crashes. On some routes, recreational motorcycling was also a key driver of curve crash risk. These factors may need to be accounted for by regional engineers and fed back to VicRoads for consideration in future asset management budgets on B and C roads. Future risk models should consider inclusion of such factors where data permits it.

Conclusions

This paper showed how overseas and local research evidence was combined to develop an engineering crash risk assessment model for ranking of curves. A funding program and project development guidelines were developed to assign standardised delineation treatment packages according to each curve's risk category. Such an approach will provide a consistent level of curve delineation and warning along selected routes, and thus, condition drivers to better respond to the crash risk of the curves ahead.

The risk model was used to secure funding for a $100 million rural curve mass treatment program to be rolled out across Victorian B and C roads over ten years. A practitioner tool was developed to deliver rapid ranking of curves on prioritised routes. Estimated benefits included savings of 28 lives and 315 serious injuries over the life of the treatments.

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Estimating crashes attributable to low and high level speeding: Melbourne compared with Perth and urban Queensland

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Abstract

Relationships linking travel speeds with the risk of casualty crashes have been combined with on-road speed surveys to estimate the proportion of crashes associated with each speed range and potentially attributable to speeding at different levels. This paper used speeds recorded by mobile speed cameras operated covertly in Melbourne 60 km/h speed limit zones. A 1% sample of mobile camera sessions was used to provide estimates of the proportion of casualty crashes attributable to low and high level speeding, using analysis methods similar to those used previously to analyse large speed surveys in Perth and urban Queensland. The analysis compared the results from functions linking casualty crash risk with absolute speed or with the difference between travel speed and the mean speed (mean-centred speed). The effect of different caps on the magnitude of the risk at high speeds was also examined.

The study concluded that a low cap placed on the risk functions is not justified; however analysis using higher caps should make use of the 95% confidence limits on the risk estimate. A rescaled version of the mean-centred speed risk function, referenced to the risk at the speed limit, provides similar results to the risk function based on the absolute speed in 60 km/h limit zones. Rescaled mean-centred speed risk functions could be applied with some confidence to estimate the casualty crash risk, relative to that at the speed limit, at speeds in other urban and rural speed limit zones. From the empirical results, it was also concluded that the pattern of speeding and its contribution to casualty crashes in Melbourne 60 km/h limit zones was very different from that in 60 km/h zones in Perth and urban Queensland.

Background

Analysis of free speeds in Perth and Queensland 60 km/h zones

The availability of two large representative surveys of travel speeds in Western Australia and Queensland during 2010 had allowed previous analysis to be carried out by the author on the contribution of different speed ranges to casualty crashes [1]. The analysis made use of Kloeden et al's [2] relationship connecting the relative risk (RR) of a casualty crash with the free speed (v) of individual vehicles travelling in 60 km/h speed limit zones:

$$RR_1(v) = \exp(-0.822957835 - 0.083680149*v + 0.001623269*v^2) \quad (1)$$

The method followed previous research that had weighted speed observations by their relative risk [3-6], except that it followed Holman's [7] approach and estimated the "population attributable risk" fraction (PARF) for each speed range. PARF is the fraction of casualty crashes attributable to the <u>increase</u> in risk due to the speeding. Other researchers had estimated the relative number of casualty crashes <u>associated</u> with each speed range, but these crashes are <u>not all attributable</u> to the illegal speeds. The concept of population attributable risk associated with crash risk factors is outlined by Elvik [8]. Its calculation for each level of a polytomous risk factor (e.g., speed range) is defined by Walter [9].

Table 1 presents ranges of illegal speeds observed in 60 km/h zones in Perth and Queensland during 2010, together with the estimated fraction of casualty crashes attributable to speeding in each range. In these jurisdictions, it is estimated that 24% to 33% of casualty crashes were attributable to high level speeding (more than 20 km/h above the limit) and 12% to 16% were attributable to low level speeding (up to 10 km/h above the limit).

Table 1: Attributable fraction of casualty crashes due to speeds on 60 km/h speed zone roads in Perth and Queensland during 2010

Speed range (km/h)	Perth 60 km/h limit zones			Queensland 60 km/h limit zones		
	Speeds observed (N = 664,414)	Percent of speeds observed	Attributable fraction of casualty crashes	Speeds observed (N = 2,532,322)	Percent of speeds observed	Attributable fraction of casualty crashes
60-65	175,230	26.37%	4.8%	607,980	24.01%	4.0%
65-70	88,133	13.26%	10.9%	276,663	10.93%	8.3%
70-75	31,134	4.69%	10.6%	105,896	4.18%	8.7%
75-80	9,846	1.48%	8.4%	41,114	1.62%	8.5%
80-90	4,343	0.65%	15.4%	23,595	0.93%	20.3%
90+	892	0.13%	8.7%	5,233	0.21%	12.4%

Analysis of mobile camera detected speeds in Melbourne 60 km/h zones

Alavi, Keleher and Nieuwesteeg [10] analysed a 1% sample of mobile speed camera sessions conducted in Victoria during 2013, including those in 60 km/h limit zones in Melbourne. Sessions sampled were limited to those with traffic volumes within one standard deviation from the mean traffic volume from all sessions at each site, in order to avoid the effect of dense or sparse traffic on the speeds recorded. The mobile speed cameras are operated covertly and are relatively invisible and unpredictable in urban areas. A total of 105,101 speed observations were recorded, excluding an inflated number of records at the offence detection threshold because this speed is used for test shots of the speed camera before and after each session. An estimate was made of the true number of actual speeds at the threshold (450).

