Department of Transport and Regional Services
Australian Transport Safety Bureau

Reanalysis of Travelling Speed and the Risk of Crash Involvement in Adelaide South Australia

Kloeden CN, McLean AJ and Glonek G

Road Accident Research Unit
The University of Adelaide

An electronic version of this document and associated data files are available on the Internet at the following location:

http://raru.adelaide.edu.au/speed
or
email: raru@adelaide.edu.au

AUSTRALIAN TRANSPORT SAFETY BUREAU
DOCUMENT RETRIEVAL INFORMATION

Report No.	Date	Pages	ISBN	ISSN
CR 207	April 2002	40	0 642 25586 5	1445-4467

Title and Subtitle

Reanalysis of Travelling Speed and the Risk of Crash Involvement in Adelaide South Australia

Authors

Kloeden CN, McLean AJ, Glonek G

Performing Organisations

Road Accident Research Unit
Adelaide University
SOUTH AUSTRALIA 5005

Sponsored by / Available from

Australian Transport Safety Bureau
PO Box 967
CIVIC SQUARE ACT 2608 Project Officer: John Goldsworthy

Abstract

Modified logistic regression modelling was used to reanalyse free travelling speed case control data in an urban 60 km/h speed limit environment. An exponentiated second order polynomial function was used to model the relative risk of being involved in a casualty crash based on free travelling speed. The relative risk was found to approximately double for each 5 km/h increase in free travelling speed. This curve and the original data were then used to estimate the effects of various hypothetical speed reduction scenarios. Illegal speeding was found to be a major factor in casualty crashes and it was found that even very small reductions in the speeds of vehicles in general could be expected to result in a major reduction in the frequency of casualty crashes in an urban area.

Keywords

Speed, Risk, Speed Limit, Casualty, Crash, Reconstruction, Urban

EXECUTIVE SUMMARY

The main aim of this project was to establish a mathematical curve that defines the relationship between free travelling speed and the risk of involvement in a casualty crash, for sober drivers in an urban setting. Data collected in a case control study (Kloeden, McLean, Moore and Ponte, 1997) were reanalysed using logistic regression modelling. The speeds of passenger vehicles involved in casualty crashes were compared with the speeds of passenger vehicles not involved in crashes but travelling in the same direction, at the same location, time of day, day of week, and time of year.

Both absolute travelling speeds and speed differences were used in the modelling process and allowance was made for uncertainties in the reconstructed case speeds.

An absolute speed curve was found to provide a good fit for speeds between 60 and 80 km/h whereby the risk of casualty crash involvement approximately doubled for each 5 km/h increase in travelling speed. Although the data were relatively sparse outside this speed range, we assumed that the curve could be used for speeds down to 26 km/h and for speeds above 80 km/h in our hypothetical analysis, since the curve modelled the available data and its general shape (exponentiated second order polynomial) is not unexpected given the physics of road crashes and injury biomechanics.

Such considerations also indicate that speed is a risk factor in and of itself. That is, the observed differences in crash risk between vehicles travelling at different speeds is primarily due to the actual travelling speeds and not other factors such as the type of drivers who choose to travel at different speeds or with the variance in travelling speeds.

A speed difference risk curve was also fitted to the data and found to produce comparable results to the absolute speed risk curve.

The secondary aim of the project was to examine the effect of hypothetical speed reductions on this set of crashes and urban crashes in general, using the derived mathematical risk curves, to allow some insight to be gained into the possible effects of changing the speed behaviour of urban drivers (although a number of unproved assumptions, as stated, had to be made to do this).

It was estimated that illegal speeding in Adelaide 60 km/h zones accounts for around 25 per cent of all casualty crashes in those zones. That is, if we could reduce the maximum speed of all vehicles in Adelaide 60 km/h speed zones to 60 km/h, we would expect casualty crashes in those zones to fall by around 25 per cent.

Moreover, nearly 60 per cent of the benefit of eliminating speeding would be achieved by eliminating speeding among those travelling between 61 and 75 km/h. This is because there are many more drivers who travel in this speed range than at faster speeds. Their relative risk of casualty crash involvement is lower than those travelling above 75 km/h, but their contribution to the total number of casualty crashes is the product of the number of these drivers and their relative risk of involvement in a casualty crash.

Examination of the estimated hypothetical effects of slowing all vehicles down by the same amount indicate that very small reductions in travelling speed (even 1 km/h or less) can be expected to have a meaningful impact on casualty crash numbers.

Estimates were also made for a hypothetical reduction in the general urban area speed limit from 60 km/h down to 50 km/h using two sets of assumptions. Casualty crashes in these speed zones would be expected to drop by around 21 per cent using a speed fine avoidance method and by 28 per cent using a speed distribution movement method. While similar reductions on local streets would be expected from a reduction in the speed limit to 50 km/h, if the speed limit reduction was limited to local streets, the relatively small proportion of casualty crashes on local streets means that the effect on all casualty crashes in the metropolitan area would be much smaller than a change in the general urban area speed limit.

CONTENTS

1. INTRODUCTION

In 1997 the Road Accident Research Unit completed a study on "Travelling Speed and the Risk of Crash Involvement" in an urban area (Kloeden, McLean, Moore and Ponte, 1997). That study enumerated the relative risks of casualty crash involvement for a range of travelling speeds in an urban area (60 km/h speed limit zones) using a case control study method. It also estimated reductions in free speed casualty crash frequency under a number of hypothetical scenarios using case by case crash reconstructions.

In 2001 the Road Accident Research Unit completed a similar study on "Travelling Speed and the Risk of Crash Involvement on Rural Roads" (Kloeden, McLean and Ponte, 2001). Considerably more sophisticated methods of statistical analysis were developed for that study that provided a mathematical expression for the risk curve and also allowed for uncertainty in the estimates of the speeds of the case vehicles obtained from crash reconstructions. The risk curve was then used to obtain estimates of probable reductions in rural casualty crashes for a number of hypothetical scenarios.

This report reanalyses the data from the 1997 study using methods similar to those developed for the 2001 study.

1.1 Aims of this Project

The main aim of this project was to establish a mathematical curve that defines the relationship between free travelling speed and the risk of involvement in an injury producing crash, for sober drivers in an urban setting. Using a case control study design and logistic regression modelling, the speeds of passenger vehicles involved in casualty crashes were compared with the speeds of passenger vehicles not involved in crashes but travelling in the same direction, at the same location, time of day, day of week, and time of year.

The secondary aim of the project was to examine the effect of hypothetical speed reductions on this set of crashes and urban crashes in general, using the mathematical risk curve, to allow some insight to be gained into the possible effects of changing the speed behaviour of urban drivers.

1.2 Definition of Free Travelling Speed

This study uses the concept of free travelling speed. Although this concept is defined in the original report on the study, it is repeated here because it forms the basis of this method of investigation and analysis of the relationship between travelling speed and the risk of involvement in a casualty crash.

The case vehicles all had a free travelling speed prior to the crash. A free travelling speed was defined as the speed of a vehicle moving along a mid-block section of road, or with right of way through an intersection, and not slowing to join, or accelerating away from, a traffic stream. This criterion operationally defined travelling speed as it is popularly understood and aimed to ensure that the association between travelling speed and crash involvement was not confused by the inclusion of vehicles executing (necessarily slow) manoeuvres or disobeying right-of-way rules.

A similar requirement applied to those vehicles selected as controls.

2. ESTABLISHING A RISK CURVE

This Section deals with various methods for ascertaining the relative risk curve for involvement in a casualty crash by free travelling speed based on the data collected in the original study.

2.1 Original Risk Curve

The original relative risk curve was obtained by grouping the speeds of the cases and controls into 5 km/h groups and then comparing the ratio of cases to controls for a given speed group with that ratio for the "60 km/h" group (which was arbitrarily set to 1). See the original report (Kloeden, McLean, Moore and Ponte, 1997) for full details.

Table 2.1 reproduces the results found in the original study and also shows the 95% confidence limits for the individual relative risk estimates. It can be seen that the relative risk approximately doubles for each 5 km/h increase in speed above 60 km/h. Below 60 km/h there is some indication that the relative risk decreases but no statistically significant results were found in that speed range (since the confidence limits all include 1).

Table 2.1
Free Travelling Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at 60 km/h in a 60 km/h Speed Limit Zone Using the Grouping Method (Kloeden, McLean, Moore and Ponte, 1997)

Nominal Speed	Speed Range	No. of Cases	No. of Controls	Relative Risk	Lower Limit*	Upper Limit*
35	33-37	0	4	0	-	-
40	38-42	1	5	1.41	0.16	12.53
45	43-47	4	30	0.94	0.31	2.87
50	48-52	5	57	0.62	0.23	1.67
55	53-57	19	133	1.01	0.54	1.87
60	58-62	29	205	1.00	1.00	1.00
65	63-67	36	127	2.00	1.17	3.43
70	68-72	20	34	4.16	2.12	8.17
75	73-77	9	6	10.60	3.52	31.98
80	78-82	9	2	31.81	6.55	154.56
85	83-87	8	1	56.55	6.82	468.77
-	88+	11	0	infinite	-	-
Total		**151**	**604**			

* 95% confidence limits of the estimated relative risk

There are a number of drawbacks to using this method:

1. it treats speeds within a range equally
2. it produces only discreet relative risk points at 5 km/h intervals
3. it is subject to large fluctuations where the number of cases or controls is small
4. it assumes no error in the individual speed measurements
5. it assumes that the underlying speed distributions of controls at different crash sites are the same

Since the results using this method appear to indicate an exponential increase in relative risk, this suggests that the data could be modelled successfully using logistic regression which would eliminate the first 3 drawbacks. Further, the model could allow for some uncertainty about the case speed estimates thus dealing with drawback 4. Finally, the model could use speed differences between cases and controls at given sites rather than absolute speed to deal with drawback 5. The following Sections explore these approaches.

