

Creation and validation of a tool to measure the real population risk of speeding

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Abstract

Speeding is a significant contributor to the road toll. The risks associated with speeding at high and low levels are well understood, as are a range of speed management programs such as speed limits and speed cameras. Speed surveys have been used to help quantify the population distribution of speeding and to evaluate the impact of road safety interventions, especially since crashes are, statistically, rare events. Crash-based evaluations necessarily take time and are subject to high levels of random variation. In contrast, speed surveys can potentially be used to demonstrate the immediate impact of road safety interventions. The results of speed surveys are available long before the associated crash data has been collected and analysed. However, the achieved changes in the distribution of vehicle speeds need to be translated into changes in the likely number and severity of crashes.

The utility of speed survey data is diminished, however, through the use of crude summary statistics such as mean, 85th percentile and percentage of drivers exceeding the speed limit. Recently D'Elia et al. (2008), Doecke et al. (2011), Gavin et al. (2010) have combined known casualty crash risk estimates with speed surveys to further our understanding of how the population level of risk of speeding can be described and evaluated through the use of speed surveys.

This paper documents the development of a tool which translates speeding identified in speed surveys into a risk measure. The tool is designed to be used both with annual general network speed surveys and with speed surveys used to evaluate the impact of road safety interventions such as enforcement programs. The tool has been validated using speed survey and crash data from evaluations of the trial introduction of the 50 km/h urban speed limit, a speed limit reduction on the Great Western Highway and an evaluation of NSW fixed speed cameras.

Introduction

Speeding is consistently recognised as a major road safety issue throughout the world. In NSW more than 170 people are killed and around 4,200 people injured each year as a result of being involved in a speeding related crash, and speeding contributes to over 30% of road related fatalities in Australia.

Speed surveys are a commonly-used tool to measure vehicle speeds at a particular point on a road, and thus evaluate the effectiveness of road safety interventions that aim to reduce speeding and crashes on a particular length of road. Examples of such

interventions include speed enforcement methods such as fixed speed cameras, or a change in speed limit.

Typically, the results of these speed surveys are reported using summary statistics such as 85th percentile speeds and proportion of vehicles exceeding the speed limit, but most often as mean speeds. Subsequently, change in mean speed has been used to estimate the expected change in fatalities, casualties and crashes using the Nilsson Power model (Elvik et al., 2004; Elvik, 2009; Nilsson, 1982; Nilsson, 2004). However, the change in mean speed is sometimes not strongly related to the actual change in casualties resulting from speeding interventions. In these circumstances, the change in distribution of speeds provides much richer and more useful information about the likely road safety benefits of these interventions (D'Elia, 2008). For example, say a speed intervention was introduced in a 100 km/h speed zone resulted in 100 vehicles decreasing their speed from 110 to 100 km/h, but also resulted in the speed of 200 vehicles increasing from 80 to 85 km/h. There would be no change in mean speed, however will be safer because the reduction in risk from the 100 vehicles not speeding is larger than the increased risk of those who increased their speed from 80 to 85 km/h.

The reporting of speed survey results using mean speed assumes a linear relationship between speed and crash frequency and severity, and does not take into account the rapidly escalating level of risk associated with speeding. A number of studies have quantified this relationship between increasing speed and increasing crash risk (Aarts & van Schagen, 2006). Studies by Kloeden et al. (1997, 2001, 2002) best describe this relationship between individual vehicle speed and crash risk.

Direct multiplication of the level of speeding (obtained from speed surveys) with the serious casualty crash risk associated with this speeding (estimates obtained from Kloeden et al. 1997, 2001, 2002) provides a more robust measure of the risk associated with the speed of travel. This methodology has already been used by Doecke et al. (2011) and Gavin et al. (2010) to provide an estimate of the relative contribution of low and high level speeding to the road toll. For example, Gavin et al. found that the largest fatal and casualty crash risks (43% and 38% respectively) can be attributed to drivers exceeding the speed limit by up to 10 km/h. So, despite the much lower risk per driver, the large number of drivers speeding at low levels makes this category of speeding a major road safety problem.

