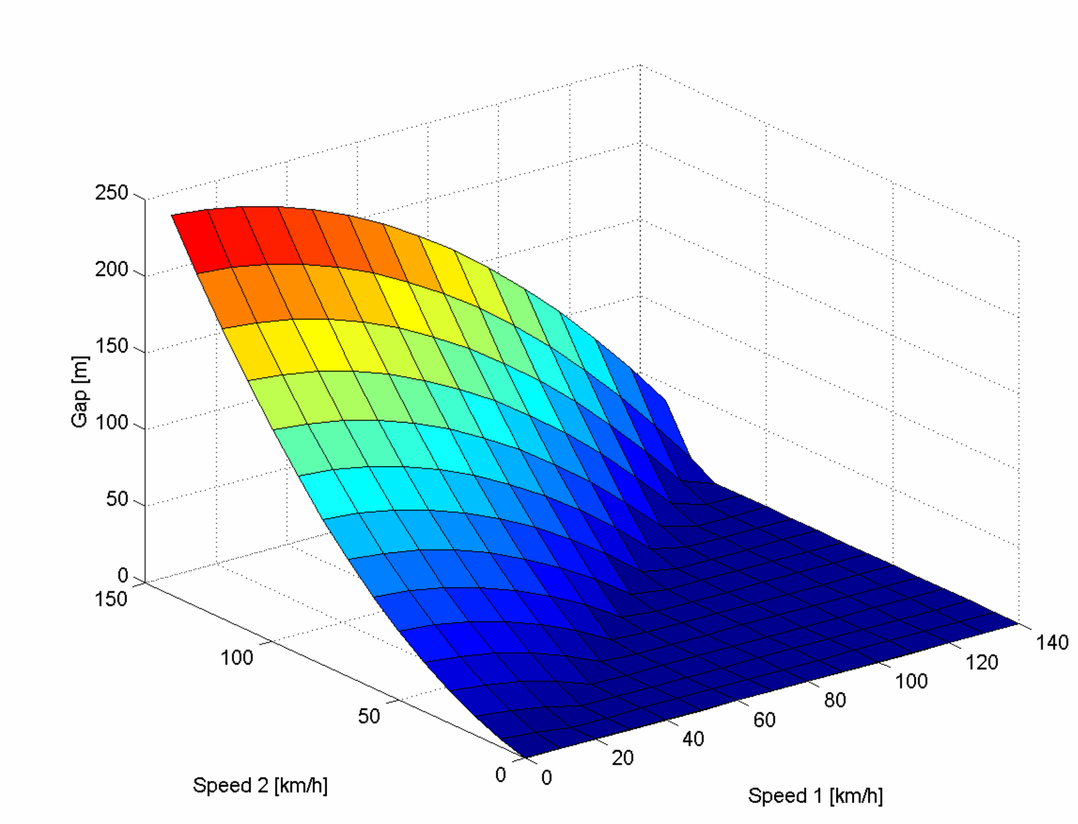

Fig. 4 A surface that marks the intersection between vehicles that are able to stop without crashing into the front vehicle and those that will not stop in time. Here it has been assumed that $\lambda_1 = \lambda_2 = 4.75$ *m/s*^{3}*,* $\Delta t_r = 1$ *s,* $\Delta t_{1_a} = 1$ *s and* $\Delta t_{2_a} = 2$ *s.*

4. Pessimistic, Neutral and Optimistic Drivers

In 1979 Gipps presented a model for the response of the following vehicle in a stream of traffic. The model is based on the assumption that each driver sets limits to his/her desired braking and acceleration rates (Gipps, 1981). From the Gipps model, Brackstone and McDonald (2003) developed a model to establish the necessary gap between vehicles according to how they brake, i.e., whether the first vehicle brakes more or less than the second one. Brackstone and McDonald argue that the gap has to be:

$$d = v\Delta t_r - \frac{v^2}{2b_n}\left(1 - \frac{1}{\gamma}\right) \qquad (3)$$

where Δt_r is the reaction time, b_n the braking deceleration [m/s^2] and γ is a non-dimensional parameter that tells whether the leading driver or the following driver decelerates more. If γ is less than 1, then the maximum deceleration of the leading driver is less than that of the following driver and the following driver is considered optimistic. One the other hand, if γ is greater than 1, then the maximum deceleration of the following driver is less than that of the leading driver and the following driver is regarded as pessimistic. If the leading and the following driver have the same maximum deceleration, the following driver is regarded as neutral. The gap in both meters and seconds for pessimistic (γ = 1.3), neutral (γ = 1.0) and optimistic (γ = 0.875) drivers can be seen on Figure 5. The braking rate is taken from Gipps as b_n = - 3 m/s^2.

