SPEED VARIATION, ABSOLUTE SPEED AND THEIR CONTRIBUTION TO SAFETY, WITH SPECIAL REFERENCE TO THE WORK OF SOLOMON

W J Frith and T L Patterson
Research and Statistics, Land Transport Safety Authority

Abstract

The effects of speed on crashes and their severity depends on a number of factors related to the driver, the road, and traffic characteristics. These are discussed with reference to the literature, particularly the work of Solomon, and with emphasis on the roles of absolute speed and speed variation.

The types of speed variation

When speed is measured the typical outputs are a speed distribution. A typical example is Figure 1 below. The parameters of the distribution, such as percentiles, mean speed and standard deviation are also often quoted.

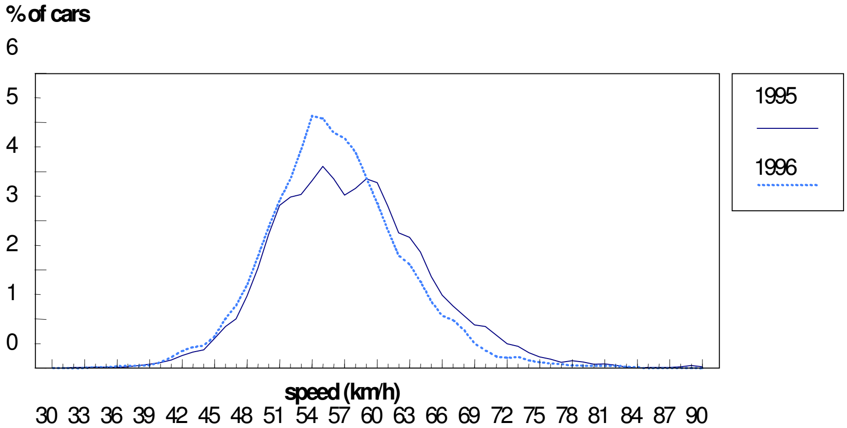

Figure 1. Estimated urban speed distributions 1995 and 1996[1]

One could forgive the reader for thinking that all these speed distributions represent basically the same thing. However, they do not. Some of the differences to watch out for are presented below.

Some measure unimpeded speed

For these distributions only the leading vehicle in a platoon has its speed measured. The rationale for measuring these is to get an estimate of the desired speed of traffic at the point of measurement. The distributions in Figure 1 are of this type. They are produced by combining the results of a number of surveys at different sites into a representative distribution weighted by the traffic flow at each site. The LTSA annual speed surveys measure unimpeded speeds.

Some measure all speeds

[1] Source: Keall and Frith (1997)

For these distributions impeded vehicles are included, giving rise to a lower average speed. Published speed distributions, depending on their purpose, may contain data from various flows, periods and places. Modern speed measuring equipment has the capability to segment the flow.

Some are spot speeds and some are travel speeds

Mostly speeds in a traffic stream are measured at a point using some sort of instrument. These are called spot speeds. In some instances speeds may be measured by timing the vehicle over a short length of road and dividing the distance by the result. These are called travel speeds. Averaging the spot speeds of a traffic stream always gives a slightly higher value than averaging the travel speeds. The difference (often about 10%) (Wardrop, 1952) is shown below.

$$\textit{Average spot speed} = \textit{Average travel speed} + \frac{\textit{Variance of the average travel speed}}{\textit{average travel speed}}$$

Differing types of speed distributions, between-vehicle interaction and safety

It is a widely-held and true belief that there is a connection between road safety and the variability of speeds on roads. Speed distributions are cited and it is suggested that, if the spread of the distribution was reduced, safety would improve. The rationale for this view is that, the wider the speed distribution, the more chance there should be for sub-optimal interaction between vehicles. This may be so in some cases. However, in many cases it is not. This is because, for this to happen, the vehicles whose speeds are measured to form the distribution need to be close enough to each other to interact which is not always so.

Some speed distributions are of vehicles in a traffic stream. Others may include vehicles at a variety of places and times under diverse flow and environmental conditions. Sometimes speeds are measured over a long length of time with a low traffic flow. Indeed, in many cases the vehicles whose speeds are being measured may have no interaction at all because they are so widely spaced in time.

Similarly, in other cases the speeds may be measured over a time span which contains varying traffic conditions (e.g. a motorway may have a very wide speed distribution if the speed survey covers periods of crawling traffic along with free-flowing traffic). In other cases speeds measured at different places at different times under different conditions may be put together to form a "grand distribution", which contains the speeds of many vehicles with significant temporal and spatial separation, thus precluding their interaction. Figure 1, which describes overall urban free speeds at off-peak times in New Zealand, is a case in point. It is meant to illustrate the urban driving public's desired speeds, rather than the characteristics of urban traffic streams.