Furthermore, reporting speed survey results in terms of change in casualty crash risk should provide a more robust measure of the impact of interventions that aim to reduce speeding. Previously, D'Elia et al. (2008) analysed speed survey data through the multiplication of speed survey results and risk to determine if this methodology was suitable in evaluation of measures introduced in Victoria in 2001/2 that were designed to reduce speeding. D'Elia et al. found that the risk-weighted speed survey results were generally consistent with the crash-based evaluation, although the magnitude of the change in risk was not always consistent with the actual crash reductions. D'Elia et al. recommended that further investigation be undertaken before the results from this method of analysis could be used as a proxy for a crash-based evaluation.

There are two primary objectives of this paper:

1. To develop a user-friendly tool to assist road safety practitioners in analysing speed survey data to determine the reduction in the likely frequency and severity of crashes, even if these data are only in summary form.

2. To validate the use of this method of estimating the change in casualty crash risk by examining speed survey and crash data before and after implementation of road safety countermeasures aimed to address speeding. The method was validated with data for the following speed initiatives:

- Introduction of the 50km/h urban speed limit in NSW.
- Speed limit reduction on the Great Western Highway.
- A sample of 16 fixed speed camera locations in NSW.

Method

Speed survey data

For the 50km/h urban speed limit trial, speed survey data that were collected in each of the local government areas in which the 50 km/h speed limit was trialled were used. These data were collected before and after the speed limit was changed. These speed survey data were previously used in an evaluation of the 50km/h urban speed limit (ARRB, 2000).

For the speed limit reduction on the Great Western Highway, speed survey data was collected before and after the speed limit was reduced from 110 km/h to 100 km/h. These speed survey data were previously used in a paper evaluating the change in speed limit (Bhatnager et al., 2010).

For the validation using fixed speed cameras, speed survey data for 16 fixed speed camera locations from before the camera was installed and from one year after installation were analysed. These speed survey data were previously used in an evaluation of the NSW fixed speed camera program (ARRB, 2005).

Summary statistics, including mean, 85th percentile speed, percentage exceeding the speed limit, percentage exceeding by 10 km/h or more, percentage exceeding by 20 km/h or more and by 30 km/h or more were available for these speed surveys. These are the standard statistics available when using speed survey data analysis packages such as MetroCount. For the development of a user-friendly analysis tool, it was considered important to be able to use speed survey summary statistics that are typically available from a standard analysis, rather than requiring specific analysis of the raw data.

Fitting a speed distribution to the speed survey data

Speed survey data are typically summarized, usually in speeding ranges in 5 or 10km/h groupings to indicate the distribution of speeding. Moreover, these ranges are typically

reported relative to the posted limit, rather than to the mean speed. This use of ranges obscures the actual distribution of speeds. In this study a distribution of vehicle speeds was fitted to these data to provide an estimation of risk that more closely resembles the actual distribution of data, rather than grouping the vehicle speeds and allocation of risk by 10km/h groupings of vehicle speeds.

The distribution was fitted to the summary statistics by firstly evenly allocating speeds exceeding the speed limit by up to 10km/h, 11-20km/h, 21-30km/h. This results in a stepped curve, which was smoothed with a linear slope such that the last point in each step is halfway to the next step, or to zero in the case of the 21-30km/h range. In cases where the observed mean speed was below the posted speed limit, the proportion of vehicles travelling at speeds between the mean and the limit were linearly extrapolated from the smoothed curve. Likewise, when the mean speed was above the posted limit, it was necessary to linearly extrapolate the proportions of vehicles travelling at speeds approaching 30km/h over the mean. See Figure 1 for an example of the original stepped and projected smoothed curves.

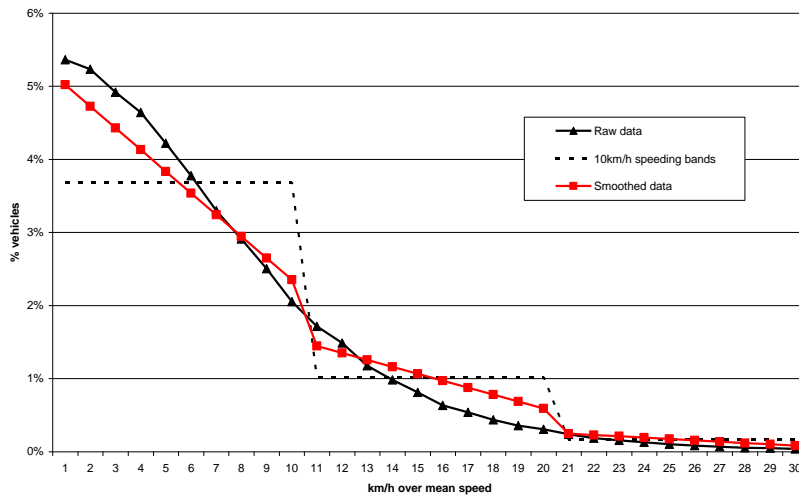


Figure 1: Comparison of raw speeding data, smoothed distribution and 10km/h speeding bands.