Alavi et al [10] weighted each detected speed by the relative risk of a casualty crash, making use of Kloeden et al's [2] second relationship connecting risk with the difference (D) between free speed (v) and the mean speed (m) at crash locations in urban areas:

$$RR_2(v) = \exp(-0.1133374*D + 0.00281717*D^2) \quad (2)$$

where D = (v – m). The mean speed detected in the sampled sessions in 60 km/h limit zones in Melbourne during 2013 was 52.7 km/h. For various reasons, Alavi et al [10] capped the relative risk function (2) at that corresponding to 21 km/h above the mean speed, i.e. 74 km/h with relative risk of 37. They then interpreted the risk-weighted detected speeds as [proportional to] the expected casualty crashes associated with each speed and potentially attributable to it. Because their focus was on illegal speeds above the limit, they summed the illegal risk-weighted speeds and calculated the percentage of expected crashes in

each speeding range (Table 2). It can be seen that these percentages differ substantially from the distributions of attributable fractions of crashes due to speeding in 60 km/h limit zones in Perth and Queensland (Table 1).

Table 2: Estimated distribution of expected casualty crashes associated with speeding across each illegal speed range, Melbourne 2013

Speed range (km/h)	Speeds detected (N = 105,551)*	Percent of speeds detected	Expected casualty crashes (sum of individual speeds by relative risk)	Percent of casualty crashes associated with illegal speeds
61-65	7,955	7.54%	32,534.3	46.6%
66-70	1,827	1.73%	18,889.2	27.1%
71-75	423	0.40%	11,698.7	16.8%
76-80	109	0.10%	4,033.0	5.8%
81+	71	0.07%	2,627.0	3.8%

Includes 450 estimated detections at the offence detection threshold, hence percentages differ slightly from Alavi et al [10] Tables 3 and 5

VicRoads surveys of trends in mean speeds in Melbourne

VicRoads has conducted bi-annual surveys of free speeds at sites in Melbourne since 1994. In each site-direction, 100 speed observations are recorded on weekdays during 10am to 12pm and 1pm to 3pm. Speeds are recorded only for vehicles with a headway of at least four seconds to ensure their speed is unimpeded (free). During May 2013, observations were made at 13 sample sites in each direction in 60 km/h limit zones. Thus it was estimated that 2,600 speed observations were collected.

The estimated mean speed at 60 km/h limit sites in Melbourne during May 2013 was 58.9 km/h [11]. This is about 6 km/h higher than the mean speed estimated from covert mobile speed camera detected speeds in Melbourne 60 km/h limit zones during the whole of 2013 [10]. It is not known which of these two sources provides a better estimate of mean speeds in that road environment. However it is possible that the VicRoads samples taken on weekdays during off-peak periods could be biased in the direction of higher speeds. In addition, the relatively small VicRoads sample (2,600) may not provide a reliable estimate of mean speed compared to the larger sample of mobile speed camera sessions (105,551 speed observations).

Research questions

The different pattern of results in Tables 1 and 2 has led to the following research questions.

1. What is the influence of the different analysis methods, in particular the following specific differences (Table 1 versus Table 2, respectively):

    a. Population attributable risk fraction versus risk-weighted speeds

    b. Relative risk function of absolute speed versus the function of difference from mean speed

    c. Capping the risk function at 90 km/h versus 74 km/h

    d. Based on speed frequencies in 5 km/h wide ranges versus individual speeds?

2. Are casualty crashes attributable to each range of speeding substantially different in Melbourne's 60 km/h limit zones compared with those in Perth and Queensland, perhaps reflecting the influence of Victoria's different operation of mobile speed cameras (covert versus overt) and other speeding-related initiatives?

Item 1(d) of these research questions will be addressed first by analysing the speeds detected at the 1% sample of covert mobile speed camera sessions in Melbourne 60 km/h zones in the same way as analysed by Cameron [1]. This will allow a direct comparison with the results from Perth and Queensland. Subsequent analysis will examine questions 1(a)-(c), but based on the richer data from Alavi et al [10] providing frequencies of individual speeds.

Research question 2 will be addressed following the results of analysis addressing question 1. While any conclusions may be tempered by the assumptions, the pattern and magnitude of the differences between the three States' urban speeds may be indicative.

Assumptions

It was assumed that the speeds detected by covert mobile speed cameras in urban Melbourne represent a reasonable proxy for free speeds measured in substantial and representative speed surveys. Although a VicRoads survey in May 2013 has suggested a mean free speed about 6 km/h higher than the camera-detected mean speed in Melbourne

60 km/h limit zones, the limited times of week, number of sites and observations, and season of the year used in the VicRoads survey does not provide conclusive evidence that the camera-detected speeds are not representative.

It was further assumed that the relative risk functions (1) and (2) developed by Kloeden et al [2] provide indicative estimates of increases and decreases in casualty crash risk, within the confidence limits given in Tables 2.2 and 2.3 of their report [2].

Analysis of Melbourne speed ranges

Cameron [1] analysed speed survey data from Perth and urban Queensland using Kloeden et al's [2] relative risk function and its 95% confidence limits, which were tabled for speeds ranging from 45 to 90 km/h [2, Table 2.2].

Natural logarithms of the function and limits are shown in Figure 1, together with quadratic functions fitted to the tabled values. This functional form reflects equation (1) when natural logarithms are taken of the relative risk.

