

Estimating Pedestrian Fatal Crash Risk

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Pedestrians are highly vulnerable in traffic with the young, aged and alcohol-affected being at even greater risk. Vehicle speeds are the primary determinant of pedestrian crash risk and, more importantly, injury severity in the event of a crash. Scientifically-based, well-established mathematical relationships exist for vehicle stopping distance, as a function of the initial travel speed, and the risk of death to a pedestrian, given the vehicle impact speed. The main purpose of the research was to build on current research evidence concerning the risk of death to a pedestrian, as a function of *impact* speed, in order to develop a reliable method for estimating the relative risk of a fatal crash involving a pedestrian, as a function of alternative *travel* speed choices. These estimates apply to a pedestrian in the path of two vehicles travelling at different initial speeds and, within meaningful limits, enable pair-wise comparison of risk for selected initial travel speeds. The model outputs offer objective new information on pedestrian fatal crash risk, based on the laws of kinematics and the biomechanical limits of humans exposed to kinetic energy. By allowing differences in travel speed choices to be translated to changes in pedestrian fatal crash risk, key groups, such as drivers and riders, pedestrians, stakeholders, policy makers, and traffic and road engineers, can be provided with scientifically-derived information on the role of speed. Proposed future developments of the model are also discussed.

1. BACKGROUND

Pedestrians are highly vulnerable in traffic with the young, aged and alcohol-affected being at even greater risk. Vehicle speeds are the primary determinant of pedestrian crash risk and, more importantly, injury severity in the event of a crash. By providing simple, scientifically-derived information about the relationship between speed, and pedestrian crash and injury risk, it is hoped that safer speed choices by drivers and riders will result.

Scientifically-based, well-accepted mathematical relationships exist for:

- the stopping distance, given the initial travel speed of a vehicle, and
- the risk of death to a pedestrian, given the vehicle impact speed (e.g., Anderson et al. 1997; Ministry of Transport and Communications, 1997).

By combining these two well-established mathematical relationships, an estimate can be made of the relative risk of a fatal pedestrian crash for two comparison initial travel speeds chosen by approaching drivers. Such estimates can apply to a pedestrian in the path of two hypothetical vehicles travelling at different initial speeds. Within meaningful limits, the model presented here was developed to enable any two travel speeds to be selected and relative risk calculated.

2. PURPOSE OF RESEARCH

The main purpose of the research reported in this paper was to build on current research evidence concerning the risk of death to a pedestrian, as a function of *impact* speed, in order to develop a reliable method for estimating the relative risk of a fatal crash involving a pedestrian, as a function of alternative *travel* speed choices.

3. METHOD

For the operational development of the model, it was necessary to make a number of important assumptions, including that:

- the pedestrian has an equal probability of being positioned at any distance ahead of both vehicles; pedestrians located beyond the minimum stopping distance of the higher speed vehicle were not considered, and
- commonly encountered values were adopted for driver perception-reaction time (PRT) and for tyre-road co-efficient of friction.

As noted above, there are two major inputs to the model, each of which is discussed below.

Stopping Distance as a Function of Initial Travel Speed

Stopping distance profiles, as a function of the initial travel speed of a vehicle, were calculated using basic laws of kinematics; specifically the equation:

$$v^2 = u^2 + 2as \quad (1)$$

where, for a given vehicle:

v = the final speed,
 u = the initial speed,
 a = the acceleration, and
 s = the distance travelled.

Equation 1 is derived from Newtonian mechanics and appears in standard secondary school textbooks on applied mathematics and physics. It can be re-expressed as:

$$s = \frac{v^2 - u^2}{2a} \quad (2)$$

In the above equations, a , the acceleration of a vehicle is equal to μg , where μ is the coefficient of friction between the tyre and the road, and g is the gravitational constant, 9.8 m/sec².

Figure 1 shows the stopping distance profile for initial speeds of 30, 40, 45, 50, 55 and 60 km/h, for a driver perception-reaction time (PRT) of 1.2 seconds and coefficient of friction of 0.7; both values are regarded as reasonably typical and suitable for this application.