In this example, for the sake of clarity, an instance is shown in which the mean speed was equal to the speed limit, so the only transformation is the smoothing of the range-based summary data to approximate the raw data. It was not necessary to extrapolate any values. It can be seen that, while far from perfect, the smoothing procedure used provides a better proxy for the true distribution than would be obtained by assuming that the 10km/h ranges were evenly-distributed or (equivalently) using their mid-point in risk calculations. In the three cases described in this paper only summary data were available. Hence the need to attempt to recreate the original distribution using the smoothing and extrapolation procedure described above.

These data were combined with the calculated level of risk associated with each level of speeding (relative to the mean speed) to determine the level of risk and before and after

the speed interventions. In each case, the mean speed of the pre-intervention speed surveys was used as the reference point for these calculations, as the comparison of risk after the intervention is relative to the speeding distribution prior to the intervention. An average risk associated with vehicles travelling under the mean speed was calculated based on a typical speed distribution for each speed limit (obtained from annual speed surveys conducted in NSW). This represents a different procedure from that employed by some other researchers, who have either ignored, or made arbitrary assumptions about, the risks associated with speeds below the mean (or the limit).

Estimation of casualty crash risk

The relative risk of serious casualty crash involvement determined in Kloeden et al.'s (2002) re-analysis of travelling speed and risk of crash involvement on urban roads was used to apportion risks associated with speeding on roads with a 50, 60 and 70 km/h speed limit. Whilst Kloeden et al.'s study relates specifically to an urban 60 km/h speed limit environment, it was decided to apply these risks in 50 km/h and 70 km/h speed limit zones as these speed limit environments have a similar types of vehicle travel and could be expected to have a similar pattern of risk associated with speeding. Equation 1 below was used to apportion risk in these speed limits.

Equation 1

$$\text{Relative Risk of } (D) = e^{(0.1133374D+0.0028171D^2)}$$

Where D = difference in travelling speed relative to the mean speed¹

The relative risk of speeding in speed limits of 80, 90, 100 and 110 km/h were based on Kloeden et al.'s (2001) study of travelling speed and risk of crash involvement on rural roads. Equation 2 below was used to apportion risk in these speed limits.

Equation 2

$$\text{Relative Risk of } (D) = e^{(0.07039D+0.0008617D^2)}$$

Where D = difference in travelling speed relative to the mean speed¹

For this analysis, the relative risks associated with speeding were capped for vehicles detected speeding at high levels. This was done for two reasons. Firstly, Kloeden et al. (2001, 2002) reported that the risk model for urban areas is accurate for speeds of up to 20 km/h over the mean speed, and that the model of risk in rural areas is accurate for speeds up to 40 km/h over the mean speed. Beyond these speeds, the difference between the upper and lower confidence limits become increasingly large, and the relative risk increases exponentially to very high levels. Secondly, it is apparent from studies of fatality crash risk and impact speed that the risks reach a limit at higher speeds, where fatality risk is already very high and cannot increase to a large extent (Richards & Cuerden, 2009; Rosen & Sander, 2009; Wramborg, 2005). For these

¹ Mean speed used instead of speed limit, because this study investigated risk for initiatives in several speed limits in this study and because several speed limits were involve in the original studies.

reasons, speed differences above 20 km/h were capped at the risk of travelling at 21 km/h over the mean speed on low speed roads, and at the risk of travelling at 31 km/h over the mean speed on high speed roads (capped at this level due to limitations in the speed range data).

Speed survey results were combined with Kloeden et al.'s risk equations by speed limit. Risk by each unit of travelling speed was calculated by multiplying the risk associated with that speed by the number of vehicles estimated to be travelling at that speed.