2.2 Fitted Absolute Speed Risk Curve

Modified logistic regression modelling was used to establish the shape of the casualty crash relative risk curve using the absolute speeds of vehicles (the raw data is presented in Appendix A).

One of the modifications involved allowing for any uncertainty in the estimation of the case vehicle speeds. While the control vehicle speeds were measured very accurately using a laser speed meter, the case vehicle speeds had to be estimated using reconstruction techniques that by their nature cannot give consistently precise results. The model used allowed for this uncertainty by assuming a standard error for the case vehicle speeds of 5 km/h. This equates to stating that 70 per cent of our estimated case vehicle travelling speeds were within 5 km/h of the actual travelling speed.

We consider this to be a reasonable assumption based on our experience with the crash reconstruction methods used. However, for comparison purposes, the model was also run using standard errors for the case vehicle speeds of 0, 2.5 and 7.5 km/h (see Appendix B).

The data were fitted using a range of logistic regression models and a quadratic model was found to provide a good fit for speeds between 60 and 80 km/h.

The final equation obtained for the relative risk of casualty crash involvement at a given free travelling speed was:

$$\text{relative risk (V)} = e^{(-0.822957835 - 0.083680149V + 0.001623269V^2)}$$

where V = free travelling speed in km/h

As an example of how this equation is applied, a vehicle that travels in a 60 km/h speed zone at a speed of 70 km/h will have a risk of being involved in a casualty crash that is 3.6 times greater than a vehicle that travels at 60 km/h. Note that this estimate of the relative risk only applies to vehicles that are travelling at a free speed.

The risk estimates derived from the above equation for a range of speeds are presented in Table 2.2 together with the 95 per cent confidence intervals of the fitted curve calculated using a simulation method.

Table 2.2
Free Travelling Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at 60 km/h in a 60 km/h Speed Limit Zone Using a Fitted Logistic Regression Model of Absolute Speed

Speed (km/h)	Relative Risk	Lower Limit*	Upper Limit*
45	0.27	0.13	0.49
50	0.39	0.26	0.54
55	0.60	0.50	0.69
60	**1****	**1**	**1**
65	1.82	1.60	2.15
70	3.57	2.70	5.28
75	7.63	4.66	15.55
80	17.66	8.08	55.49
85	44.36	13.73	236.10
90	120.82	22.98	1222.70

* 95% confidence limits of the estimated relative risk
** Relative risk arbitrarily set to 1 for 60 km/h

Note that the relative risk estimates for low speeds vary smoothly and are more precise than those shown in Table 2.1 since here we are modelling all speeds at once using a logistic model. However, there is still uncertainty about the risks associated with those speeds at the ends of the distribution not captured by the confidence limits since the shape of the “real” risk curve may not be this particular quadratic exponential beyond the 60 to 80 km/h range.

To reiterate, the 95% confidence limits shown in Table 2.2 are not the same as in Table 2.1. There, they represented confidence in the estimate of an individual point. Here they represent confidence in the fit of the whole exponential curve at that point.

The quadratic coefficient in the logistic model gives a U-shaped curve but the slope of the curve only changes sign at around 26 km/h (where there is no case or control data) and is therefore almost certainly an artefact of matching the rapid increase in relative risk at the top end of the distribution (eliminating high speed cases from the analysis was found to greatly reduce the quadratic effect which supports this theory). The available data do not, therefore, demonstrate any increase in the relative risk of involvement in a casualty crash at free travelling speeds below the 60 km/h speed limit. It also follows that if the curve is to be interpreted below 60 km/h, it should not be interpreted literally below where the slope of the curve changes sign. Where we needed to do this for the hypothetical scenarios in Section 3 we assumed that the curve was flat below 26 km/h.

The relative risk curve is presented graphically in Figure 2.1. The lower part of the curve is presented in Figure 2.2 to show more clearly the relationship between free travelling speeds below 75 km/h and the relative risk of casualty crash involvement.

Figure 2.1
Free Travelling Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at 60 km/h in a 60 km/h Speed Limit Zone Using a Fitted Logistic Regression Model of Absolute Speed (Overview)

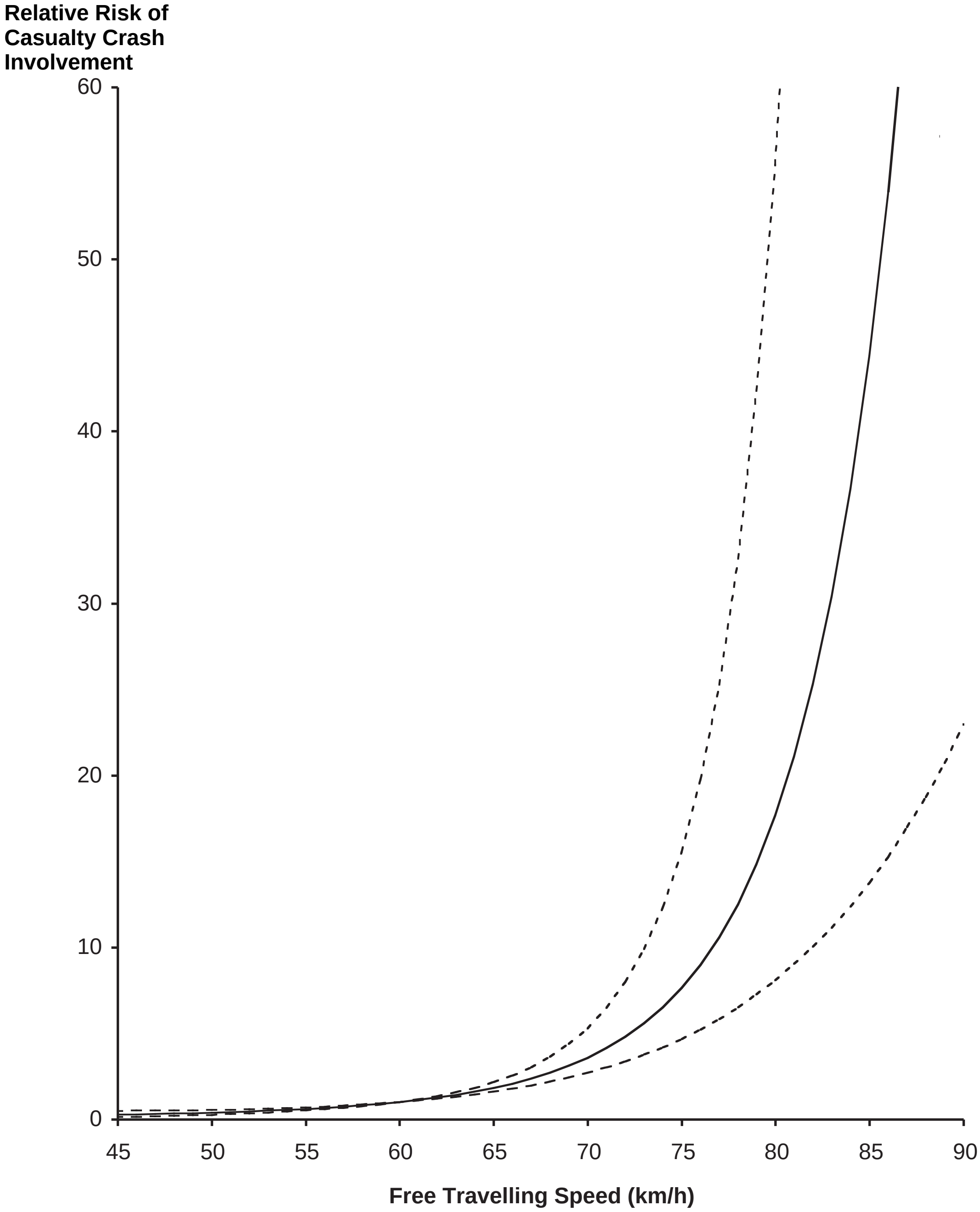
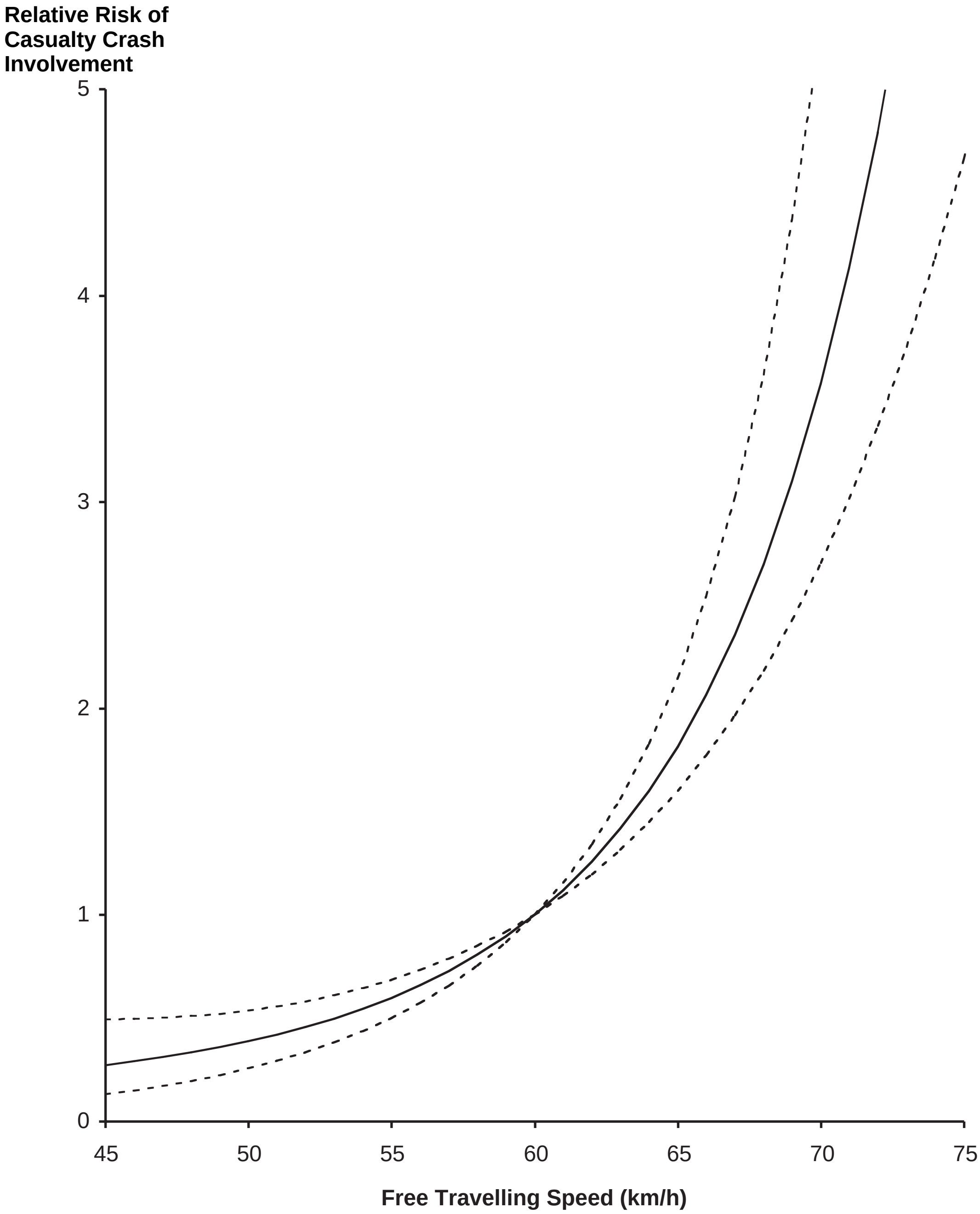