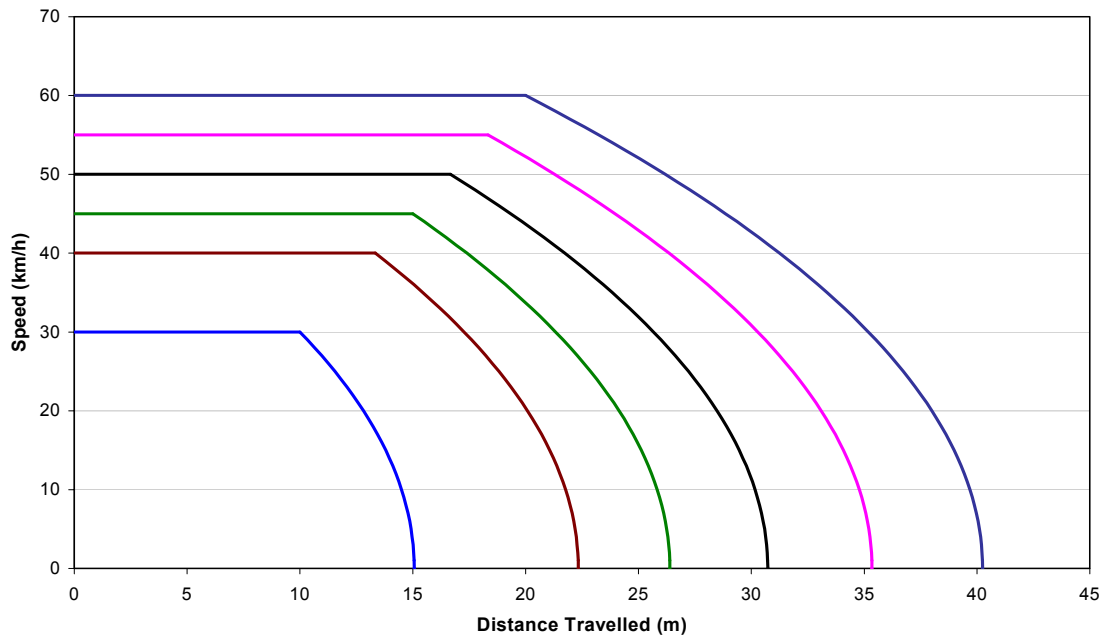


Figure 1 Stopping Distance Profiles for a Range of Initial Travel Speeds

The stopping distance profile is made up of two parts: first, the horizontal part, representing the distance travelled at the initial speed during the driver's PRT and, secondly, the curved part which reveals increasing reduction in speed as a function of distance during the braking phase. It is noteworthy that the stopping distance increases non-linearly with increasing initial speed, due to the 2nd-power relationship in equation (2).

Risk of Death to a Pedestrian as a Function of Impact Speed

A number of studies have attempted to establish the relationship between the risk of pedestrians being killed as a function of impact speed (Anderson et al. 1997; Ministry of Transport and Communications, 1997). This relationship is shown in Figure 2, for the results of Anderson et al. (1997). It is clear that the probability of death is most sensitive to collisions that occur within the range of impact speeds of approximately 35-55 km/h.