In the same way as Cameron [1], the relative risk function and limits were applied to the mobile speed camera-detected speeds after classifying the speeds into the ranges shown (Table 3). The speed ranges differ somewhat from Cameron [1], so the mid-mark speed used to estimate each relative risk and limits also differ. In particular, 93 km/h with an estimated relative risk of 229.2 was used as the reference speed for the 91+ km/h speed range.
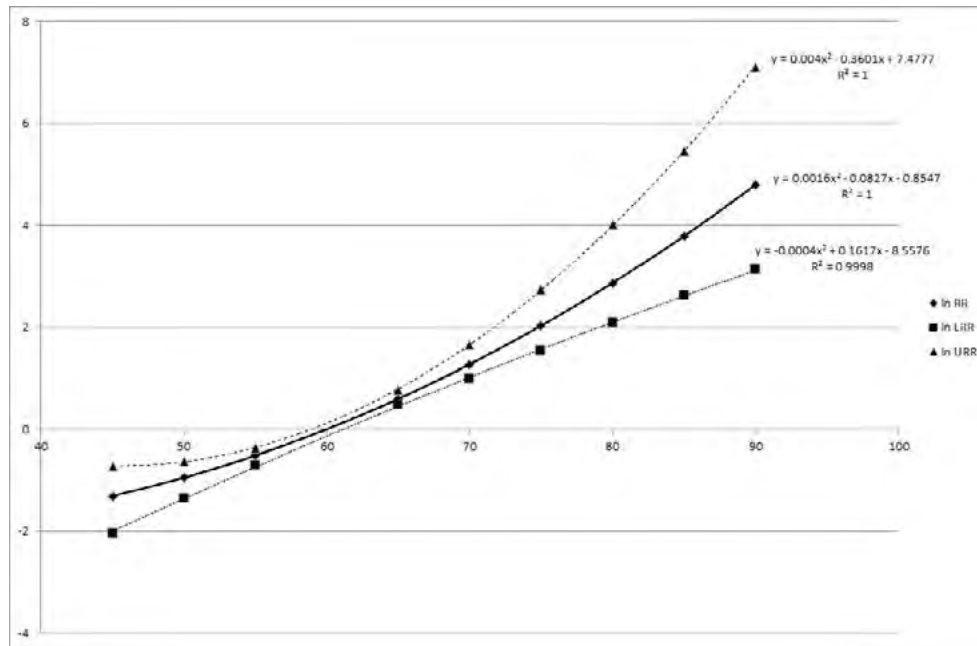
Figure 1: Natural logarithms of Kloeden et al's [2] relative risks (RR) and upper (URR) and lower (LRR) confidence limits versus travel speed in 60 km/h limit zones

Table 3: Attributable fraction of casualty crashes due to speeds detected on 60 km/h speed zone roads in Melbourne, 2013

Speed range (km/h)	Count of speeds detected in 2013 (N = 105,551)	Percent of speeds detected (p*100)	Estimated relative risk of casualty crash (RR)	Contribution to speed attributable fraction: p*(RR – 1)			Estimated population attributable risk (PAR) fraction of casualty crashes		
				Based on relative risk (RR)	Based on lower limit of relative risk (LRR)	Based on upper limit of relative risk (URR)	Attribut-able fraction (%)	Lower attribut-able fraction (%)	Upper attribut-able fraction (%)
1-30	477	0.45%	0.150	-0.0038	-0.0045	0.0078	-0.6%	-0.7%	1.1%
31-40	3,342	3.17%	0.183	-0.0259	-0.0302	-0.0107	-3.8%	-4.4%	-1.6%
41-45	8,873	8.41%	0.242	-0.0637	-0.0753	-0.0419	-9.3%	-11.0%	-6.1%
46-50	22,532	21.35%	0.333	-0.1424	-0.1705	-0.1075	-20.7%	-24.8%	-15.6%
51-55	35,025	33.18%	0.497	-0.1668	-0.2056	-0.1324	-24.3%	-29.9%	-19.3%
56-60	24,917	23.61%	0.806	-0.0458	-0.0698	-0.0262	-6.7%	-10.2%	-3.8%
61-65	7,955	7.54%	1.416	0.0314	0.0209	0.0458	4.6%	3.0%	6.7%
66-70	1,827	1.73%	2.699	0.0294	0.0220	0.0442	4.3%	3.2%	6.4%
71-75	423	0.40%	5.578	0.0183	0.0118	0.0344	2.7%	1.7%	5.0%
76-80	109	0.10%	12.503	0.0119	0.0059	0.0316	1.7%	0.9%	4.6%
81-90	58	0.05%	30.395	0.0162	0.0056	0.0695	2.4%	0.8%	10.1%
91+	13	0.01%	229.165	0.0281	0.0035	0.4662	4.1%	0.5%	67.9%

Table 3 indicates that 8.9% of casualty crashes are attributable to low-level speeding in the 61-70 km/h range and 6.5% of crashes are attributable to high-level speeding more than 20 km/h above the 60 km/h limit. This compares with the analysis of 60 km/h limit zone speeds in Perth and Queensland, where 24% to 33% of casualty crashes were attributable to high level speeding and 12% to 16% were attributable to low level speeding (Table 1).

Table 3 also indicates that there was a substantial contribution to preventing casualty crashes due to many vehicles travelling well below the speed limit in 60 km/h zones in Melbourne. The largest negative attributable fractions suggest that 21% of casualty crashes expected, if all vehicles were driven at 60 km/h, were saved by those driving at 46-50 km/h, and a further 24% of crashes were saved by those driving at 51-55 km/h.
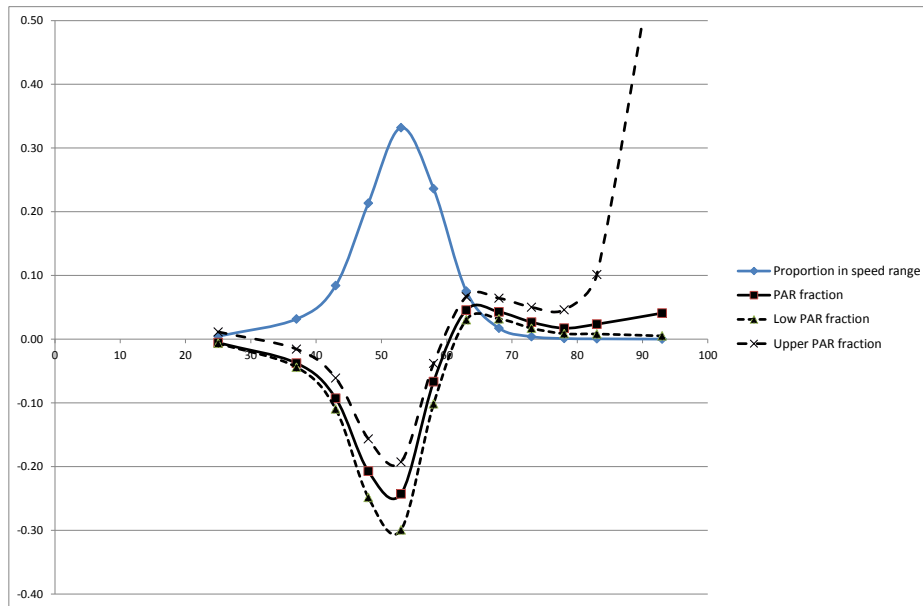