Solomon's work

An interesting case is Solomon (1964), the first significant study that allowed an examination of the relationship between vehicle speeds, their distribution and crash risk. This study, which contained a case-control element, is often quoted in support of the idea that a strong relationship exists between crash risk and speed variance, in the sense of different speeds in a traffic stream causing sub-optimal interaction.

Solomon examined the reports of 10,000 crashes that occurred on 35 sections of rural highway (a total of 600 miles) from 1955 to 1958. In most cases, the crash reports contained an estimate of the pre-crash speed of the crash-involved vehicle[2], as obtained from the driver, the police, or witnesses (in 20% of cases, vehicle speed was estimated based on details in the report). Solomon did not discuss the accuracy of the speed estimates in the crash reports. To obtain the control vehicle speed, the speeds of 290,000 vehicles not involved in crashes were measured (in 1957 and 1958) at one location on each of the 35 sections of highway, and the mean speed for each section was calculated. Solomon then, among other things, calculated the degree to which the estimated pre-crash speed of each crash-involved vehicle deviated from the mean speed of the control vehicles[3] on the section of highway where the crash occurred. When deviations from the mean speed were found – either faster or slower than the mean speed – crash-involvement rates were high, whereas speeds close to the mean had low crash-involvement rates (Figure 2)[4]. As we will now show, this apparent finding is more an artefact of the way in which speeds and crashes were measured than a real relationship between and safety and the variation of speeds in a traffic stream.

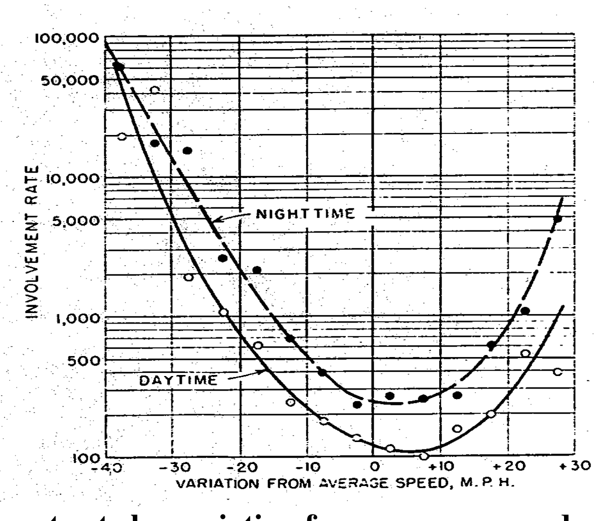

Figure 2: Involvement rate by variation from average speed on study section, day and night

---

2 The speed at which the crash-involved vehicle was travelling before the driver became aware of the impending crash.

3 The deviation from the mean (or average) speed for each section of highway included vehicles travelling slower than, as well as faster than, the mean speed. A crash-involved vehicle travelling at the mean speed had a deviation score of 0, those travelling faster than the mean speed had positive scores, and those travelling slower than the mean speed had negative scores.

4 It is important to note that the mean speed was calculated from measurements of the free-flowing traffic at only one location on each highway segment (these were up to 91 miles in length), and the variance was calculated as the deviation of speeds from this average. Therefore the u-shaped curve in Figure 2 does not represent the speed variance of crashes across the entire length of a highway. It represents the range of speeds of crash-involved vehicles on the entire highway in relation to one overall average on a specific section of the highway.

The highways on which the crashes occurred contained a number of access points (intersections and driveways) and were likely at times to contain congestion. The crashes at low speeds were generally due to these highway factors. Solomon, who cannot be held responsible for those who quoted him later on, urged caution in interpreting the results, saying inter alia that "the highways having lower average speeds also had more intersections and business driveways per mile of highway compared with highways on which average speeds were higher. Other studies have shown that the presence of intersections and roadside businesses are associated with a large number of accidents".

Lower-speed crashes (42 mph or less) were 46% of the total crashes. Of these, 51% were rear-end crashes (which are typical of congested conditions) and 38% were angle crashes (which typically occur at intersections). In these crashes the speeds involved were not the driver's chosen speed of travel on a rural highway. Hence the high crash-involvement rate found at slower speeds cannot be interpreted to mean that there is a high chance of crashing when a driver chooses a slow speed at which to travel on a rural highway. Instead it may be interpreted to mean that there is a high number of crashes when travel speed is slowed by congestion or intersections. Indeed, as the average speeds were taken from speed observations 'during day and night hours, on weekdays and Sundays, and in the different seasons of the year', there is no knowing what was the variation in speed of vehicles in the stream at the time of the accident, or indeed how many of the crashed vehicles were part of a stream of traffic.