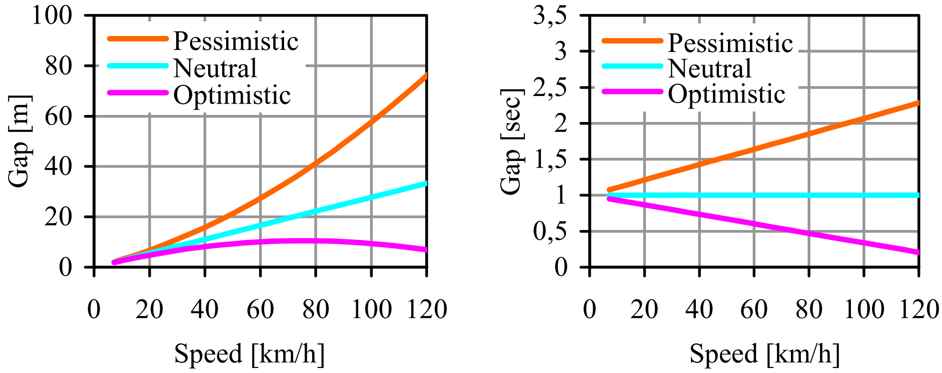

Fig. 5 Comparison of necessary gap for pessimistic, neutral and optimistic drivers. a) Gap in meters and b) gap in seconds.

5. Field Data

To illustrate how the surface that marks the risky drivers from other drivers and how the Gipps model can been used, data from a dual loop traffic counter on a two lane arterial highway at Molduhraun in Iceland has been used (see Figure 6). In Figure 6 each dot represents a pair of vehicles in a traffic stream and the gap between them. Dots lying under the surface represent risky drivers where the gap is too short to avoid a crash.

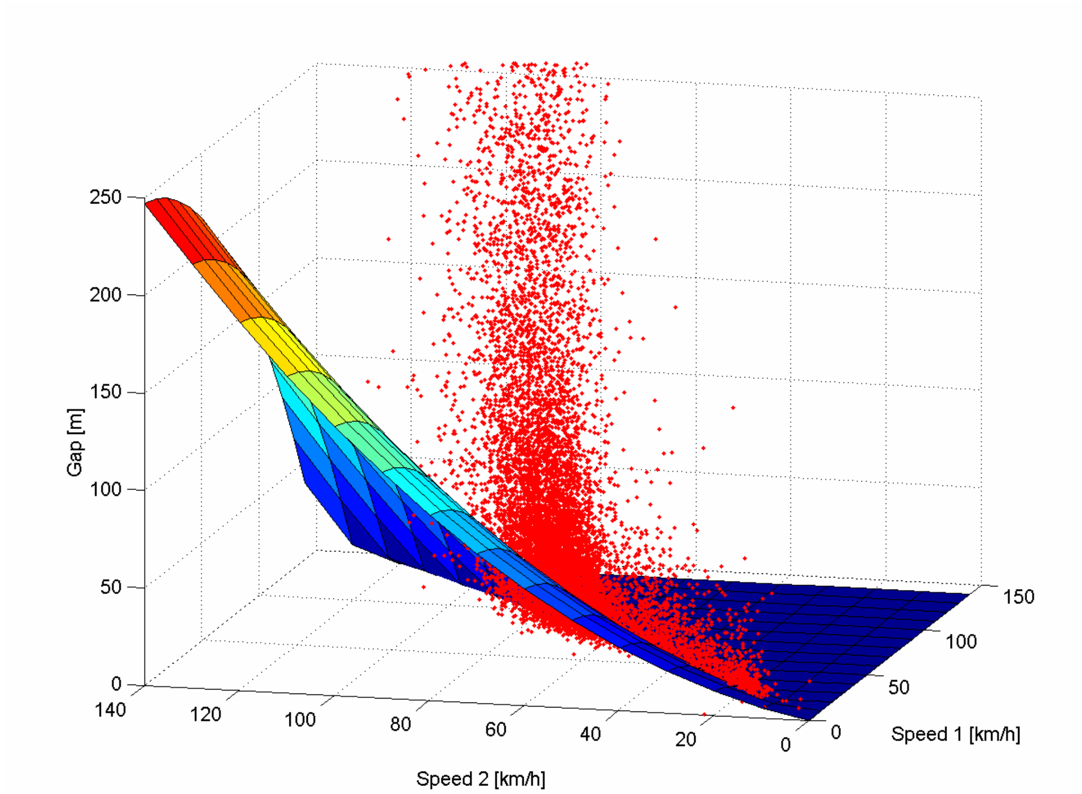

Fig. 6 Field data from a traffic counter plotted together with the surface that marks risky drivers. The dots below the surface represent risky drivers, i.e., drivers that will not be able to avoid a crash if the vehicle in front suddenly starts to brake. Here it has been assumed for the surface that $\lambda_1 = \lambda_2 = 4.75\ m/s^3$, $\Delta t_r = 1\ s$, $\Delta t_{1_a} = 1\ s$ and $\Delta t_{2_a} = 2\ s$.