Figure 2: Estimated attributable fraction of casualty crashes for each speed range in Melbourne 60 km/h zones during 2013
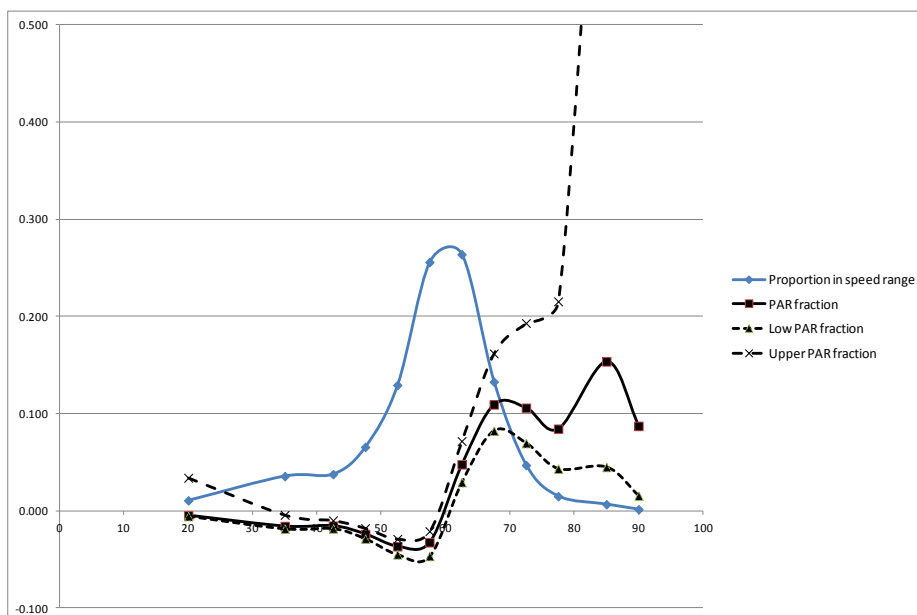

Figure 3: Estimated attributable fraction of casualty crashes for each speed range in Perth 60 km/h zones during 2010
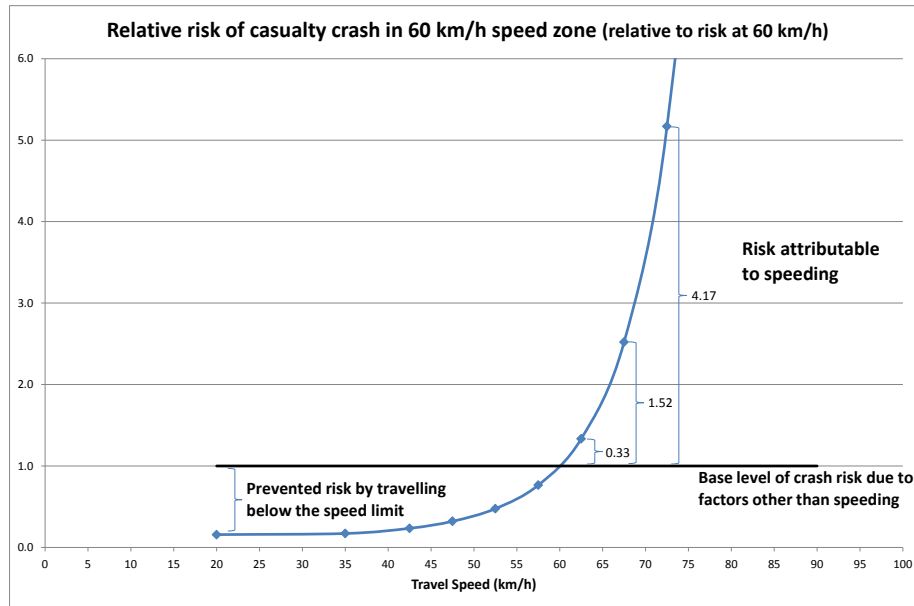
Figure 4: Kloeden et al's [2] relative risk function, showing the component of risk attributable to speeding and the risk prevented by travelling below the speed limit

These contributions to preventing casualty crashes in Melbourne, together with confidence limits on the population attributable risk (PAR) fraction of crashes saved, are shown in Figure 2. This compares favourably with the situation in 60 km/h limit zones in Perth, where vehicles driven below the limit contributed less than 4% savings in any legal speed range (Figure 3). As noted above, vehicles being driven above the 60 km/h limit in Perth appear to contribute substantially to casualty crashes, especially at high-level illegal speeds. The situation appears to have been even less favourable in urban Queensland, as shown in Cameron's [1] Figure 8 (not presented here).

The contribution of speeds below the limit in reducing relative risk, and hence saving casualty crashes, is illustrated in Figure 4. It can be seen that speeds below the 60 km/h limit are associated with a lower risk of a casualty crash, at the very least because they are associated with lower kinetic energy to produce injury in any crashes which occur.

Analysis of Melbourne individual speeds

The availability of the frequency of individual speeds in the 1% sample of covert mobile speed camera sessions in Melbourne 60 km/h zones [10] provided richer data for the analysis. In the following sections, the data was used to calculate the expected casualty crashes associated with each speed (and speed range), following Alavi et al's [10] method, and also the attributable fraction of crashes due to each speed range. These comparisons were made for each relative risk function and, in some cases, for different caps on the relative risk.

Relative risk related to difference from mean speed

Alavi et al's [10] analysis of individual speeds, weighting each by the relative risk equation (2) to provide an estimate [proportional to] casualty crashes, has been described above. However, their results provided only the expected casualty crashes and their distribution across the illegal speed ranges (Table 2), in particular the percentage associated with low-level speeding (up to 10 km/h above the limit). Here, Alavi et al's [10] analysis was extended to cover speeds between the mean speed and the limit, and below the mean speed (Table 4).