Figure 2.2
Free Travelling Speed and the Risk of Involvement in a Casualty Crash
Relative to Travelling at 60 km/h in a 60 km/h Speed Limit Zone
Using a Fitted Logistic Regression Model of Absolute Speed (Close Up View)



2.3 Fitted Speed Difference Risk Curve

While the crashes all occurred in 60 km/h speed limit zones (and not on curves with advisory speed signs) it is at least possible that the locations of the different crashes had markedly different underlying speed distributions. This could lead to skewing of the resultant risk curve unless a speed difference approach is used which is what we examine in this Section.

In the rural speed case control study, it was known that some of the locations had different fundamental speed distributions and/or speed limits and this was handled by using the mean speed of the ten controls at each particular site as a reference rather than the speed limit.

In the current study, only 4 control speeds were collected for each case which limited the level of precision of any attempt to determine how much of the average control speed variation between sites was due to random variation and how much was due to fundamental site differences. However, we could still use the difference method to obtain a relative risk curve based on speed difference as was done in the rural study.

A similarly modified logistic regression modelling as was used in the absolute speed approach was used to establish the shape of the casualty crash relative risk curve but using speed differences rather than absolute speeds. Again, uncertainty in the estimation of the case vehicle speeds was taken into account by assuming a standard error for the case vehicle speeds of 5 km/h. This equates to stating that 70 per cent of our estimated case vehicle travelling speeds were within 5 km/h of the actual travelling speed. For comparison purposes, the model was also run using standard errors for the case vehicle speeds of 0, 2.5 and 7.5 km/h (see Appendix C).

The speed difference data (given in raw form in Appendix A) were fitted using a range of logistic regression models and a quadratic model was found to provide a good fit for speed differences between 0 and +20 km/h (the speed of the case vehicle minus the average speed of the control vehicles at a given crash site).

The final equation obtained for the relative risk of casualty crash involvement at a given free speed difference from the mean traffic speed was:

$$\text{relative risk (D)} = e^{(0.1133374D + 0.0028171D^2)}$$

where D = difference in travelling speed in km/h

As an example of how this equation is applied, a vehicle that travels in a 60 km/h speed zone in the metropolitan area at a speed 10 km/h faster than the average speed of the rest of the traffic at a particular location will have a risk of crashing that is 4.1 times greater than a vehicle that travels at the average speed of the rest of the traffic at that particular location. Note that this estimate of the relative risk only applies to vehicles that are travelling at a free speed.

The relative risk estimates derived from the above equation for a range of speed differences are presented in Table 2.3 together with the 95 per cent confidence intervals of the fitted curve calculated using a simulation method.

Table 2.3
Differences Between Case Vehicle Free Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed for a Given Crash Site Using a Fitted Logistic Regression Model of Speed Difference

Speed Difference*	Relative Risk	Lower Limit**	Upper Limit**
-15	0.34	0.08	0.56
-10	0.43	0.19	0.55
-5	0.61	0.44	0.67
0	**1*****	**1**	**1**
+5	1.89	1.69	2.36
+10	4.12	2.97	6.52
+15	10.32	5.14	22.44
+20	29.77	8.56	99.44
+25	98.90	13.31	556.27
+30	378.22	19.24	4060.15

* Difference of case and control speeds from average control speed at given sites (km/h)
** 95% confidence limits of the estimated relative risk
*** Relative risk arbitrarily set to 1 for zero difference between case vehicle travelling speed and average control speed at given sites

Note that the relative risk estimates for all speed differences vary smoothly since we are modelling all speeds at once using a logistic model. However, there is greater uncertainty about the risks associated with those speed differences at the ends of the distribution not captured by the confidence limits since the shape of the "real" relative risk curve may not be this particular quadratic exponential beyond the 0 to +20 km/h range.

To reiterate, the 95% confidence limits shown in Table 2.3 are not the same as in Table 2.1. There, they represented confidence in the estimate of an individual point. Here they represent confidence in the fit of the whole exponential curve at that point.

The quadratic coefficient in the logistic model gives a U-shaped curve but the slope of the curve only changes sign at around -20 km/h (where there is virtually no case or control data) and is therefore almost certainly an artefact of matching the rapid increase in relative risk at the top end of the distribution (eliminating high speed difference cases from the analysis was found to greatly reduce the quadratic effect which supports this theory). The available data do not, therefore, demonstrate any increase in the relative risk of involvement in a casualty crash at free travelling speed differences below 0 km/h. It also follows that below a -20 km/h speed difference the curve should not be interpreted literally. Where we needed to do this for the hypothetical scenarios in Section 3 we assumed that the curve was flat below a -20 km/h speed difference.

The relative risk curve is presented graphically in Figure 2.3. The lower part of the curve is presented in Figure 2.4 to show more clearly the relationship between free travelling speed differences below 75 km/h and the relative risk of casualty crash involvement.

Figure 2.3
Differences Between Case Vehicle Free Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed for a Given Crash Site Using a Fitted Logistic Regression Model of Speed Difference (Overview)