Crash data

For the evaluation of the introduction of the 50km/h urban speed limit, summary crash data from a trial of 50km/h urban speed limit in 22 participating local government areas were used. This evaluation compared crash data for a three year period from September 1994 to August 1997 for the before time period with crash data for a 21-month after period from April 1998 to December 1999. These data were published in an evaluation of the 50km/h urban speed limit (ARRB, 2000). Both sets of data were annualised for the purposes of comparison.

For the evaluation of the speed limit reduction on the Great Western Highway the number of casualty crashes in the four year period before and after the speed limit reduction was used. These data were published in an evaluation of the speed limit reduction (Bhatnager et al., 2010).

For the fixed speed cameras, an analysis of crash data at the camera location before and after the camera was installed at each location was conducted. Crash data were analysed for 500 metres either side of the fixed speed camera location, given recent research demonstrating that the effects of fixed speed cameras are sustained for an approximate 1,000 metre total length around the camera (Hess, 2004).

Results

Introduction of 50km/h urban speed limit

The aggregated speed survey data for the introduction of the 50 km/h urban speed limit are presented in Table 2. Prior to the introduction of the 50 km/h speed limit, the mean speed was 57.2 km/h, which reduced to 56.7 km/h. The proportion of vehicles exceeding 60 km/h reduced from 37.6% to 15.6%, and the proportion of vehicles travelling at more than 70 km/h reduced from 9.6% to only 2.6%.

Table 2: Aggregated speed survey data for 50 km/h speed limit introduction

Time period	Mean speed (km/h)	Proportion of vehicles exceeding 60 km/h (%)			
		By 1-10 km/h	By 11-20 km/h	By 21-30 km/h	By 31+ km/h
Before	57.2	28.0	8.1	1.5	0.0
After	56.7	13.0	2.6	0.4	0.0

Risk calculations were conducted using pre and post speed surveys conducted in areas where the speed limit was reduced to 50km/h. The distribution of casualty crash risk by level of speeding is shown in Figure 3. Prior to the introduction of the 50km/h speed limit 92% of the casualty crash risk was associated with drivers traveling over the original mean speed. The largest proportion of risk was attributed to drivers exceeding the mean speed by 11-20km/h. After the speed limit was reduced to 50km/h, the casualty crash risk was calculated as 42.9% of the original crash risk, a reduction of 57.1%.

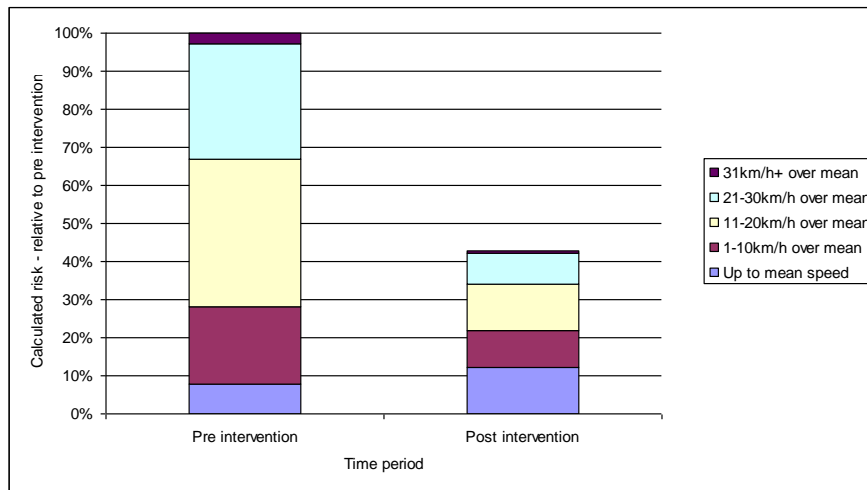


Figure 3: Calculated risk for 50km/h urban speed limit using speed surveys conducted pre and post implementation.

Crash data in the original evaluation indicate that there was a reduction in fatalities by 44.5% (not statistically significant), statistically significant reduction in injuries by 22.3% and in crashes by 25.3% (ARRB, 2000).