Table 4: Distribution of expected casualty crashes associated with each speed range, and attributable fraction of crashes due to speed above mean speed, Melbourne 2013. Relative risk as function of speed difference from mean speed, capped at risk for 74 km/h (21 km/h above mean)

Speed range (km/h)	Expected casualty crashes (sum of individual speeds by relative risk)	Percent of casualty crashes associated with speed range (%)	Attributable fraction (%)	Lower attributable fraction (%)	Upper attributable fraction (%)
Below mean	31,611.8	18.0%	-9.6%	-14.9%	-6.5%
Mean to limit	73,785.3	42.1%	15.5%	10.2%	25.4%
61-65	32,534.3	18.6%	14.0%	9.1%	24.7%
66-70	18,889.2	10.8%	9.7%	4.4%	22.7%
71-75	11,698.7	6.7%	6.4%	1.8%	21.5%
76-80	4,033.0	2.3%	2.2%	0.5%	8.3%
81+	2,627.0	1.5%	1.5%	0.3%	5.4%

Table 4 also shows the attributable fraction of casualty crashes due to each speed range, based on the relative risk equation (2) and its confidence limits. These limits were estimated from those tabled in Kloeden et al [2], Table 2.3, after taking natural logarithms as shown in Figure 5.

The function and limits were capped at the relative risks corresponding to 21 km/h above the speed limit, as done by Alavi et al [10], to maintain comparability of the results from the two analysis methods.
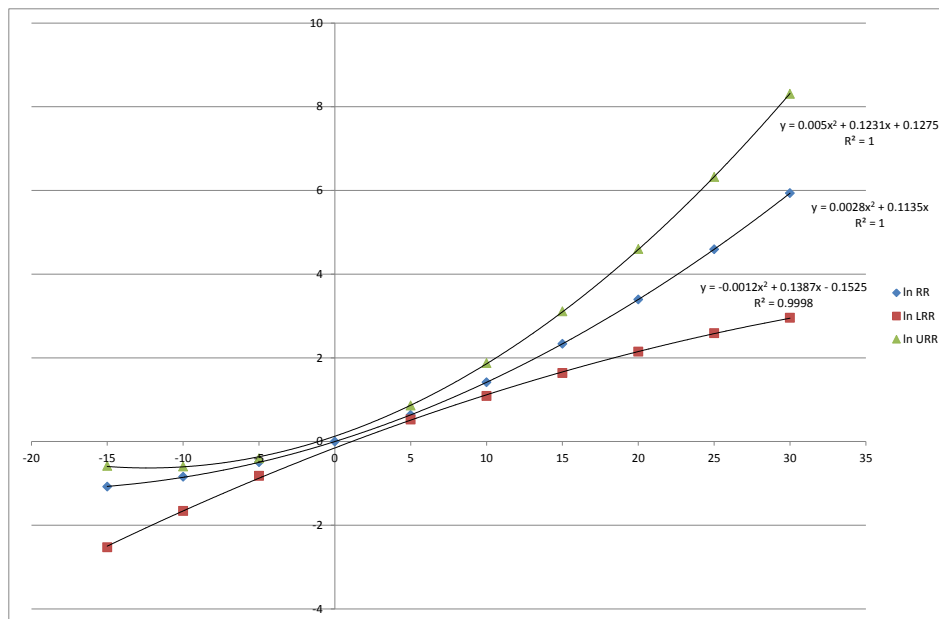

Figure 5: Natural logarithms of Kloeden et al's [2] relative risks (RR) and upper (URR) and lower (LRR) confidence limits versus speed difference from mean travel speed in 60 km/h limit zones

As implied by the points to the right in Figure 5, Kloeden et al [2] had provided confidence limits for their risk function (equation 2) at 25 and 30 km/h above the mean speed. Alavi et al [10] had capped the relative risk function at that for 21 km/h above the limit for their analysis. This had the effect of under-estimating the contribution of speeds above 74 km/h to the estimated expected crashes, and also to under-estimating the attributable fractions of crashes due to speeds

in the 76-80 km/h and above 80 km/h ranges. The effect of this relatively low cap on relative risk can be seen in Table 5 where the cap has been reset at 83 km/h. This corresponds to a speed 30 km/h above the mean speed, which was the highest speed difference in 60 km/h limit zones that Kloeden et al [2] provided an estimated relative risk and confidence limits.

Table 5: Distribution of expected casualty crashes associated with each speed range, and attributable fraction of crashes due to speed above mean speed, Melbourne 2013. Relative risk as function of speed difference from mean speed (52.7 km/h), capped at risk for 83 km/h (30 km/h above mean)

Speed range (km/h)	Expected casualty crashes (sum of individual speeds by relative risk)	Percent of casualty crashes associated with speed range (%)	Attribut-able fraction (%)	Lower attribut-able fraction (%)	Upper attribut-able fraction (%)
Below mean	31,611.8	15.3%	-8.2%	-12.6%	-5.5%
Mean to limit	73,785.3	35.8%	13.1%	8.7%	21.6%
61-65	32,534.3	15.8%	11.9%	7.7%	21.0%
66-70	18,889.2	9.2%	8.3%	3.7%	19.3%
71-75	12,534.4	6.1%	5.9%	1.5%	20.6%
76-80	11,117.3	5.4%	5.3%	0.6%	32.5%
81+	25,615.2	12.4%	12.4%	0.6%	100.0%

It can be seen that the attributable fractions of crashes due to the higher speed ranges, when estimated using the higher cap on relative risk (that at 83 km/h compared with 74 km/h), are higher than those estimated using the lower cap. However these attributable fractions have wider limits, due to the greater uncertainty in the relative risk equation (2) at the higher speeds. Nevertheless, the estimates in Tables 4 and 5 are within each other's limits.

Tables 4 and 5 each provide estimates of the fraction of casualty crashes attributable to speeds above the mean speed, not just those attributable to speeding. Equation (2) applied to the distribution of individual speeds in 60 km/h limit zones suggests that relative risk is already 2.658 at the speed limit compared with the risk at the mean speed. Thus the attributable risk associated with each speeding range in Tables 4 and 5 starts from that base. In the following sections, the effect of using an estimate of risk relative to that at the speed limit (i.e., relative risks associated with speeding and not speeding) is examined.