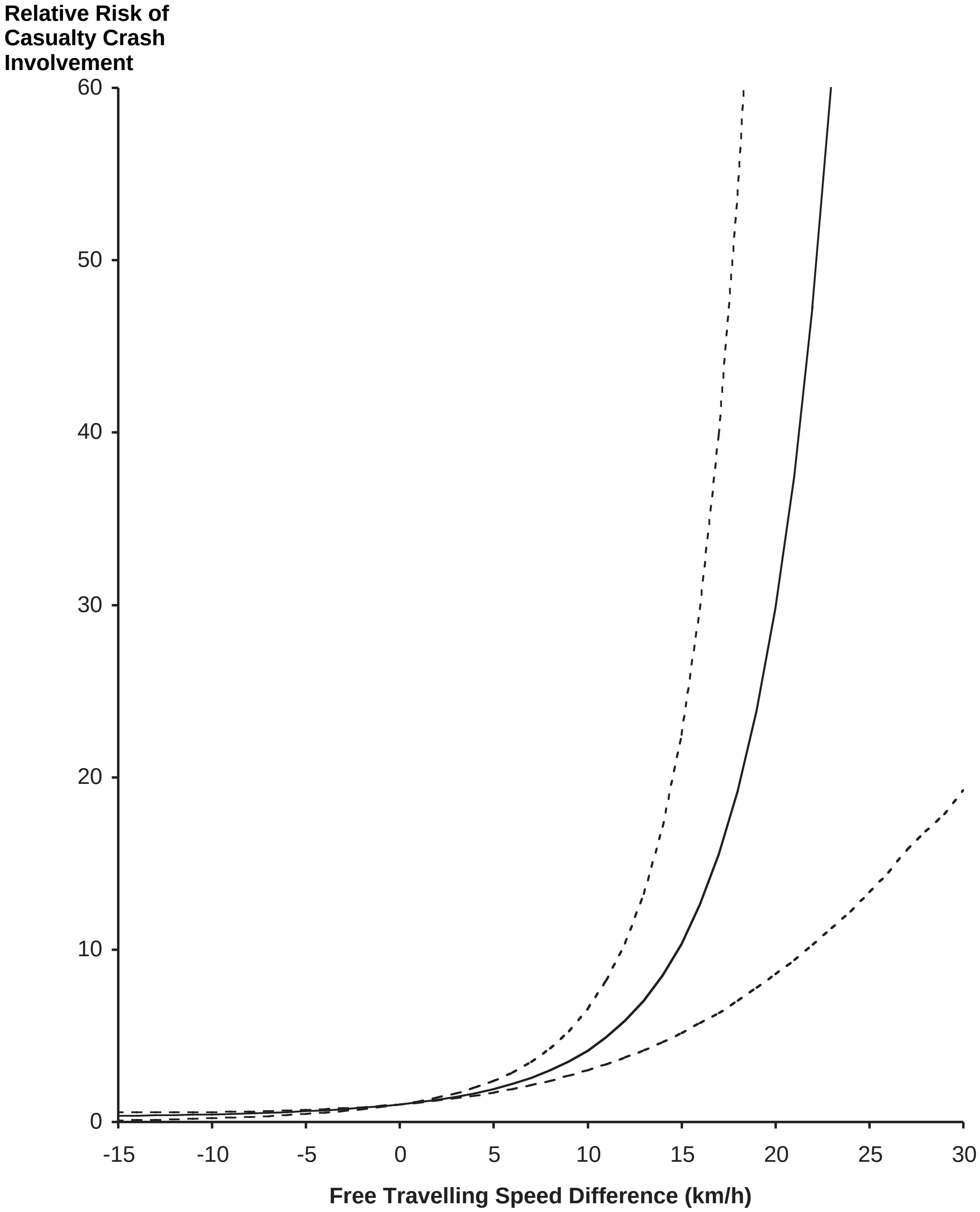
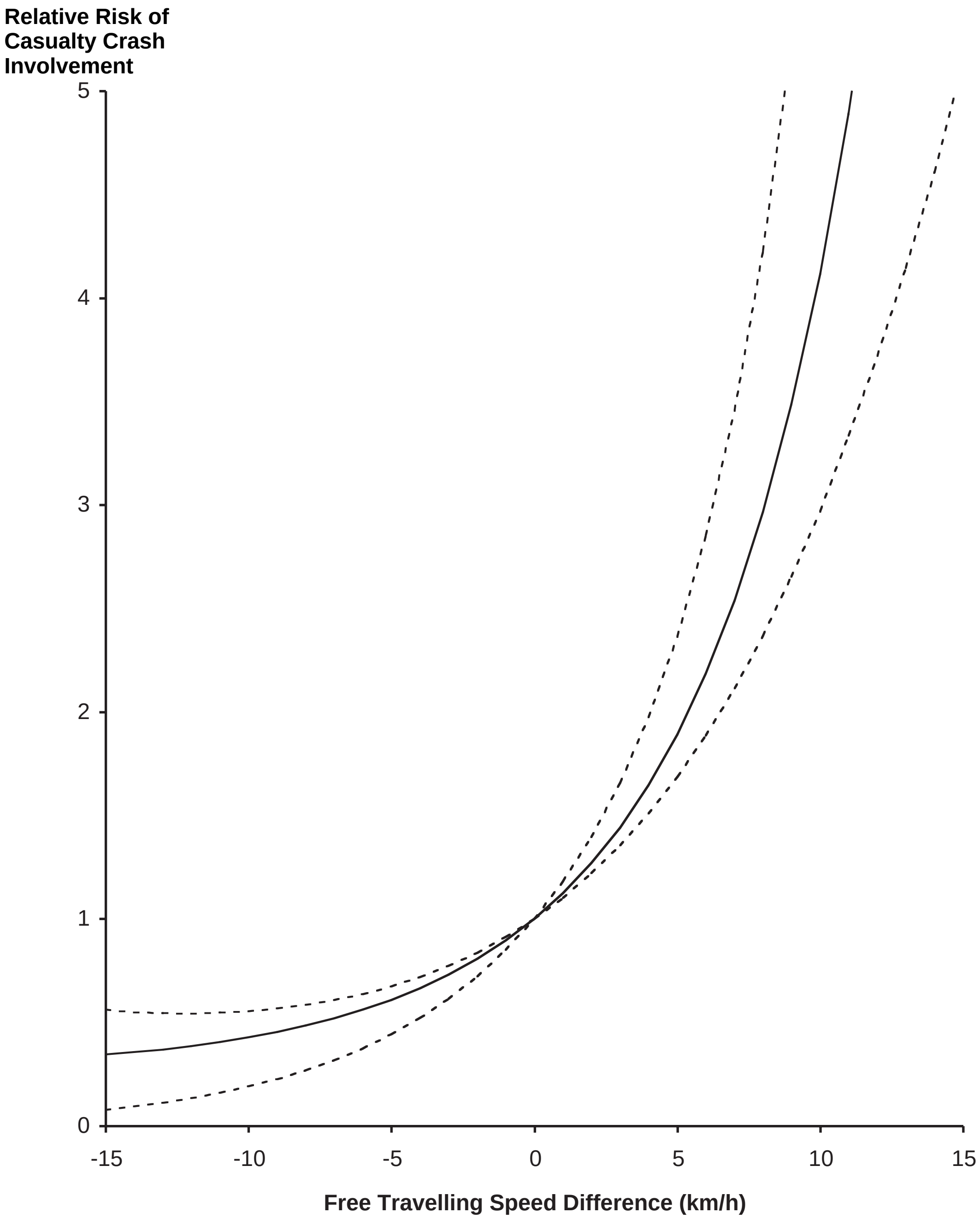


Figure 2.4
Differences Between Case Vehicle Free Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed for a Given Crash Site Using a Fitted Logistic Regression Model of Speed Difference (Close Up View)



2.4 Comparing the Various Risk Curves

It is instructive to compare the three different methods of constructing the relative risk curve. While the absolute speed and speed difference curves are not strictly comparable, since they measure different things, there are some justifications for plotting them against one another: the range of average control speeds in the study was relatively small; and the average speed of all the controls was 58.8 km/h which is very close to 60 km/h. Figure 2.5 shows that the three methods give very similar curves that all have the same basic shape.

Figure 2.5
Comparing Various Models Relating Free Travelling Speed to the Relative Risk of Involvement in a Casualty Crash (Overview)

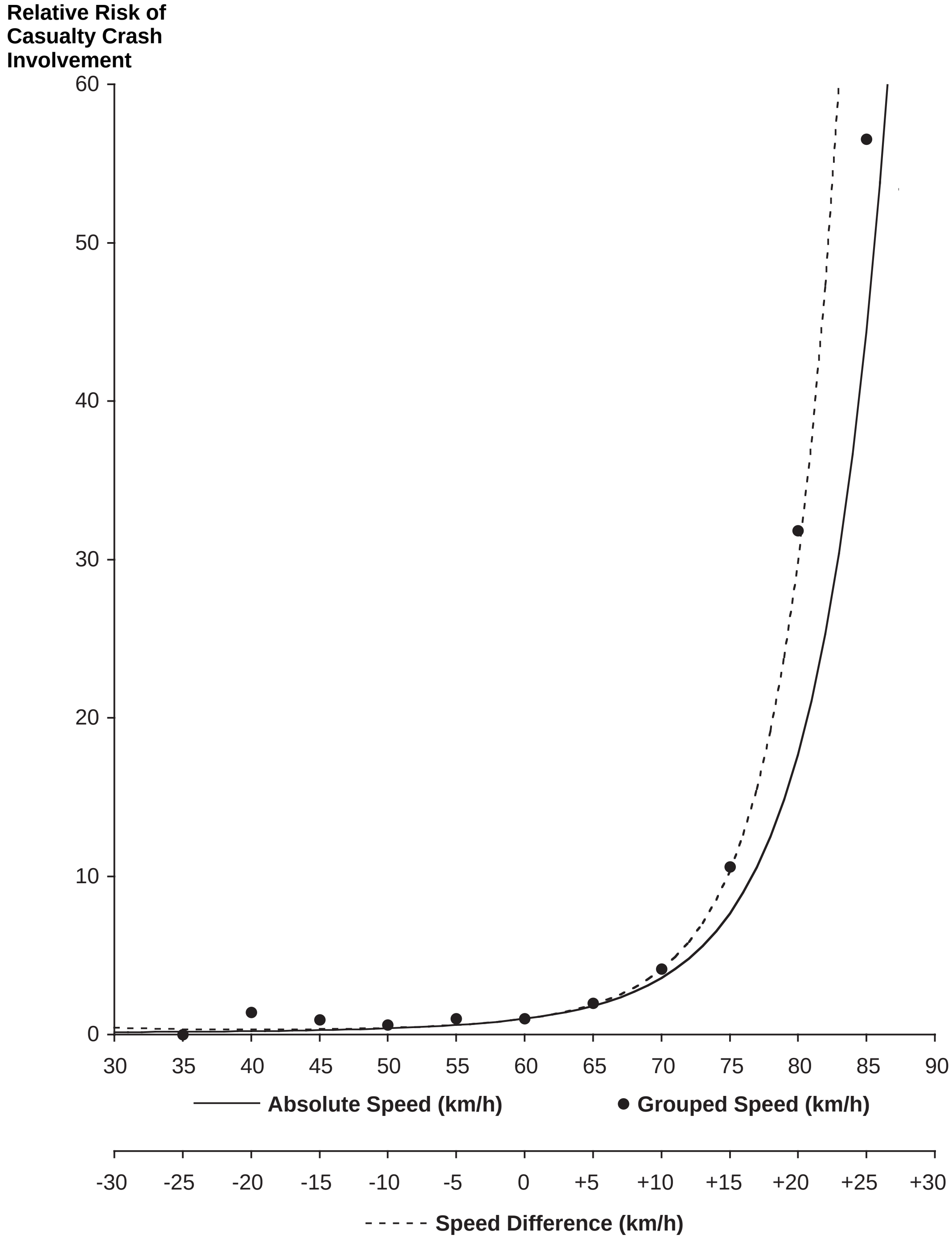
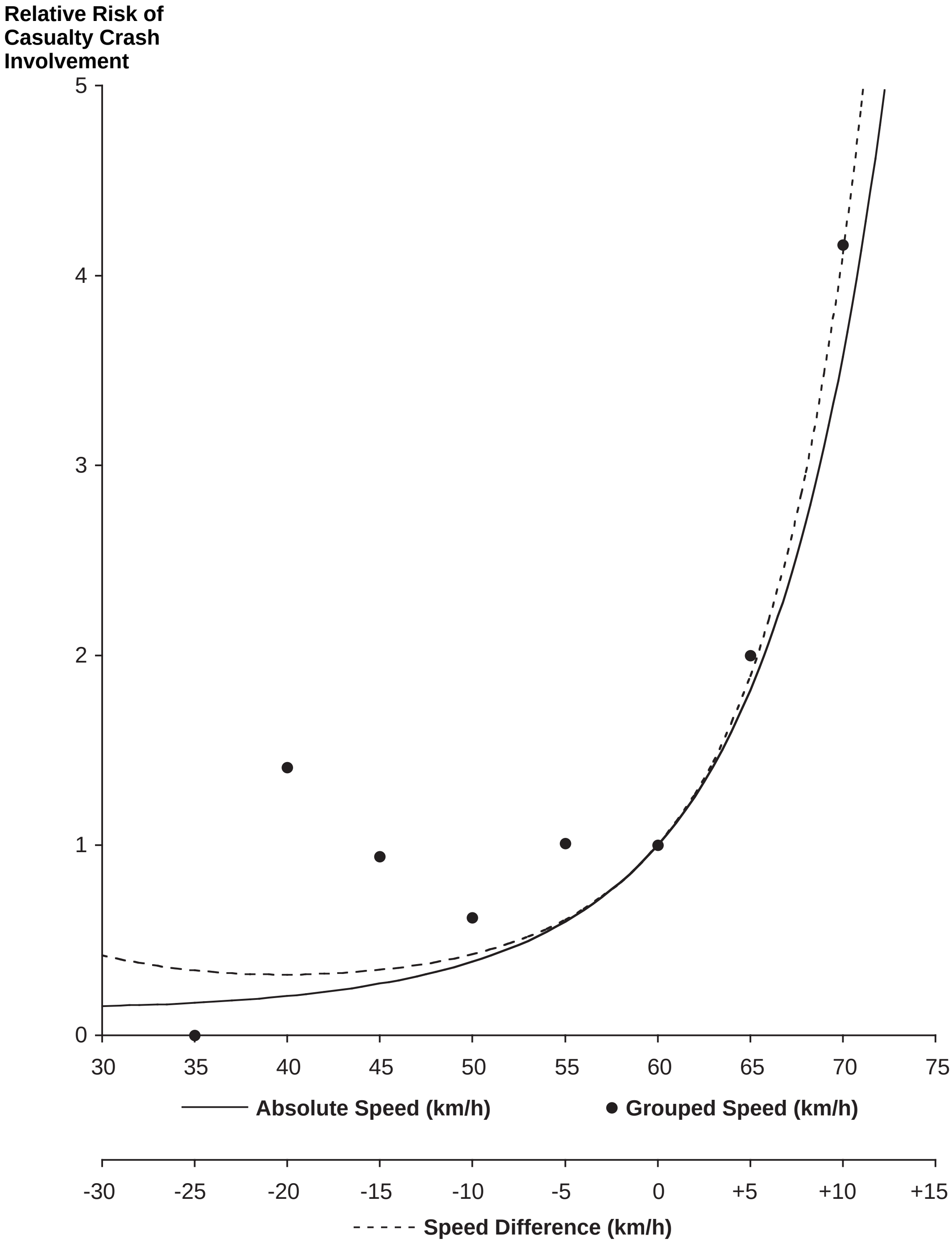