Conversely, the high crash rate at speeds above the mean *can* be interpreted, as there is a high crash rate when drivers choose to travel at high speeds. For example, Solomon found that, as the speed of the crash-involved vehicles increased, particularly above 50 mph, the number of single-vehicle crashes increased. Typically drivers have chosen their speed prior to being in a single-vehicle crash.

Solomon plotted the percentage of accident involvements by speed disaggregated by type of accident (Figure 3). This clearly shows single-vehicle crashes increasing steeply with increased vehicle speed until they reach 40% of all involvements at 80 mph. Similarly, head-on crashes increase with increased speed but reach their maximum at just under 20% at 80 mph. The rear-end and angle types of crash, associated with congested conditions and access points, predominate at lower speeds.

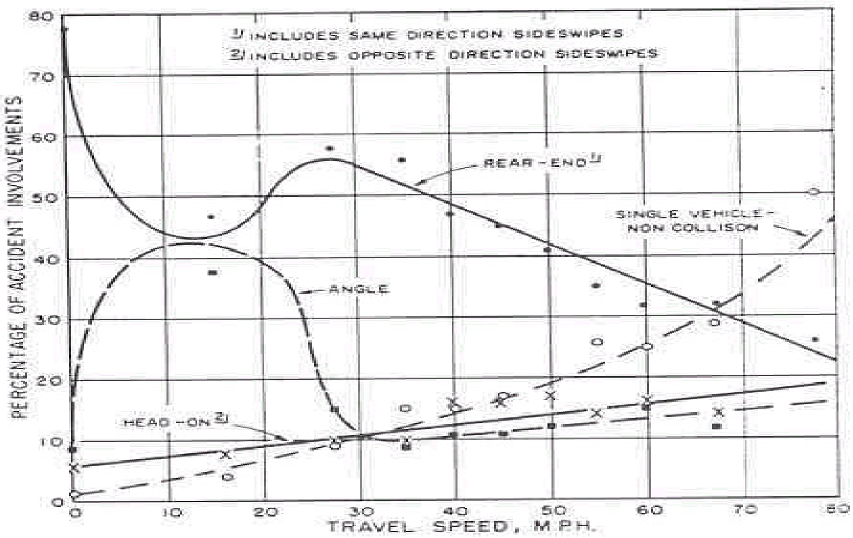

Figure 3: Percentage of accident involvements by travel speed and type of collision for all vehicles, day

As well as the high crash risk when drivers choose to travel at a high speed, there is also a high risk of injury if they are involved in a crash. For example, when Solomon analysed the number of people injured per 100 crash-involved vehicles by the speed of the vehicle, the U-shaped curve was replaced by a monotonically-increasing slope (see Figure 4). That is, the number of people injured per 100 crash-involved vehicles increased with increasing speed. There was no mention of any changes in vehicle occupancy with changes in crash speed. Generally, as one would expect, the low-speed crashes in Solomon are much less severe than the high-speed ones, as evidenced by Figure 4.