Reduction in speed limit from 110 km/h to 100 km/h on the Great Western Highway

The aggregated speed survey data for the introduction of the 100 km/h speed limit on the Great Western Highway are presented in Table 2. Prior to the speed limit reduction, the mean speed was 102.4 km/h, which reduced to 97.5 km/h. The proportion of vehicles exceeding 110 km/h reduced from 18.7% to 3.6%, and the proportion of vehicles travelling at more than 120 km/h reduced from 2.4% to only 0.5%.

Table 2: Speed survey data for the Great Western Highway speed limit reduction

Time period	Mean speed (km/h)	Proportion of vehicles exceeding 60 km/h (%)			
		By 1-10 km/h	By 11-20 km/h	By 21-30 km/h	By 31+ km/h
Before	102.4	18.7	2.4	0.4	0.1
After	97.5	3.6	0.5	0.1	0.0

Risk calculations were conducted using pre and post speed surveys. The distribution of casualty crash risk by level of speeding is shown in Figure 4. The serious casualty crash risk on the Great Western Highway was calculated as being reduced by 43.8% following the reduction in speed limit.

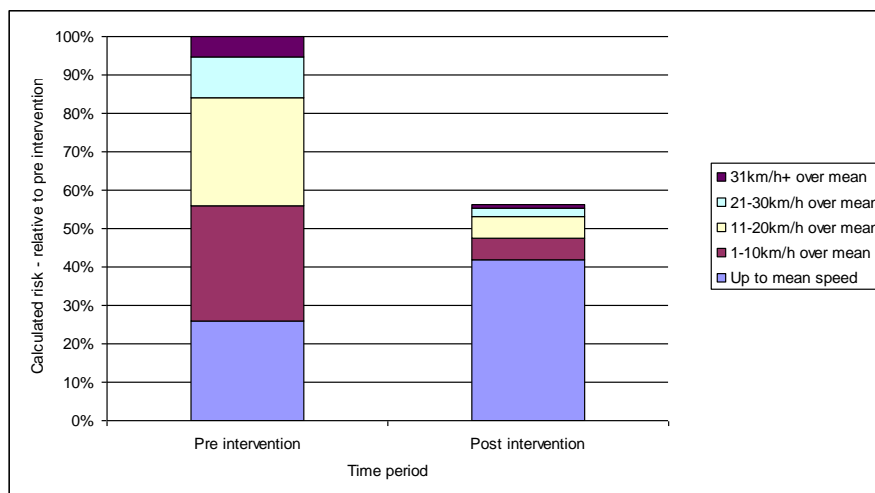


Figure 4: Calculated risk for the speed limit reduction on the Great Western Highway using speed surveys conducted pre and post implementation.

Crash data in the original evaluation indicate that there was a reduction in casualty crashes by 26.7% (Bhatnager et al., 2010).

Fixed speed cameras

The aggregated speed survey data for fixed speed camera locations is presented in Table 1 below. Before the introduction of fixed speed cameras at these locations, 67.6% of vehicles were recorded exceeding the speed limit, and 26.0% were recorded exceeding the speed limit by greater than 11 km/h or more. Following the introduction of fixed speed cameras at these locations only 20.4% of vehicles were recorded exceeding the speed limit, and only 2.9% exceeding the speed limit by 11 km/h or more.

Table 1: Aggregated speed survey data for fixed speed cameras

Time period	Proportion of vehicles exceeding the speed limit (%)			
	1-10 km/h	11-20 km/h	21-30 km/h	31+ km/h
Before	41.7	20.6	4.4	1.0
After	17.5	2.5	0.3	0.1

Risk calculations were conducted using pre and post speed surveys for all 16 fixed speed camera locations and aggregated to provide an overall risk profile before and after the speed cameras were installed. The distribution of casualty crash risk by level of speeding is shown in Figure 5. Prior to the fixed speed cameras being installed, 88% of the casualty crash risk was associated with drivers traveling over the mean speed, a large proportion due to drivers exceeding the original mean speed by more than 11km/h. After the installation of fixed speed cameras, the low proportion of speeding drivers result in the estimated crash risks associated with speeding drivers falling to a small proportion of the overall risk. Overall, the casualty crash risk was calculated as 32.3% of the original crash risk, a reduction of 67.7%.