Figure 2.6 is a close up view of the lower part of the three risk curves. The low number of cases and controls at low speeds and the susceptibility of these cases to measurement error probably account for the apparent noise in the grouped speed points while both the absolute and speed difference curves are very similar.

Figure 2.6
Comparing Various Models Relating Free Travelling Speed to the Relative Risk of Involvement in a Casualty Crash (Close Up View)



It is clear from all three methods that small increases in speed above either 60 km/h or the average speed of other vehicles at a particular site are associated with large increases in the relative risk of being involved in a casualty crash. It is less clear at lower speeds or negative speed differences. However, given the physics of reaction time, stopping distance, impact energy and injury causation (as discussed in the original report) which, combined, suggest some kind of exponential relationship, we consider both the absolute and speed difference curves to be reasonable approximations of the real risk curve down to the point where the slope changes sign due to the mathematical artefact described above.

3. HYPOTHETICAL SCENARIOS

The relative risk curves defined in the preceding Section suggest important safety consequences for individuals in their choice of free travelling speed. The following Sections attempt to estimate, based on the risk curves, the effect on casualty crashes as a whole of slowing down the entire population of vehicles in various hypothetical ways.

It should be noted that this involves going beyond the data collected in determining the risk curves and needs a number of assumptions to be made that cannot be substantiated directly.

3.1 Original Hypothetical Scenario Method

The main hypothetical scenarios conducted in the original report did not use the established risk curve. Instead, the hypothetical speed reductions were applied to the free travelling speeds of the case vehicles and the individual crash reconstructions were re-run using the lower speeds from the point where the driver first became aware that a crash was going to take place. The results were expressed primarily in terms of three factors: an estimated reduction in the number of crashes due solely to those crashes not happening; and, in those crashes that would still have occurred, the reduction in the change in velocity (delta V) and the crash energy experienced by the vehicle occupants (Table 3.1).

Table 3.1
Hypothetical Outcomes for Reduced Travelling Speeds (Original Method)

Hypothetical Situation	% Reduction in number of Crashes[1]	% Reduction in average Delta V [2]	% Reduction in average Crash Energy [2]
10 km/h speed reduction	41.5	25.5	38.7
5 km/h speed reduction	15.0	16.1	23.6
Limit 60 km/h with total compliance	28.6	11.8	21.7
Limit 50 km/h with compliance as at present	32.7	24.9	37.5
Limit 50 km/h on local streets only with compliance as at present	6.1	2.8	4.7

[1] Reductions due solely to the crash not happening under the scenario.
[2] Average reduction for persons injured in crashes that would still have happened under the scenario.

While this method has the advantage of relying on very few assumptions and treating each crash individually, it has a fundamental limitation. It can only estimate the number of crashes totally avoided at a hypothetical lower speed. Since there are no reliable data available on the probability of a casualty resulting from an impact at a given change in velocity or crash energy, we could not determine how many of the crashes that would still have happened would have been reduced from casualty crashes to non-casualty crashes under the hypothetical scenarios.

However, these results are useful in setting a lower bound for the expected reductions using a method quite different from that used in the following Sections.

Note that the “limit 50 km/h with compliance at present” hypothetical scenario in Table 3.1 assumed that all drivers exceeding the 60 km/h speed limit would exceed a 50 km/h speed limit by the same amount and that all drivers travelling between 50 and 60 km/h under a 60 km/h speed limit would travel at 50 km/h under a 50 km/h speed limit. This is slightly different to the assumptions made in the following Sections.

3.2 Risk Curve Based Hypothetical Scenario Assumptions

The first assumption that needs to be made, when using the risk curves to estimate hypothetical reductions in casualty crash frequency, is that an individual driver who reduces their free travelling speed will also reduce their risk of being involved in a casualty crash according to the relative risks determined in Section 2. Those relative risks technically only define the association between free travelling speed and risk of casualty crash involvement.

For example we have estimated that the group of drivers travelling at 65 km/h have approximately double the risk of being involved in a casualty crash as the group travelling at 60 km/h. It could, in theory, be the case that drivers who choose to travel at 65 km/h may also be more likely to be distracted or drive recklessly or would have slower reaction times. In this scenario, lowering the speeds without changing this behaviour would not lower the casualty crash risk for that group by as much as the risk curve suggests. While we concede that such an effect is possible, we have no direct data to evaluate its size or even its direction (slower reaction times may be associated with slower drivers leading to an underestimation of the steepness of the real risk curve). We therefore assume that when individuals lower their speeds, their risk of involvement in a casualty crash will reduce according to the risk curves defined in Section 2.

There is some indirect justification for this approach in that the risks for higher speeds are much greater than any found for other factors except alcohol use, which was eliminated from the study, and that the basic shape of the curve is to be expected from the physical properties of reaction time, stopping distance and impact energy, as discussed in the original report.

The second assumption is that the case speeds collected for this study are representative of all free speed casualty crashes and that the speeds of the controls are representative of all free traffic speeds at the locations of all free speed casualty crashes. Since the original study was not designed to collect a truly representative sample of crashes, we cannot positively justify this assumption. However, as discussed in the original report, we have no evidence to suggest that the free speeds collected are biased compared to all free speed crashes and crash locations apart from this sample of crashes representing slightly more serious crashes. We therefore assume here that both case and control speeds are representative.

Once we accept the above assumptions, we have a method for calculating a reduced risk of being involved in a free speed casualty crash when hypothetically lowering the travelling speed of an individual vehicle. However, when applying speed reductions to the whole population of vehicles, a number of other assumptions must be made.

While lowering the speeds of all vehicles can be expected to reduce the risk according to the risk curve for single vehicle crashes, it is more complicated for multiple vehicle crashes and in particular for those that involve a vehicle accelerating across the path of a free speed vehicle travelling much faster than the speed limit. In this latter case, the driver of the crossing vehicle must make a judgement about the acceptable time gap for making the crossing. This judgment is partly based on that driver's previous experience with the "usual" speeds of other approaching vehicles in that situation (the driver's expectancies). Under a hypothetical uniform speed reduction scenario, an approaching vehicle that was originally travelling 20 km/h faster than the average speed of the rest of the traffic will still be travelling 20 km/h faster than the average speed of the rest of the traffic, if all traffic speed is hypothetically lowered by the same amount.