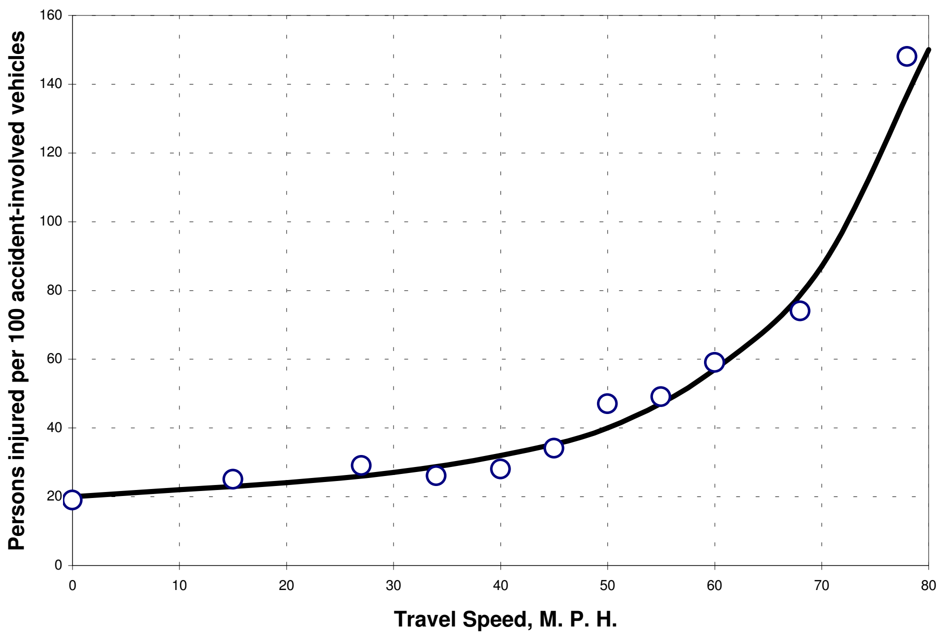

Figure 4: The number of people injured per 100 crash-involved vehicles

Together Figures 3 and 4 show there is a trend towards increased crash severity, and decreased inter-vehicle interaction crashes, as speed increases.

Thus, regarding safety and speed, the main messages which can be deduced from Solomon when one takes out the low-speed, congestion and intersection-related crashes are as follows:

- severity increases with increased speed
- crashes increase with increased speed, particularly single-vehicle crashes
- above the mean speed the risk of crash involvement increases with increased speed

How many open road crashes involve more than one vehicle?

The role of speed variance is most hotly debated as a cause of crashes on the open road . Of New Zealand open road crashes in 1999, 53% were single vehicle ones. Speed consistency in the major stream may be a factor in some side-impact and head-on crashes. The remaining categories of overtaking and rear-end, which by their very nature imply that a stream existed at the time of the crash, represent 20% percent of the total. Work carried out for the LTSA using the 1993 National Traffic Database indicates that of the total vehicle kilometres of travel on New Zealand roads only about 10% are by vehicles at headways of less than 20 metres. It is thus not surprising that more than half our rural crashes involve a single vehicle.

How then should speed variation be treated?

Given the above, what level of importance does speed variation have in safety vis-à-vis other considerations like the mean speed of traffic travelling in a stream? There is a lot of face validity in the notion that, the smaller the variation within the stream, the smoother and safer the traffic flow will be. This is true, but the crucial factor in the equation is the speed of the stream, usually represented by the mean speed. At open road speeds, fatality risk is proportional to the 4^{th} power of speed (Joksch, 1993). Absolute speed has a fundamental effect on safety irrespective of whether a lone vehicle or a stream of vehicles is traversing the road. As stated in Andersson and Nilsson (1997), there is no such relationship with speed variation. Thus, getting the speed of the stream at an appropriate level is crucial to safety. Once this is achieved, orderly traffic flow is a worthy objective.

Mean vehicle speed and vehicle speed variation

Studies in New Zealand have demonstrated that, when mean speed is reduced, speed variation also decreases, and vice versa. For example, Frith and Toomath (1982) found that, when the New Zealand open road speed limit was reduced to 50 mph in December 1973, there was a sharp drop in mean speeds. This drop in mean speeds was accompanied by a sharp contraction in the distribution of these speeds.

Similarly, Keall and Frith (1997) found a significant decrease in the New Zealand national mean speed in urban areas from 1995 to 1996. This reduction was associated with a significant decrease in the spread of speeds at the top end of the distribution – that is, a decrease in the 85^{th}, 90^{th}, and 95^{th} percentiles[5]. In other words, the spread of

[5] For example, the 85^{th} percentile decreased from 65.5 to 63.5 km/h, the 90^{th} from 67.5 to 65.5 km/h, and the 95^{th} from 71 to 69 km/h.

speeds was reduced at the high end of the speed distribution, thus contracting the overall speed distribution. A similar result was found when mean speeds decreased in the Police's Midland region of New Zealand following the introduction of hidden cameras in the area (Keall, Povey and Frith, 1999).

Managing mean vehicle speed and variations in vehicle speed

The focus of road safety campaigns and enforcement strategies on reducing the mean speed of traffic on our roads is supported by the above arguments. However, despite the greater importance to road safety of mean traffic speed, there is some suggestion in the literature that speed variation should also be targeted through enforcement strategies (for example Lave, 1985, cited in Zaal, 1994). If we accept that it is desirable to reduce speed variation, there are two obvious approaches to doing so – encouraging drivers who travel at the **slowest** end of the speed distribution to **increase** their speed and/or encouraging drivers who travel at the **fastest** end of the speed distribution to **decrease** their speed.