Mean-centred risk referenced to risk at speed limit (60 km/h)

Equation (2) was rescaled by dividing it by the relative risk at the speed limit (i.e., $RR_2(60) = 2.658$). The rescaled relative risk function is:

$$RR_3(v) = RR_2(v) / RR_2(60) = \exp(-0.1133374*D + 0.0028171*D^2) / 2.658 \quad (3)$$

where $D = (v - m)$. It then represents the risk of a casualty crash at each speed above and below the limit, relative to that at 60 km/h rather than relative to the mean speed. The effect of the rescaling on equation (2), the difference [from mean] risk, is shown in Figure 6. The rescaled function (solid line) has a relative risk of 1 at 60 km/h, but otherwise is proportional in shape to equation (2). Also shown in Figure 6 is equation (1), the relative risk associated with absolute speed in 60 km/h limit zones, relative to the risk at 60 km/h (small dashed line). It can be seen that the rescaled equation (3) is close to equation (1), but is higher at speeds above the speed limit.
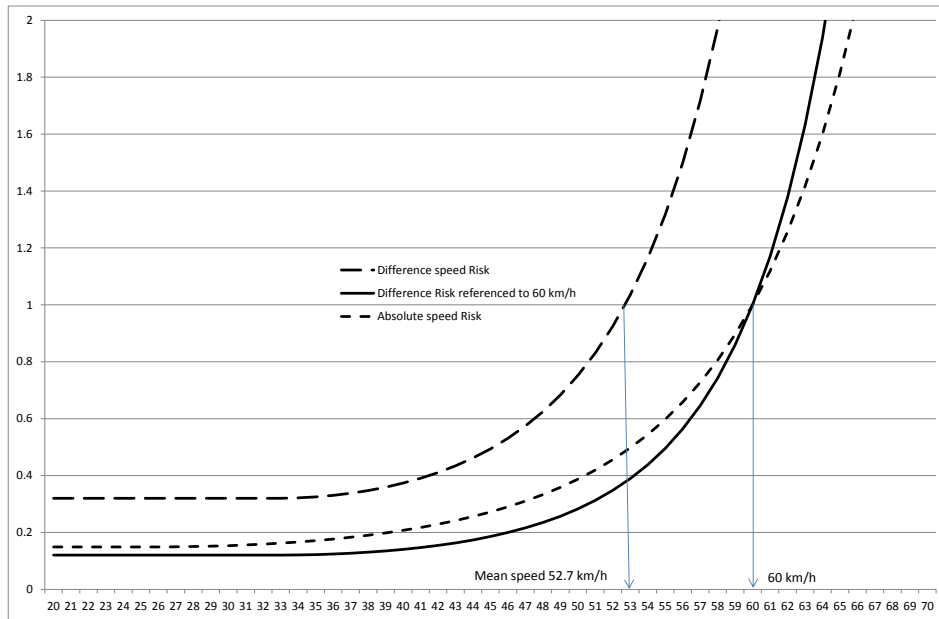
Figure 6: Relative risk functions in 60 km/h limit zones

The rescaled equation (3) was then applied to the individual speeds in the 1% sample of covert mobile speed camera sessions in Melbourne 60 km/h zones in the same way as the analysis reported in Table 5. The confidence limits on the relative risk function (2) were rescaled in the same way, i.e. dividing by 2.658. The results are shown in Table 6.

It can be seen that the distribution of expected casualty crashes over each speed range is the same as in Table 5. This is to be expected because the relative risk function has been divided by a constant and is otherwise unchanged, resulting in relativities being preserved.

However, Table 6 provides more appropriate estimates of the fractions of casualty crashes attributable to each level of speeding, in particular the estimates of the fractions attributable to low-level speeding. The estimated fractions attributable to the higher levels of speeding in Table 6 are almost identical to those estimated in Table 5. This is because the relative risks estimated at the higher speeds, no matter whether estimated by the raw or rescaled equation (2), both suggest very high attributable risks of similar magnitude. However, it should be noted that the attributable fractions due to higher level speeding ranges in both Tables 5 and 6 have high levels of uncertainty, as implied by the wide ranges of their limits.

Relative risk related to absolute speed in 60 km/h speed zones

A second method of examining the effect of using an estimate of risk relative to that at the speed limit, instead of risk relative to the mean speed, was to use equation (1). This function of relative risk related to the absolute speed in 60 km/h limit zones is shown in Figure 6. For consistency with previous analysis (Tables 5 and 6), the relative risk and its limits were capped at the highest speed (90 km/h) for which estimates were provided by Kloeden et al [2], Table 2.2. The results from using equation (1) are shown in Table 7.

It can be seen that the second method provides lower estimates of the attributable fraction of crashes due to speeds in each speeding range, compared with Table 6. The attributable fractions due to the higher speed ranges appear to be more reliable, based on the relative widths of their limits given in Table 7 compared with Table 6. The second method also provides estimates compatible with those in Table 3 based on aggregated speed ranges rather than individual speeds. However, this is to be expected given that the same relative risk function had been used in conjunction with the same raw speed data.