However, even in this case, the lower absolute speed of the approaching vehicle can be expected to lower the risk of a casualty crash resulting since: speed estimates are easier to make if the approaching vehicle is travelling at a lower speed; the approaching vehicle will be closer when the decision to cross its path is made (and it is easier to judge the speed of closer objects); the energy of an impact will be much less at a lower speed (since energy is proportional to speed squared); if braking of the approaching vehicle occurs much more energy will be lost before the impact occurs at the lower speed.

We assume here that the effect of driver expectancies on the relative risk of involvement in a casualty crash is much less than the effect of absolute speed and, therefore, that the relative risk curves can be used to estimate the reduction in the risk of casualty crash involvement for individual vehicles even when reducing the speed of all vehicles.

For these same reasons, we also assume that we can use the mean speed of the controls in the speed difference relative risk curve as an absolute reference point that does not change when changing the speeds of all vehicles.

The combined effect of these assumptions is that the hypothetical reductions calculated below are probably slightly optimistic although it is also possible that they err on the side of being conservative. The study was not set up specifically to conduct this analysis and other independent data do not exist to verify the assumptions made. However, we do consider it to be a useful exercise using the data that is available to obtain best estimates of the likely effects of the following scenarios.

3.3 Risk Curve Based Hypothetical Scenario Method

Each of the 148 original free speed casualty crashes was classified into one of 4 categories. The method for calculating the probability of a casualty crash occurring under the hypothetical scenario given that a casualty crash happened in actuality for each of the categories is given below.

Category 1 (22 crashes):
In a free travelling speed single vehicle crash, the probability of that crash happening under the hypothetical scenario was calculated as the relative risk associated with the hypothetical speed divided by the relative risk associated with the actual speed.

Category 2 (121 crashes):
In a two vehicle crash where only one vehicle was travelling at a free speed, the probability of that crash happening under the hypothetical scenario was calculated as the relative risk associated with the free travelling speed vehicle's hypothetical speed divided by the relative risk associated with its actual speed.

Category 3 (3 crashes):
In a two vehicle crash where both the vehicles were travelling at a free speed but we were only able to estimate the travelling speed of one of them, the probability of that vehicle crashing under the hypothetical scenario was calculated as the relative risk associated with its hypothetical speed divided by the relative risk associated with its actual speed. This probability was then squared to give the probability of the crash happening under the hypothetical scenario.

Category 4 (2 crashes):
In a two vehicle crash where both the vehicles were travelling at a free speed and both travelling speeds were estimated, the probability of each of the vehicles crashing under the hypothetical scenario was calculated as the relative risk associated with the hypothetical speed divided by the relative risk associated with each vehicle's actual speed. The two probabilities of crashing for both vehicles were than multiplied together to give the probability of that crash happening under the hypothetical scenario.

After applying the calculations above to all 148 crashes, the expected number of crashes was summed to give a total expected number of crashes under the scenario. The percentage reduction in free speed casualty crashes expected under the hypothetical scenario was then calculated.

3.4 Uniform Speed Reduction Hypothetical Scenarios

This Section aims to estimate the reduction in free speed casualty crashes that would be expected to result from specified speed reductions by all of the case vehicles as defined in the previous Section.

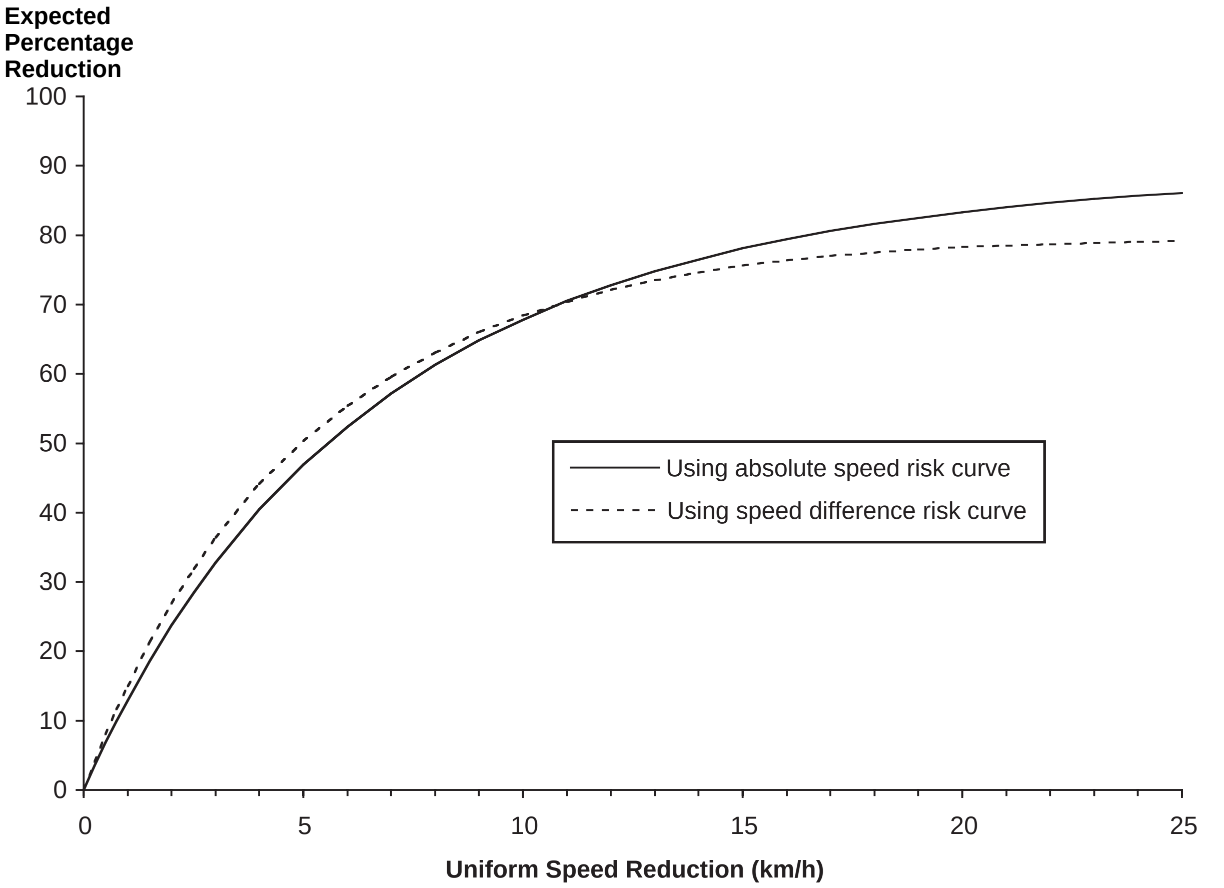
Both the absolute speed and speed difference relative risk curves are used. For the reasons noted in Sections 2.2 and 2.3, these curves are assumed to be a horizontal line below 26 km/h for the absolute speed curve and below -20 km/h for the speed difference curve.

The expected reductions in free speed casualty crashes from various uniform reductions in free travelling speeds are shown in Table 3.2 and graphically in Figure 3.1. There appear to be large potential benefits from a uniform lowering of speeds with the majority of the benefit arriving after reductions of less than 5 km/h. The reductions do not tend to 100 per cent due to the lower relative risk estimates being non-zero.

Table 3.2
Expected Percentage Reductions in Free Speed Casualty Crashes from Hypothetical Uniform Reductions in Free Travelling Speeds

Uniform Speed Reduction (km/h)	Estimated Percentage Reduction in Free Speed Casualty Crashes	
	Using Absolute Speed Risk Curve	Using Speed Difference Risk Curve
0.25	3.5	4.1
0.50	6.8	8.0
0.75	9.9	11.6
1	12.9	15.0
1.5	18.6	21.3
2	23.7	26.9
2.5	28.4	31.9
3	32.8	36.4
4	40.4	44.1
5	46.9	50.3
6	52.4	55.4
7	57.2	59.6
8	61.3	63.1
9	64.8	66.0
10	67.8	68.4
11	70.5	70.4
12	72.8	72.1
13	74.8	73.5
14	76.5	74.6
15	78.1	75.6
16	79.4	76.4
17	80.6	77.0
18	81.6	77.5
19	82.5	77.9
20	83.3	78.3
21	84.0	78.5
22	84.7	78.7
23	85.2	78.9
24	85.7	79.0
25	86.1	79.1

Figure 3.1
Expected Percentage Reductions in Free Speed Casualty Crashes from Hypothetical Uniform Reductions in Free Travelling Speeds



In order test the sensitivity of the analyses to the speed or speed difference below which the risk is held to a constant value (the "cutoff" speed or speed difference), the data were reanalysed using different lower cutoff points as seen in Tables 3.3 and 3.4. The cutoff point actually makes very little difference until it reaches 55 km/h or a difference of -5 km/h. Even if the assumption were to be made that there is no risk benefit to travelling slower than 60 km/h or slower than the mean traffic speed, there would be only a marginal decrease in the expected reduction in free speed casualty crashes. This is encouraging as it shows the results are largely unaffected by the uncertainties of the risk curve below these cutoff points.