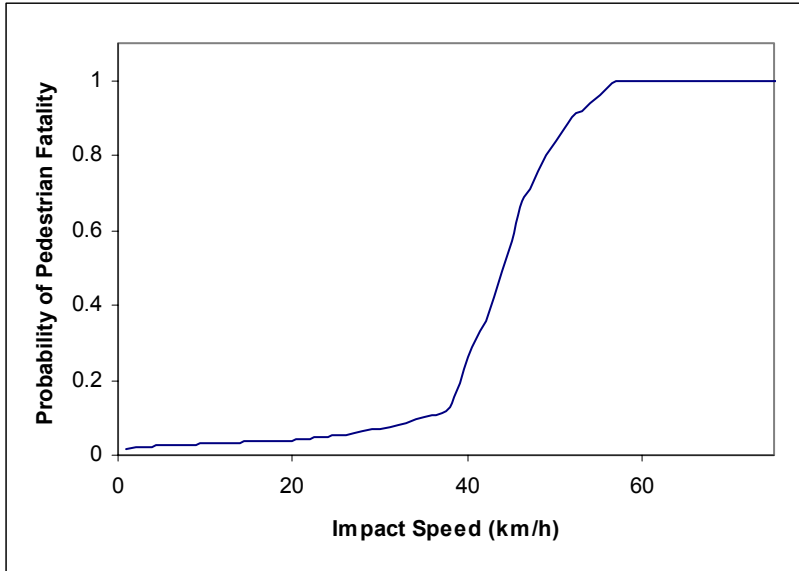


Figure 2 The Probability of a Pedestrian Fatality as a Function of Impact Speed

Combining Both Relationships

Stopping distance scenarios such as those illustrated in Figure 1, define the travel speed of a vehicle as a function of distance from the moment when the need to brake becomes evident to a driver. Assuming that a pedestrian could be struck with equal probability at any distance up to the minimum stopping distance (an assumption that is not entirely realistic and will be discussed later), a new relationship can be defined to relate the risk of a fatal pedestrian crash as a function of the distance along a vehicle's stopping trajectory. By combining Figures 1 and 2 mathematically, estimates of the risk of death to a struck pedestrian are able to be estimated, plotted and compared for any point along a vehicle's stopping path, for any two alternative travel speeds.

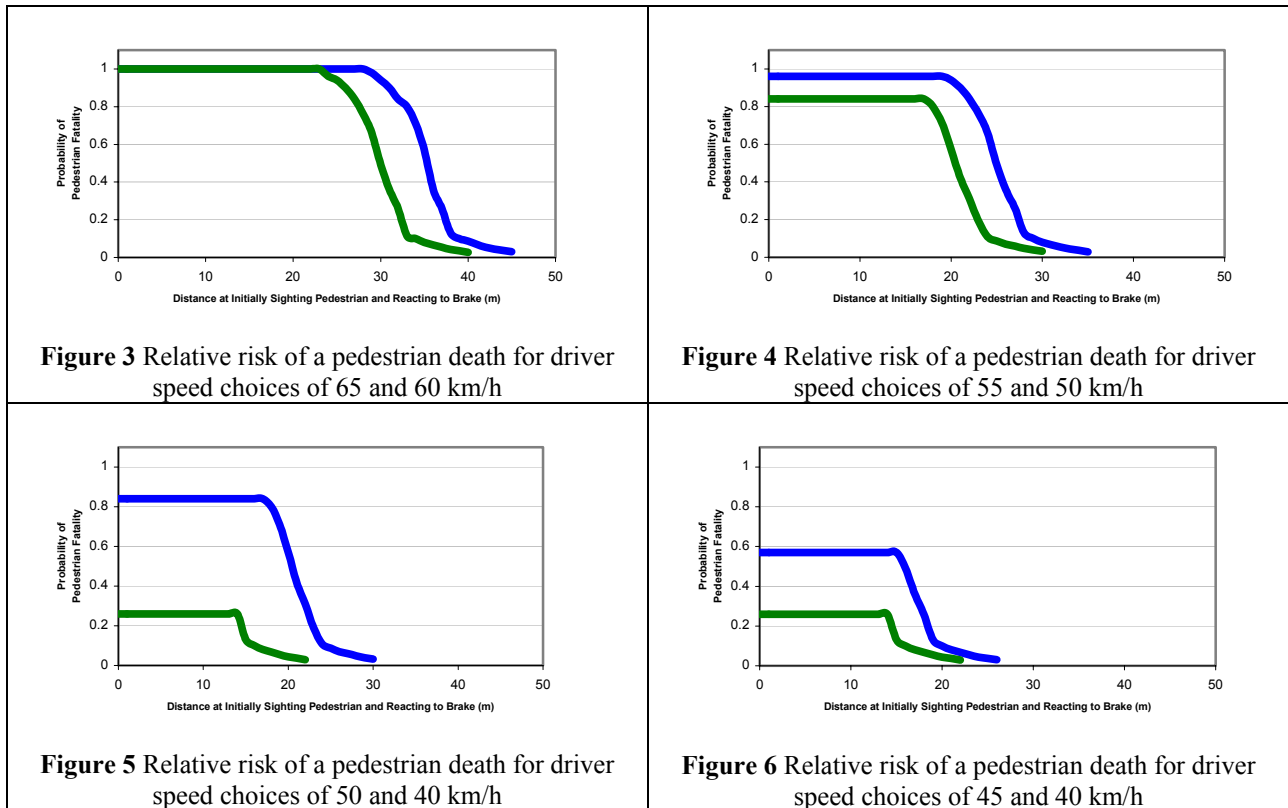
Under the assumption that a pedestrian can be located along the path of an approaching vehicle at any distance with equal probability, it is hypothesised in this paper that the ratio formed by the area under the curve for one choice of travel speed and the area for another choice of travel speed, estimates the relative risk of a struck pedestrian being killed for two initial speed choices. That is, the ratio of these areas permits pair-wise comparison of the effect of driver travel speed choice on the relative risk of death to a pedestrian located along the trajectory of an approaching vehicle. Pedestrians located in the path of the vehicle at a distance greater than the minimum stopping distance of the faster vehicle are assigned a probability of zero of being struck, and so are not considered here.