Table 6: Distribution of expected casualty crashes associated with each speed range, and attributable fraction of crashes due to speed above mean speed, Melbourne 2013. Relative risk as function of speed difference from mean speed, capped at risk for 83 km/h (30 km/h above mean), and rescaled by the risk at the speed limit (60 km/h), i.e. relative risk = 1 at 60 km/h

Speed range (km/h)	Expected casualty crashes (sum of individual speeds by relative risk)	Percent of casualty crashes associated with speed range (%)	Attributable fraction (%)	Lower attributable fraction (%)	Upper attributable fraction (%)
Below mean	11,894.1	15.3%	-47.1%	-51.6%	-44.5%
Mean to limit	27,762.1	35.8%	-24.4%	-28.9%	-16.0%
61-65	12,241.2	15.8%	5.5%	1.3%	14.6%
66-70	7,107.2	9.2%	6.8%	2.3%	17.8%
71-75	4,716.1	6.1%	5.5%	1.2%	20.2%
76-80	4,183.0	5.4%	5.3%	0.5%	32.4%
81+	9,637.8	12.4%	12.3%	0.6%	100.0%

Table 7: Distribution of expected casualty crashes associated with each speed range, and attributable fraction of crashes due to speed above mean speed, Melbourne 2013. Relative risk as function of absolute speed, capped at risk for 90 km/h (30 km/h above limit)

Speed range (km/h)	Expected casualty crashes (sum of individual speeds by relative risk)	Percent of casualty crashes associated with speed range (%)	Attribut-able fraction (%)	Lower attribut-able fraction (%)	Upper attribut-able fraction (%)
Below mean	16,460.8	23.2%	-45.1%	-54.0%	-31.2%
Mean to limit	31,617.8	44.6%	-21.3%	-28.4%	-15.3%
61-65	10,745.8	15.1%	3.9%	2.4%	6.0%
66-70	4,697.3	6.6%	4.0%	3.0%	6.1%
71-75	2,219.6	3.1%	2.5%	1.6%	4.7%
76-80	1,301.1	1.8%	1.7%	0.8%	4.5%
81+	3,905.2	5.5%	5.4%	1.3%	42.6%

Discussion

Capping the relative risk functions

In the analysis by Alavi et al [10] and this paper, the relative risk (RR) functions developed by Kloeden et al [2] have been capped at various levels, as follows:

- Mean-centred speed risk capped at 21 km/h above the mean speed of 52.7 km/h (RR = 37) (Alavi et al [10])

- Mean-centred speed risk capped at 83 km/h equal to 30 km/h above mean speed (RR = 411.7)

- Rescaled mean-centred speed risk capped at 83 km/h equal to 30 km/h above mean speed (RR = 154.9)

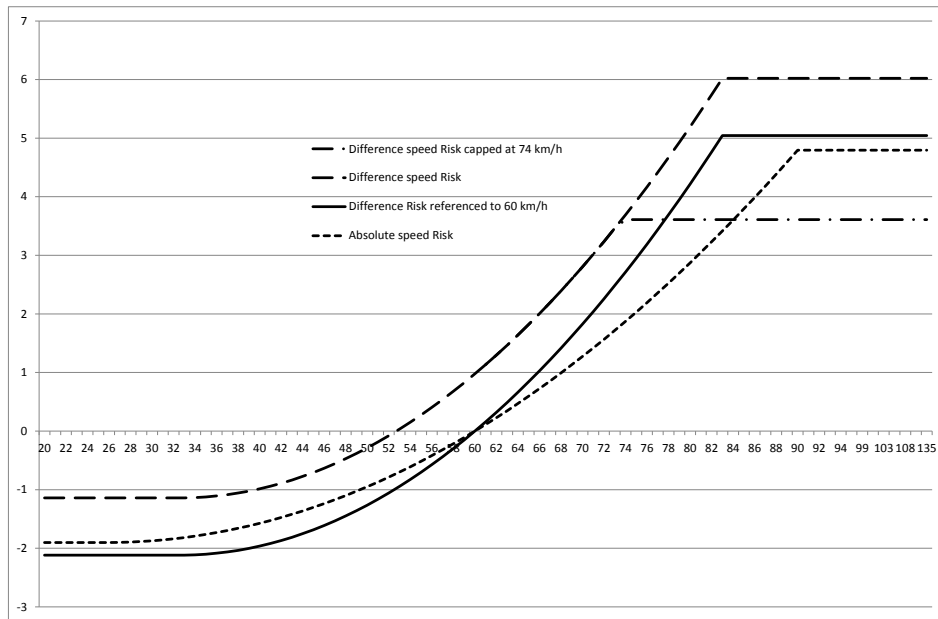- Absolute speed risk capped at 90 km/h equal to 30 km/h above the 60 km/h speed limit (RR = 120.8)

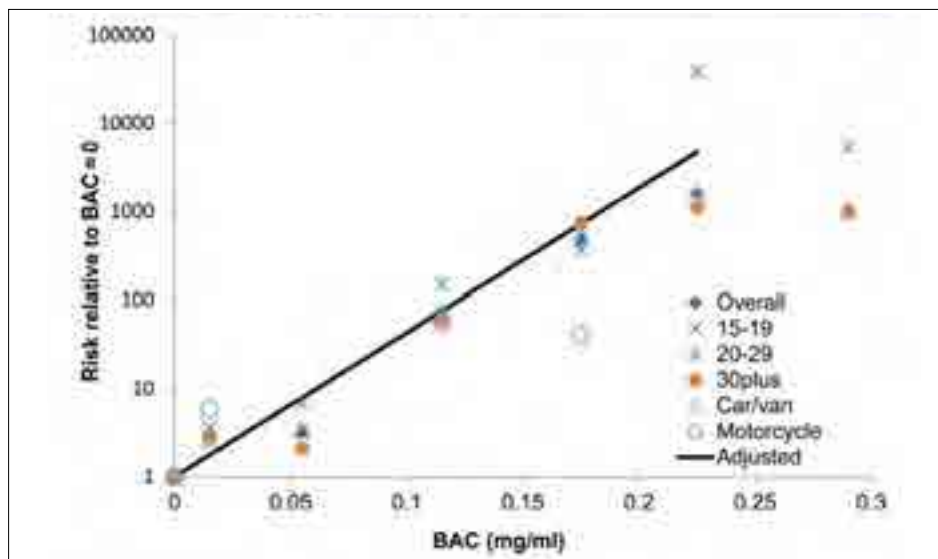**Figure 7: Natural logarithms of relative risk functions in 60 km/h limit zones**

Figure 8: Logarithm of relative risk of driver/rider fatality versus BAC level for all drivers and specific driver age groups and vehicle types, estimated by Keall et al [12]

The last three caps were based on the highest speed (or speed difference) for which relative risk estimates and 95% confidence limits were provided by Kloeden et al [2], Tables 2.2 and 2.3. The influence of these caps is shown in Figure 7 based on the natural logarithm of each of the relative risk functions used in the analyses.