Table 1 shows the number of vehicles that passed the traffic counter during one-hour observation time on Friday, 1 October 2004, between 16:00 and 17:00. Both lanes are shown. On lane 1, 16.2% of all drivers and 19.1% of all drivers on lane 2 will not be able to avoid a crash if the vehicle in front of them should suddenly start to brake.

Table 1 Percentage of risky drivers during the one-hour observation time on Friday, 1 October 2004 on a two lane arterial highway in Molduhraun, Iceland between 16:00 and 17:00 p.m.

	Lane 1	Lane 2
Number of vehicles	13,221	13,695
Number of vehicles with to short gap	2,135	2,611
Percentage [%]	16.2	19.1

In order to find out the percentage of drivers that are pessimistic, neutral or optimistic, according to Gipps' theory, data from the same traffic detector on the arterial highway from Friday, 1 October 2004, were used. Figure 7 shows the lines for pessimistic, neutral and optimistic drivers along with the field data from the traffic counter. Only gaps smaller than 100 m are shown.

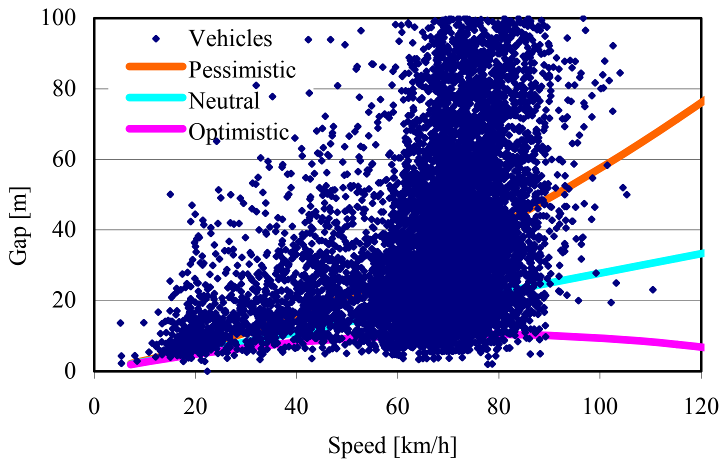

Fig. 7 Drivers on an arterial highway on 1 October 2004, with a gap smaller than 100 m. Gipps' pessimistic, neutral and optimistic driver's criteria are also shown.

Figure 7 reveals that a large number of drivers maintained far too short gaps. Table 2 summarizes this where the number of drivers (dots) falling below the three coloured lines in Figure 7 are shown, both for the whole day and for the rush hour between 6:30-9:30 and 15:30-18:30, respectively.

Table 2 Number and percentage of pessimistic, neutral and optimistic drivers.

	24 hours		Rush hours	
	Number	[%]	Number	[%]
Drivers	13219	100.0	5527	100.0
Pessimistic	4885	37.0	2088	37.8
Neutral	1794	13.6	724	13.1
Optimistic	441	3.3	182	3.3

From Table 3 it can be seen that there was hardly any difference in the driving behaviour over the 24 hour period and the data for the rush hours. In both cases 37% of drivers drove allowing too short gaps if the leading vehicle brakes harder than the following one. If both the leading and the following vehicle brake equally hard 13% of the drivers drive with too short gaps. The most shocking finding is that 3.3% of all drivers drive with such a short gap that even if they brake harder than the vehicle in front it isn't enough – they can't avoid a collision.

6. Conclusion

The paper describes a simple kinematical concept which can be used to set up criteria for a minimum gap drivers should strive to hold in a traffic stream in order to be able to react and avoid a crash if the vehicle in front suddenly starts to brake. This criterion can be expressed with a surface in three dimensional space using the speeds of the two vehicles and the minimum gap on the co-ordinate axes. Using field data from a dual loop traffic counter on a two lane arterial highway revealed that 16.1% and 18.9% of the total number of drivers in each lane did not maintain the necessary minimum gap. Using the model proposed by Gipps to classify drivers into pessimistic, neutral and optimistic drivers, similar results were found. Around 37%, 13% and 3.3% of all drivers were classified as pessimistic, neutral and optimistic drivers, respectively. Furthermore, there were no significantly different driving behaviours in rush hours as compared to the 24-hour day.

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