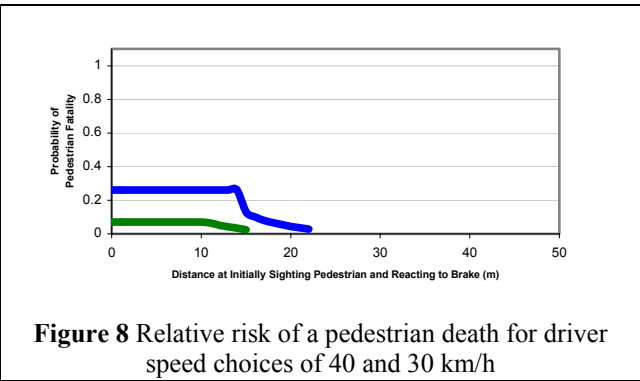
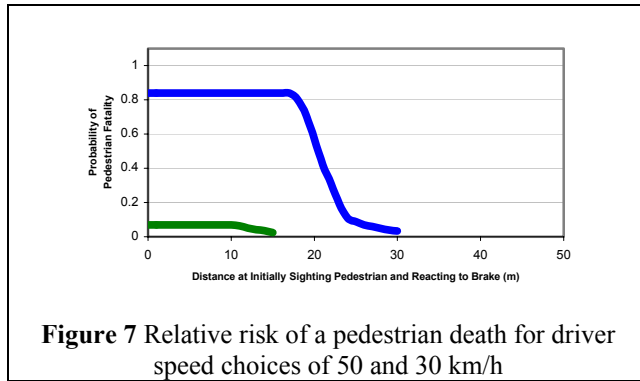
4. RESULTS

The resultant ratio offers an objective means by which to assess, using the laws of physics and the biomechanical properties of the human body, the relative impact of driver speed choice on the risk of death to a pedestrian. Figures 3, 4, 5, 6 and 7 show the risk curves for the comparison of initial speed choices of drivers that are common in Australia's urban settings:

- 65 and 60 km/h,
- 55 and 50 km/h,
- 50 and 40 km/h,
- 45 and 40 km/h,
- 50 and 30 km/h, and
- 40 and 30 km/h respectively.

It is the ratio of the areas under each of these pair-wise comparisons that provides an estimate of the relative risk of a crash leading to a pedestrian death.





To illustrate how this new relationship might be applied in practice, consider the results summarised in Table 1, for these six scenarios of initial paired-speed choices.

Table 1 Comparison of Relative Risk for six scenarios of initial speed choice

Initial Travel Speed Comparison (km/h)	Stopping Distance Comparison (m)	Relative Risk of Pedestrian Fatality for lower speed choice c.f. higher speed choice (ratio)	Reduction in Risk (%)
65	45		
60	40	0.85	15
55	35		
50	31	0.74	26
50	31		
40	22	0.24	76
45	26		
40	22	0.41	59
40	22		
30	15	0.22	78
50	31		
30	15	0.05	95

From these comparisons, it is clear that the risk of death to a pedestrian is strongly related to driver speed choice and that small reductions of the order of 5-10 km/h can produce substantial to major reductions in risk. For example, choosing a travel speed of 30 km/h in a busy pedestrian environment compared with, say, 40 km/h is estimated to reduce the risk of death to a pedestrian by almost 80%.

Nilsson (1982) published the results of research that related increases or decreases in mean travel speed to corresponding increases or decreases in the risk of fatal, serious injury or other injury crashes. Nilsson found that changes in the risk of fatal crashes were related to changes in mean travel speed by a 4th-power relationship; serious injury crashes by a 3rd-power relationship and casualty crashes by a 2nd-power relationship. For example, reducing mean travel speed by 10% (i.e., to 0.9 of the original value) results in an estimated reduction in fatal crash risk of 34% (i.e., $(1 - (1 - 0.1)^4) \times 100 = (1 - 0.66) \times 100 = 34\%$). Nilsson's research, published in 1982, was recently reviewed by Elvik (2005), who concluded some two decades later, that Nilsson's research findings remain valid.