It could be expected that the true risk of a casualty crash in a 60 km/h limit zone would increase more than exponentially with speed, as implied by Kloeden et al's [10] functions, but eventually would asymptote to a level

approaching certainty. It is unclear where this asymptotic level of risk lies in the case of speeding.

For drink-driving, the risk of a fatality appears to initially rise exponentially with blood alcohol concentration (BAC) and then asymptote at a risk about 1000 times that at zero BAC. Figure 8 shows the estimated risks provided by Keall et al [12].

On this basis, it would seem likely that the relative risk of a casualty crash associated with speeding could be up to 1000 times the risk at the mean speed or the speed limit in 60 km/h limit zones.

Thus, Alavi et al's [10] cap of the mean-centred risk function at a relative risk of 37 seems not to be supported by the possibility that the true risk is approaching an asymptote at 21 km/h above the mean speed. While the use of Kloden et al's [2] mean-centred risk function at higher speeds should be done with caution, the availability of confidence limits on the function allows the uncertainty in estimates from it to be provided (as done for the estimates of attributable risk fractions in Tables 3 to 7).

Risk related to mean-centred speed compared with absolute speed

Attributable risk fractions based on the mean-centred risk function, equation (2), are different from estimates of attributable fractions based on the absolute speed function, equation (1). The fractions of crashes estimated from equation (2) are those attributable to speeds in ranges above the mean speed, including some speeding ranges, but are not directly attributable to the speeding (range) *per se*. This is because the reference point for equation (2) is the mean speed, not the speed limit like equation (1).

However, the rescaled mean-centred speed risk function (3) is referenced to the 60 km/h limit. This was achieved by dividing the risk function (2) by the relative risk at 60 km/h, relative to the risk of 1 at the mean speed (which is the reference for the raw mean-centred risk function). If the true mean-centred speed risks were known absolutely, then exactly the same rescaled mean-centred relative risks would be obtained by dividing each absolute risk at a given speed by the absolute risk at 60 km/h.

Figures 6 and 7 show that the rescaled mean-centred risk function (3) and the absolute speed risk function (1) are not greatly different in shape and scale, and their caps are at similar levels. The limits on the attributable fraction estimates from the rescaled mean-centred risk function (Table 6) generally cover the limits from the absolute speed risk function (Table 7), although the magnitudes of some fraction estimates are different. In general, it appears that the two risk functions produce similar results when applied to speed data from 60 km/h limit zones, provided attention is given to the uncertainty in each function at the higher speeds.

Estimating attributable risk fractions in other speed limit zones

Kloeden et al's [2] relative risk functions were developed only for 60 km/h limit zones in an urban area. There is the question of whether they could be applied to estimate the relative risk of casualty crashes, and the attributable fractions due to each speed(ing) range, in other urban speed limit zones. It is not possible to address that question directly because Kloeden et al's [1] function related to

absolute speed has not been calibrated for other than 60 km/h speed limit zones. However, the results of this paper provide some confidence that the mean-centred risk function, equation (2), based on each zone's mean speed and rescaled to the relative risk at the zone's speed limit, could be so applied.

Kloeden et al [13] provided a relative risk function of the difference between each specific speed and the mean speed in rural speed limit zones ranging from 80 to 110 km/h. Again, the results of this paper provide some confidence that their rural mean-centred risk function, based on the zone's mean speed and rescaled to the relative risk at the zone's speed limit, could be applied to estimate the attributable fractions due to rural speeding.

Comparison of Melbourne with Perth and urban Queensland

The most direct comparison was between attributable fractions associated with each speeding range shown in Tables 1 and 3, where the same analysis method was applied to speeds recorded in ranges generally 5 km/h wide. In Melbourne, about 7% of casualty crashes were attributable to high level speeding (more than 20 km/h above the 60 km/h limit), compared with 24% to 34% in Perth and urban Queensland. At the other extreme, about 9% of casualty crashes were attributable to low level

speeding (up to 10 km/h above the limit) in Melbourne, compared with 12% to 16% in urban areas in the other two States.

The Melbourne results in Table 3 were generally confirmed by the analysis of individual speeds, when the relative risk function was not capped unduly and when the mean-centred function was rescaled (Tables 6 and 7). Analysis of individual speeds suggested that 5% to 12% of casualty crashes were attributable to high level speeding, and 8% to 12% were attributable to low level speeding. It should be noted that the attributable fractions associated with high level speeding have wide confidence limits, but the separate estimates are within each other's limits.

Thus it seems clear that the pattern of speeding and its contribution to casualty crashes in Melbourne 60 km/h limit zones was very different from that in Perth and urban Queensland. The magnitude of the difference appears greater than that which could be explained by the distribution of speeds recorded by covert mobile speed cameras not being representative of all speeds on Melbourne 60 km/h roads.

The full explanation for the difference in speeding patterns in Melbourne compared with Perth and urban Queensland is beyond the scope of this paper, but may lie with the influence of Victoria's different operation of mobile speed cameras (covert versus overt) and other speeding-related initiatives.

Conclusions

1. A low cap placed on Kloeden et al's [2] relative risk functions is not justified in analysis to estimate the association and attribution of observed speeds with casualty crashes.

2. Analysis using Kloeden et al's [2] relative risk functions with higher caps should make use of the 95% confidence limits provided by the original authors.

3. The rescaled mean-centred speed relative risk function, referenced to the risk at the speed limit, provides similar results to the relative risk function based on the absolute speed in 60 km/h limit zones.

4. Because of conclusion three, the mean-centred speed relative risk functions [2, 13] could be applied with some confidence to estimate the casualty crash risk, relative to that at the speed limit, at free speeds in other urban and rural speed limit zones apart from the 60 km/h zone.

5. The pattern of speeding and its contribution to casualty crashes in Melbourne 60 km/h limit zones during 2013 was very different from that in 60 km/h zones in Perth and urban Queensland during 2010.

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