Table 3.3
Expected Percentage Reductions in Free Speed Casualty Crashes from Hypothetical Uniform Reductions in Free Travelling Speeds with Varying Lower Speed Cutoffs Using the Absolute Speed Risk Curve

Lower Cutoff Speed (km/h)	Estimated Percentage Reduction in Free Speed Casualty Crashes for the Given Uniform Speed Reduction		
	1 km/h	5 km/h	10 km/h
none	12.9	46.9	67.8
26	12.9	46.9	67.8
30	12.9	46.9	67.8
35	12.9	46.9	67.7
40	12.9	46.8	67.3
45	12.8	46.3	66.0
50	12.6	44.9	62.4
55	11.9	40.6	54.1
60	9.9	32.7	41.3

Table 3.4
Expected Percentage Reductions in Free Speed Casualty Crashes from Hypothetical Uniform Reductions in Free Travelling Speeds with Varying Lower Speed Difference Cutoffs Using the Speed Difference Risk Curve

Lower Cutoff Speed Difference (km/h)	Estimated Percentage Reduction in Free Speed Casualty Crashes for the Given Uniform Speed Reduction		
	1 km/h	**5 km/h**	**10 km/h**
none	15.0	50.2	68.0
-20	15.0	50.3	68.4
-15	15.0	50.3	68.1
-10	14.9	49.4	65.8
-5	14.4	46.2	59.2
0	12.7	38.4	47.5

3.5 Speed Limit Compliance Based Hypothetical Scenarios

Given the assumptions we have made, we can make an estimate of the proportion of free speed crashes that can be attributed to illegal speeding (speeds above 60 km/h). By this we mean the expected proportion of crashes that would not have occurred had none of the free travelling speed case vehicles been exceeding the speed limit (but rather had been travelling at 60 km/h).

Table 3.5 shows that an estimated 44 per cent of the free speed casualty crashes can be attributed to illegal speeding indicating that illegal speed is a very significant issue in such crashes. Table 3.5 also examines various levels of illegal speeding for their individual contribution to the frequency of free speed casualty crashes. While speed is certainly more of a relevant risk factor for high speeds, the greater number of drivers exceeding the speed limit by a small amount means that drivers travelling at speeds from 61 to 75 km/h account for 60 per cent of the crashes that are attributable to illegal speeding.

Table 3.5
Expected Percentage Reductions in Free Speed Casualty Crashes from Hypothetical Elimination of Speeding in Selected Speed Groups

Travelling Speed Group (km/h)	Estimated Percentage Reduction in Free Speed Casualty Crashes when Eliminating Speeding in Group	
	Using Absolute Speed Risk Curve	**Using Speed Difference Risk Curve**
61 - 65	6.8	7.4
66 - 70	11.2	11.7
71 - 75	8.2	8.6
76 - 80	5.0	5.1
81 - 85	5.2	5.3
86 - 90	2.7	2.7
91 - 95	2.7	2.7
96 - 100	0.7	0.7
101+	2.7	2.7
Total	**44.3**	**45.9**

Note: individual percentages do not sum exactly to 44.3 due to the calculation method for multiple free speed vehicle crashes

3.6 Lowering the General Urban Speed Limit Hypothetical Scenario

When attempting to estimate the effect of lowering speed limits on the free speed casualty crash rate, additional assumptions need to be made.

The distribution of the speeds of the controls at crash sites collected for the original study shows a remarkably normal (in the statistical sense) curve centred around the 60 km/h speed limit. Since there is presumably nothing inherently special about 60 km/h we would expect as a first approximation that, in the long term with sufficient enforcement, the whole speed distribution would move down by the difference between the old and new speed limits. While the distribution would probably also have a lower variance, we are not sure by how much and assume here that it would be the same. We would therefore expect to observe free speed casualty crash reductions around the percentage levels shown in Table 3.2 for a given reduction in the general urban speed limit.

One exception to the above assumption may be those vehicles travelling "very fast". In these cases, the choice of free travelling speed will more likely be based on vehicle or road layout limitations than on what the speed limit is, since these drivers are clearly knowingly breaking the speed limit laws. Since it is not clear at what speed this effect becomes significant, we have considered a range of such speeds for the hypothetical scenario of lowering the urban area speed limit from 60 km/h to 50 km/h and estimating free speed casualty crash reductions in the long term with sufficient enforcement.

The "high cutoff" speed is defined here as the point where we assume that vehicles travelling at this speed or higher will not reduce their speed under this hypothetical scenario. The expected reductions are shown in Table 3.6.

Table 3.6
Expected Percentage Reductions in Free Speed Casualty Crashes from Hypothetical Lowering of the Speed Limit from 60 km/h to 50 km/h Assuming Various High Cutoff Speeds

High Cutoff Speed (km/h)	Estimated Percentage Reduction in Free Speed Casualty Crashes	
	Using Absolute Speed Risk Curve	Using Speed Difference Risk Curve
none	67.8	68.4
100	65.2	65.8
95	63.5	63.9
90	61.1	61.4
85	58.9	58.9
80	55.3	55.0
75	50.6	50.0
70	43.1	42.0
65	26.9	25.5

When estimating the effect of lowering the 60 km/h speed limit to 50 km/h only on crashes on local streets we found that the estimated reduction in free speed casualty crashes, assuming a 75 km/h high speed cutoff, was almost the same as for all roads using the speed difference curve (50.8% and 50.0% respectively). There was a greater difference using the absolute speed risk curve (43.8% in local streets, 50.6% on all roads). However, when considering the reductions in local street free speed casualty crashes in the context of all the free speed casualty crashes, lowering local street speed limits would only reduce all free speed casualty crashes by 6.2 per cent (using the absolute speed risk curve) or by 7.2 per cent (using the speed difference risk curve). This is primarily due to the much greater incidence of free speed crashes on main roads compared to local streets.

We also attempted to estimate the likely effect of lowering the urban area speed limit from 60 km/h to 50 km/h based on a speed fine avoidance method as detailed in Table 3.7.

Table 3.7
Assumed Speed Fine Avoidance Effects on Free Travelling Speeds
When Lowering the Urban Area Speed limit from 60 km/h to 50 km/h

Current Speed (km/h)	Speed Under Hypothetical 50 km/h Limit
≤ 50	No change - these drivers are already under the 50 limit and so have no immediate motivation to slow down
51 - 60	50 - these drivers are under or at the 60 limit and so are assumed to slow down to the new limit
61 - 69	10 km/h slower - these drivers feel comfortable exceeding the 60 limit by a small amount and so are assumed to exceed the new limit by the same amount to remain inside the perceived police tolerance
70+	no change - these drivers are exceeding the 60 limit by the perceived police tolerance and so are assumed to be unaffected by a lower limit in the short term

When the hypothetical changes in free travelling speeds in Table 3.7 were modelled, it was found that free speed casualty crashes would be expected to fall by 37.7 per cent using the absolute speed risk curve and by 37.8 per cent using the speed difference risk curve.

The expected reductions in free speed casualty crashes on local streets were 29.5 per cent (using the absolute speed risk curve) and 34.7 per cent (using the speed difference risk curve). In the context of all free speed casualty crashes, these percentages were 4.2 and 4.9, again due to the much greater incidence of free speed crashes on main roads compared to local streets.

3.7 Extrapolating to Casualty Crashes in General

All of the previous hypothetical scenarios deal only with expected reductions in those casualty crashes in 60 km/h speed zones (without advisory speed signs) in the Adelaide metropolitan area that involve at least one car or car derivative travelling at a free speed.

In order to extrapolate these reductions to all Adelaide metropolitan area casualty crashes, further assumptions need to be made.

Lacking any evidence to the contrary we assume the vehicles other that cars or car derivatives have the same free speed distribution and free speed risk curves as determined here.

We ignore sections of road with advisory speed signs since there are very few in the Adelaide metropolitan area.

We assume that 56 per cent of metropolitan casualty crashes in 60 km/h speed zones involve at least one vehicle with a free travelling speed and that the remaining 44 per cent will not be affected by any hypothetical reductions in the free travelling speeds of vehicles in general. These percentages are based primarily on data collected for the original study on the reasons for exclusion of cases not further investigated. However, that data was not collected with this aim in mind and so it can only provide a rough estimate. Some independent evidence is available where it was found that between 25 and 70 per cent of vehicles on various Adelaide roads were travelling with at least a 4 second headway (Dyson, personal communication, 2001). In a similar rural study of speed and crash risk, it was found that over 80 per cent of casualty crashes involved at least one free speed vehicle, however, the corresponding figure for metropolitan crashes is probably lower due to the greater volume of traffic in a metropolitan area.

There may be some effect whereby the hypothetical lowering of free speeds could also slow down non-free speed vehicles, such as vehicles that were accelerating up to speed when they crashed. In this case, it is possible that a general lowering of free speeds would also have an effect on their speeds and their resultant crash risk. Due to the lack of data on these possible effects, we assume no beneficial effects of hypothetical speed reductions on non-free speed crashes.

We also assume that the proportion of crashes that involve a free speed vehicle will not alter under any of the hypothetical scenarios.

When considering hypothetical reductions in Adelaide metropolitan casualty crashes as a whole we also need to take into account those crashes happening on roads zoned higher or lower than 60 km/h that would presumably not be affected by lowering speeds of vehicles on 60 km/h roads. In Adelaide, at the time of the study, 84 per cent of all casualty crashes occurred on roads zoned 60 km/h (McColl 2000).

Given these assumptions, the free speed casualty crashes analysed in the previous Sections represent 56 per cent of Adelaide metropolitan casualty crashes in 60 km/h speed zones and 47 per cent of all Adelaide metropolitan casualty crashes. The estimated reductions in free speed casualty crashes should therefore be multiplied by 0.56 to get the expected effect on Adelaide metropolitan casualty crashes in 60 km/h speed zones and by 0.47 to get the expected effect on Adelaide metropolitan casualty crashes in general. This was done for what we consider to be the most reasonable estimate for each of the major hypothetical scenarios (see Table 3.8). The absolute risk curve estimates are used here as they tend to be slightly more conservative than the very similar speed difference risk curve estimates.