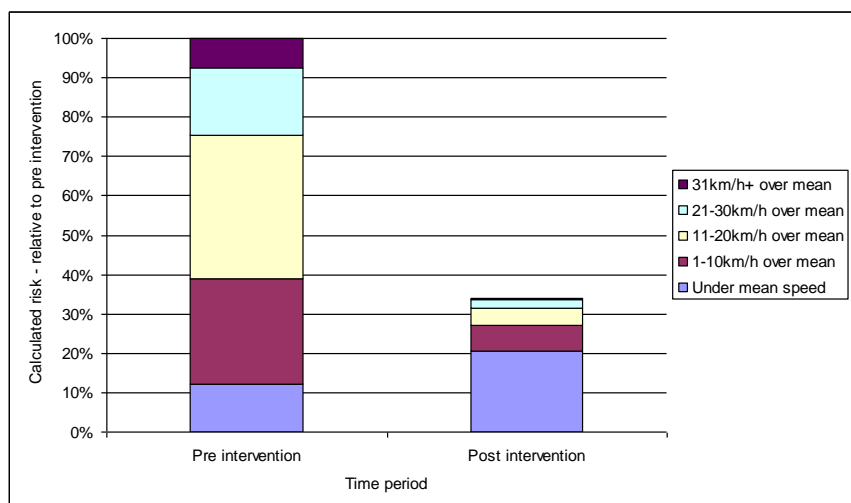


Figure 5: Calculated risk for fixed speed cameras using speed surveys conducted pre and post implementation.

Crash data were aggregated for the 16 fixed speed camera locations. In these locations, there was a reduction in fatalities by 80% (5 pre to 1 post), reduction in injuries by 10.5% (181 pre to 162 post) and reduction in crashes by 14.1% (347 pre to 298 post).

Discussion

This study shows that a tool can be developed to estimate the serious casualty crash reductions for speed interventions by combining speed survey data with our knowledge of the increasing risk of a serious crash for each increment of speeding. To this end, speed survey data has generally been grouped (say, into 10km/h speeding bands) and reported based on these groupings. This study applied a smoothing method to speed survey data in order to more closely resemble the actual distribution of vehicle speeds and more accurately allocate crash risks. It also corrects the data for situations in which the mean speed differs from the posted speed limit, as is typically the case. This tool has been developed in Microsoft Excel and allows road safety practitioners to estimate the change in casualty crash risk from road safety interventions that reduce speeding or vehicle speeds.

Using speed survey data to estimate the change in risk associated with road safety interventions enables the magnitude of the change in speeds to be more readily understood. It directly translates the change in speeding to a change in crash risk based on Kloeden et al.'s (1997, 2001, 2002) studies of serious casualty crash risk.

To illustrate how this is beneficial, the introduction of the 50km/h speed limit resulted in a mean speed reduction of 0.5km/h. Using the Nilsson Power model this mean speed reduction would be expected to reduce fatal crashes by 2.3% and serious casualty crashes by 1.3% (Elvik, 2009). Whilst the mean speed only reduced by a small margin, there was a large reduction in the proportion of vehicles exceeding 60km/h (reduced from 37.6% to 15.6%) and 70km/h (reduced from 9.6% to 2.6%). Clearly, there were benefits from reducing the number of vehicles traveling over 60km/h in these areas,

although this did not translate into a large mean speed reduction. However, applying Kloeden et al.'s (1997, 2001, 2002) risk formulas, the change in risk was estimated as a 57.1% reduction in the serious casualty crash risk. The actual crash reductions were not as large, fatal crashes were reduced by 44.5% and injury crashes reduced by 22.3%.

For the evaluation of the speed limit reduction on the Great Western Highway the estimated serious casualty crash reduction using Kloeden et al.'s (1997, 2001, 2002) model of risk was closer to the actual casualty crash reduction. The estimated serious casualty crash reduction was 43.8%, compared to a casualty crash reduction of 26.7%

For fixed speed cameras the estimated reduction in serious casualty crashes calculated using Kloeden et al.'s (1997, 2001, 2002) risk models was 67.7% However, the injury and crash reductions were lower. While the fatality reduction was similar in magnitude (80%), this result is based on a small number of fatal crashes, due to the use of only 16 locations.

These results are similar to that shown by D'Elia et al. (2008) who previously estimated risk reductions associated with speed interventions introduced in Victoria from 2001-2004. In their study, the estimated casualty reductions were up to 40% in metropolitan areas, while the actual serious casualty reductions in these areas were around 6%. D'Elia et al. did, however, find that casualty crash reductions were similar to those estimated in 100km/h and 110km/h zones in their study.