It has been argued that some ways of targeting speed variance would not be beneficial for road safety (Zaal, 1994) – encouraging the slowest drivers to speed up is clearly in that category. This strategy may actually increase the crash risk of the slow drivers. Slow drivers may choose to travel at a slower speed in the face of probable peer pressure to go faster because they feel less comfortable with travelling faster (Evans, 1991). This in turn is likely to be related to driver or vehicle ability. For example, older drivers may slow down to compensate for reduced vision and visual acuity, or slower response times.

Encouraging or forcing slow drivers to speed up beyond their comfort levels is contrary to accepted road safety wisdom. Not only is this strategy likely to increase the crash risk of the slowest drivers but, if these drivers subsequently became involved in a crash, any injuries would be much more severe than if they had travelled at slower speeds (Fildes and Lee, 1993). Thus, rather than encouraging slow drivers to increase their speeds and expose themselves to greater risk, a more beneficial road safety measure would be to encourage them to pull over at safe locations whenever they hold up traffic and to keep well to the left, and to encourage all other drivers to slow down.

The other approach – that of encouraging the fastest drivers to slow down – would have greater benefits for overall road safety. There are no increased risks associated with this approach. One strategy for achieving this aim is to place more emphasis on the drivers who travel at speeds that are excessively above the speed limit than on those who travel at speeds that are moderately above the speed limit. This is already being done worldwide through targeting all speeding drivers and having an increasing penalty rate for increasing speeds – that is, excessive speeders receive higher penalties than moderate speeders.

The overall aim of targeting speeders is to reduce the number of drivers travelling at excess or inappropriate speeds. This aim reduces the mean speed of all vehicles as well as variations from the mean speed – that is, the slow drivers do not speed up but the fast drivers slow down, leading to a downward movement in the overall distribution of speeds. These results are in fact predictable from the nature of the statistics we are dealing with.

Conclusion

The u-shaped curve of Solomon is more an artefact of the road conditions used in his study than evidence that driving below the mean speed is dangerous. For much of the time New Zealand rural roads are empty or relatively sparsely occupied by vehicles. In these circumstances the potential for crashes involving more than one vehicle is reduced. This is a major factor in as to why New Zealand has an internationally high percentage of single vehicle crashes. These crashes increase in probability and severity with the absolute speed of the vehicle involved. The variation in speeds of vehicles is a crash factor only when vehicles are travelling closely enough to each other for interaction to occur. Speed reduction measures aimed at high speeders tend to improve orderliness of flow (by reducing the variation) and also reduce absolute speeds. They are thus winners on both counts.

References

Andersson, G; Nilsson, G (1997) *Speed Management in Sweden: Speed, Speed Limits and Safety*. Swedish National Road and Transport Research Institute.

Evans, L (1991) *Traffic Safety and the Driver.* Van Nostrand Reinhold, New York.

Fildes B N; Lee, S J (1993) *The Speed Review: Road Environment, Behaviour, Speed Limits, Enforcement and Crashes.* Monash University Accident Research Centre, Prepared for Road Safety Bureau, New South Wales, & Federal Office of Road Safety, Canberra.

Frith W J; Toomath, J B (1982) *The New Zealand open road speed limit.* Accident Analysis and Prevention 14 (3), pp. 109-218.

Joksch, H. C. (1993). Velocity change and fatality risk in a crash – A rule of thumb. *Accident Analysis and Prevention*, 25(1), 103-104.

Keall, M D; Frith W J (1997) *Roadside speed surveys: design and estimation.* Paper presented in the Technical Programme of the IPENZ Annual Conference, Wellington, February 7-9.

Keall, M D; Povey, L J; Frith, W J. (2001). *The relative effectiveness of a hidden versus a visible speed camera programme* in: Accident Analysis and Prevention (33) 2 pp. 277-84.

Patterson, T L; Frith W J; Small, M W (2000) *Down with Speed: A Review of the Literature, and the Impact of Speed on New Zealanders*. Accident Compensation Corporation and Land Transport Safety Authority, Wellington, New Zealand.

Solomon, D (1964) *Accidents on Main Rural Highways related to speed, driver and vehicle.* US Department of Commerce & Bureau of Public Roads, Washington DC.

Wardrop, J G (1952) Some theoretical aspects of road traffic research. Proc. Inst. Civ. Eng. 2(1), pp. 325-78.

Zaal, D (1994) *Traffic Law Enforcement: A Review of the Literature.* Monash University Accident Research Centre, Report No. 53. Prepared for Road Safety Bureau, New South Wales, & Federal Office of Road Safety, Canberra.