While Nilsson's findings apply to all types of crash, not just pedestrian crashes, it can be instructive to compare results of the model developed here with those that can be derived from Nilsson's research to assess whether there is a reasonable degree of agreement between both sets of estimates. Table 2 summarises these results for the same six scenarios presented in Table 1.

Table 2 Comparison of Relative Risk for six scenarios initial speed choice, with Nilsson's Predictions

Initial Travel Speed Comparison (km/h)	Relative Risk of Pedestrian Fatality (ratio)	Reduction in Risk (%)	Nilsson's Predicted Reduction in Risk of a Fatal Crash
65			
60	0.85	15	27
55			
50	0.74	26	32
50			
40	0.24	76	59
45			
40	0.41	59	38
40			
30	0.22	78	68
50			
30	0.05	95	87

Overall, there is a reasonable level of agreement between the work of Nilsson and the model presented here. Differences between the two risk prediction methods are to be expected given that Nilsson's relationships were derived for fatal crashes of all types while the model developed and presented here is for fatal pedestrian crashes only. A correlation coefficient (R^2) was calculated for these two sets of estimates of risk reduction to assess the level of agreement. An R^2 value of 0.931 suggests a strong relationship between these two independently derived methods of prediction. Although only six pairs of estimates were used to calculate the correlation coefficient, the comparison is considered reliable, as the estimates developed by each model are deterministic rather than probabilistic in nature.

5. DISCUSSION

The purpose of developing this new model is to provide insight and, therefore, practical guidance with respect to speed limits setting and, importantly, in relation to driver speed choice in pedestrian-oriented environments. To illustrate the utility of the model, it predicts that a driver who chooses to travel at 50 km/h in a high pedestrian activity area, exposes pedestrians who might attempt to cross within the vehicle's minimum stopping distance to, on average, a four-fold increase in the risk of death, compared with a travel speed choice of 40 km/h.

The important advance between this model and previously available models is that it focuses on driver *travel speed choice* – a variable within the driver's direct control – whereas past research focuses primarily on *impact speed*, which is less directly under the control of the driver.

6. FUTURE DEVELOPMENTS OF THE MODEL

As noted above, there are a number of shortcomings in, or enhancements possible for, the fatal pedestrian crash risk model. One of the main shortcomings is that in work to date it has been assumed that pedestrians have an equal probability of being struck at any distance along the trajectory of the stopping vehicle. Research carried out by Anderson et al. (1997) found that about half of all fatally injured pedestrians in their study were struck at the initial travel speed; that is the driver had not braked before impact. This finding is consistent with the findings of numerous studies of pedestrian safety conducted by MUARC (e.g., Corben and Diamantopoulou, 1996; Corben, Deery, Diamantopoulou and Dyte, 1998; and Corben, Deery, Diamantopoulou, Shtifelman and Wilson, 1999) in which it was found that pedestrians were commonly struck in situations where the pedestrian had been obscured from the view of approaching drivers until just before impact. In other words, the pedestrian entering the path of the approaching vehicle chooses to cross on the basis of information other than their distance from the vehicle. Further work is proposed to represent real-world pedestrian crashes more accurately with respect to their profiles of crash risk as a function of distance.

Other opportunities exist for enhancing the utility of the model, including the development or integration of risk profiles defining the serious injury risk as a function of vehicle impact speed; the levels of pedestrian protection of different vehicle designs in the event of a crash; and age-related factors such as frailty and gap choice.

These and other refinements should be feasible in the future, subject to the required data becoming available to define new probability profiles. Once comparable fatal (or serious) injury risk versus impact speed curves are known for other crash types, such as vehicle-to-vehicle side-impacts at intersections and head-on crashes, this method can be used to compare fatal (or serious) injury crash risk as a function of driver speed choice.

7. CONCLUSIONS

The model outputs offer objective new information on pedestrian fatal crash risk, which is based on sound mathematical relationships derived from the laws of kinematics and the biomechanical limits of humans. Calculation of these risk values permits pair-wise comparison of risk for selected initial travel speeds, leading to calculations of relative risk for alternative speed choices. By allowing differences in driver travel speed choices to be translated to changes in fatal pedestrian risk, key groups such as road users, stakeholders, policy makers, and traffic and road engineers, can be provided with scientifically-derived information on the role of speed.

Further refinements to the assumptions underpinning the model are required to better reflect real-world situations.

8. REFERENCES

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