There are a number of possible explanations for the observed variability between estimated serious casualty reductions and actual fatality, injury and crash reductions.

Firstly, the severity of crash outcomes reported in this study differs from Kloeden et al.'s (1997, 2001, 2002) studies. Crash data presented here were for fatalities, all injuries and all crashes. However, Kloeden et al.'s distributions of the increase in crash risk by individual speed are based on serious casualty data, where the majority of casualties were either treated or admitted to hospital, or were fatalities. These data are not currently collected in this form in NSW. Therefore, predicted risk reductions might be expected to more accurately reflect actual casualty data for the more severely injured casualties. Indeed, in this study, predicted risk reductions were of a similar magnitude to the actual casualty reductions for fatalities (although based on a small number of cases), and not for injuries and overall crashes. Furthermore, when looking at the injury crash reductions the predicted reductions most closely matched casualty crash reductions for the speed limit reduction on the Great Western Highway, where casualties are likely to be more serious due to the high speed limit.

Secondly, Kloeden et al.'s (1997, 2001, 2002) studies include only crashes where at least one vehicle was traveling at a 'free' speed (that is, a speed that is not influenced by other traffic). While speed surveys in this study also measured 'free' travel speeds, the crash outcomes are based on all crashes regardless of whether one or all vehicles were traveling at a 'free' speed. One would expect that crashes involving at least one vehicle traveling at a 'free' speed would have more severe outcomes, which may partly explain

the lower reductions in injuries and crashes than risk estimates based on Kloeden et al.'s studies predict.

There is also the possibility that the reduced speeds measured at a point do not reliably translate to reduced speeds over a length of road. For instance, the overt nature and predictability of fixed speed camera enforcement means that the actual reduction in speeding is so large that using Kloeden et al.'s (1997, 2001, 2002) formulas to estimate the change in risk may not be appropriate for this program. Examination of crash data for 1,000 metres around fixed speed cameras clearly demonstrate the crash benefits of the cameras, but these crash benefits may not directly relate to the speed survey results at the speed camera. This may be because speed surveys are taken at a particular point near the camera location, and therefore may not accurately represent travel speeds for the whole 1,000 metres. There is evidence of a 'halo' effect associated with fixed speed cameras, such that drivers report slowing down for these cameras before speeding up again after passing them (Walker et al., 2009), and speed surveys have also demonstrated this effect (Hess, 2004). This unsynchronised deceleration and acceleration may itself be a source of crashes, partially offsetting the gains made from localized speed reductions.

Notwithstanding the above limitations that are mostly relevant to fixed speed cameras, it should be expected that the introduction of a 50km/h urban speed limit would be a reasonable test of validity. However, the predicted change in casualty crash risk was a reduction of 57.1%, a much larger reduction than the actual number of casualty crashes (22.3% reduction) and fatal crashes (44.5%).

These results suggest that while speeding interventions, or speed limit reductions do result in a significant change in casualties and crashes, the current validation indicates that the Kloeden et al.'s (1997, 2001, 2002) models of relative risk of speeding are most valid with respect to serious casualty and fatal crash outcomes. Predicting the reduction of injury and other crash outcomes however needs further validation or an alternate basis for estimating risk. In addition, further investigation into developing risk curves that can be applied to different types of speeding interventions in an appropriate manner is recommended.

Conclusion

A tool has been developed which converts summary speed survey data into an estimate of casualty crash risk. This tool can be used to determine the change in risk following the implementation of road safety interventions to reduce the speed of vehicles. This study sought to validate this tool against crash and casualty data from the introduction of the 50km/h urban speed limit in NSW, a speed limit reduction on the Great Western Highway and from a sample of NSW fixed speed cameras. The results were found to generally be consistent with crash-based reductions, however this tool is more accurate for more severe crashes, especially fatal crashes. It is recommended that further research and validation be conducted to develop risk curves for estimating all injury reductions and for use with particular types of speeding interventions. The tool assists with the interpretation of speed survey results given that raw data alone do not indicate

the degree of change in behaviour and associated crash risk. However, these results must be considered with caution, as the change in risk may not directly translate to fatality, casualty and crash reductions.

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