Table 3.8
Expected Percentage Reductions in Free Speed Casualty Crashes and Casualty Crashes in General Under Various Hypothetical Scenarios

Hypothetical Scenario Changing Speeds of Free Speed Vehicles in 60 km/h speed zones	Expected Percentage Reduction in Free Speed Casualty Crashes	Expected Percentage Reduction in 60 km/h zone Casualty Crashes	Expected Percentage Reduction in all Metropolitan Casualty Crashes
No vehicles exceeding the speed limit	44.3	24.8	20.8
Uniform reduction of 1 km/h	12.9	7.2	6.1
Uniform reduction of 2 km/h	23.7	13.3	11.1
Uniform reduction of 5 km/h	46.9	26.3	22.0
Uniform reduction of 10 km/h	67.8	38.0	31.9
Lowering 60 limit to 50*	37.7	21.1	17.7
Lowering 60 limit to 50**	50.6	28.3	23.8
Lowering 60 limit to 50 only on local streets*	4.2	2.4	2.0
Lowering 60 limit to 50 only on local streets**	6.2	3.5	2.9

* Assuming drivers maintain their speed fine avoidance behaviour
** Assuming the speed distribution of drivers below 75 km/h moves down by 10 km/h

It should be noted that the estimated effects on casualty crashes of the hypothetical scenarios are dependent on the actual distribution of travelling speeds in the Adelaide metropolitan area. Consequently, the effects in other metropolitan areas which have a 60 km/h speed limit may differ from those estimated here.

4. DISCUSSION

4.1 Main Findings

This study has established mathematical curves that define the relationship between free travelling speed and the relative risk of involvement in a casualty crash, for sober drivers in 60 km/h speed zones in the Adelaide metropolitan area. The choice of absolute travelling speeds or speed differences as the basis for the relative risk curve was found to have little effect.

The absolute speed curve produces a good fit to the observed data for speeds between 60 and 80 km/h. The paucity of data outside this range means that we cannot be sure if the curve applies there. However, lacking other data, we have assumed that it can be used for speeds down to 26 km/h and for speeds above 80 km/h when conducting our hypothetical analyses. There is some indirect justification for this since the curve models the available data and its general shape (exponentiated second order polynomial) is not unexpected given the physics of road crashes and injury biomechanics.

Such considerations also indicate that speed is a risk factor in and of itself. That is, the observed differences in crash risk between vehicles travelling at different speeds is primarily due to the actual travelling speeds and not other factors such as the type of drivers who choose to travel at different speeds or with the variance in travelling speeds.

This and a number of other assumptions have allowed us to estimate the expected reduction in casualty crashes due to a hypothetical reduction in vehicle speeds. We have estimated that illegal speeding in Adelaide 60 km/h zones accounts for around 25 per cent of all casualty crashes in those zones. That is, if no vehicles exceeded 60 km/h in Adelaide 60 km/h speed zones, we would expect a 25 per cent reduction in casualty crashes in those zones.

Moreover, nearly 60 per cent of the benefit of eliminating speeding could be achieved by just eliminating speeding among those travelling between 61 and 75 km/h. This indicates that it is not just very high levels of speeding that significantly contribute to the number of casualty crashes.

Examination of the estimated hypothetical effects of slowing all vehicles down by the same amount indicates that even very small reductions in travelling speeds (such as 1 km/h or less) can be expected to have a meaningful effect on casualty crash numbers.

Estimates were also made for a hypothetical reduction in the general urban area speed limit from 60 km/h down to 50 km/h using two sets of assumptions. Casualty crashes in these speed zones would be expected to drop by around 21 per cent using a speed fine avoidance method and by 28 per cent using a speed distribution movement method. While similar reductions on local streets would be expected from a reduction in the speed limit to 50 km/h, if the speed limit reduction was limited to local streets, the relatively small proportion of casualty crashes on local streets means that the effect on all casualty crashes in the metropolitan area would be much smaller than a change in the general urban area speed limit.

4.2 Validity of Findings

The method used for obtaining the absolute and speed difference relative risk curves relied on very few assumptions and is primarily based on directly observed data. Hence, we have great confidence in the curves between 60 and 80 km/h absolute speeds and 0 and +20 km/h speed differences within the calculated confidence intervals.

Outside of these speed ranges, the confidence intervals do not adequately indicate the level of uncertainty due to the regression method used and the paucity of data available there. However, the various hypothetical situation analyses were found to be relatively insensitive to the detailed shape of the risk curve outside the 60 to 80 km/h and the 0 to +20 km/h ranges.

While we feel that the other assumptions that were made to allow casualty crash reductions under hypothetical scenarios to be calculated were reasonable, we have no direct evidence for many of them. That is why they are listed as assumptions and they are open to question. In light of this, the hypothetical estimates should be considered as reasoned approximations of the probable effects of the scenarios and not as hard facts. This is especially true when extrapolating the results to casualty crashes in general as we had to use some approximations of unknown ratios.

However, even given these uncertainties, it is clear from all levels of the analysis that very small reductions in travelling speed have the potential to greatly reduce the incidence of casualty crashes.

ACKNOWLEDGMENTS

The help of the following people and organisations is greatly appreciated:

South Australia Police, for the provision of information on crashes.

The South Australian Ambulance Service for notification of crashes.

Brian G. and Raymond R. McHenry, McHenry Software, Inc. Carey, North Carolina, USA for assistance with computer-aided crash reconstruction.

Lisa Wundersitz for the drafting of site diagrams.

Those people who worked on the collection of data for the original study: Giulio Ponte, Roland Earl, Roger Galbraith, Robert Baird and Matthew Baldock.

The original study was funded by the Federal Office of Road Safety (now the Australian Transport Safety Bureau) of the Commonwealth Department of Transport and Regional Services and supported by the secondment of an engineer from the South Australian Department of Transport (now Transport SA).

The Road Accident Research Unit was supported by a Research Unit Grant from the National Health and Medical Research Council at the time of the original study.

REFERENCES

Kloeden CN, McLean AJ, Moore VM, Ponte G. 1997. Travelling speed and the risk of crash involvement. Volume 1 - Findings. CR 172. Federal Office of Road Safety. Canberra, Australia.

Kloeden CN, Ponte G, McLean AJ. 2001. Travelling Speed and the Risk of Crash Involvement on Rural Roads. CR 204. Australian Transport Safety Bureau. Canberra, Australia.

McColl, RA. 2000. Estimated casualty crash reductions from reduced travelling speeds. In Road Safety Research, Policing and Education Conference Proceedings, 26-28 November 2000, Brisbane, Australia. Brisbane: Carrs-Q, pp. 259-264.

APPENDIX A - Speed data used in the analyses

The following Table A.1 gives all the data used in the analyses using the following set of definitions:

Case: Crash case number
Speed: Estimated case vehicle speed
C1-C4: The four control speeds measured at that site
Ave: Average of the four control speeds
Road: Type of road where the crash occurred
Type: Type of free speed crash
F = one free speed vehicle
FU = two free speed vehicles but only one speed estimated
FF = two free speed vehicles and both speeds estimated

Table A.1
Data used in the Analysis as Defined Above

Case	Speed	C1	C2	C3	C4	Ave	Road	Type
001	67	45	48	57	55	51.3	main	F
004	66	51	52	63	57	55.8	main	F
009	99	67	64	57	50	59.5	local	F
015	58	52	50	54	60	54.0	main	F
021	61	54	63	53	48	54.5	local	F
025	71	62	65	62	70	64.8	main	F
026	66	81	67	82	67	74.3	main	F
027	67	84	67	70	72	73.3	main	F
029	66	53	65	61	57	59.0	main	F
031	72	69	60	62	60	62.8	main	F
035	78	62	66	76	63	66.8	main	F
036	66	57	62	62	55	59.0	main	F
037	68	54	54	39	54	50.3	local	F
038	61	72	56	59	59	61.5	main	F
040	61	60	54	63	56	58.3	main	F
041	66	61	60	60	61	60.5	main	F
042	60	60	51	60	59	57.5	main	F
044	54	56	67	62	67	63.0	main	F
045	45	52	55	45	48	50.0	main	F
047	64	60	69	61	61	62.8	main	F
048	87	63	65	62	59	62.3	main	F
050	67	67	57	63	66	63.3	main	F
057	59	57	61	57	59	58.5	local	F
058	65	46	50	53	54	50.8	main	F
059	65	66	61	59	36	55.5	main	F
060	63	61	53	74	52	60.0	main	F
062	68	57	58	51	59	56.3	main	F
063	58	57	58	51	59	56.3	main	F
064	79	65	63	55	54	59.3	main	F
066	70	62	58	58	60	59.5	main	F
068	68	55	62	53	70	60.0	local	F
074	55	65	68	58	60	62.8	main	F
076	54	47	53	59	59	54.5	main	F
077	86	61	70	58	69	64.5	local	F
079	68	54	61	61	60	59.0	main	F
080	53	63	55	59	63	60.0	main	F
082	72	58	65	54	58	58.8	main	F
083	95	63	62	54	69	62.0	main	F
084	92	59	51	53	55	54.5	main	F
085	68	64	51	60	51	56.5	main	F
088	66	63	60	69	60	63.0	main	F
089	62	75	64	68	54	65.3	main	F
090	83	55	59	55	62	57.8	main	F
091	67	48	49	55	47	49.8	main	F
092	60	56	56	67	60	59.8	main	F
093	78	68	64	61	43	59.0	main	F
094	95	58	61	66	60	61.3	local	F
095	83	60	61	61	64	61.5	main	F

098	63	68	50	65	64	61.8	main	F
099	63	67	68	63	56	63.5	main	F
100	67	59	61	64	65	62.3	main	F
101	50	60	46	44	53	50.8	main	F
102	64	58	66	59	61	61.0	main	F
103	70	47	58	46	54	51.3	main	F
106	90	61	65	60	64	62.5	main	F
108	51	55	59	54	60	57.0	main	F
109	63	55	62	43	49	52.3	local	F
110	65	62	45	72	53	58.0	main	F
111	120	60	61	66	59	61.5	local	F
112	69	63	68	65	64	65.0	main	F
113	59	54	59	55	65	58.3	main	F
115	64	54	47	46	53	50.0	local	F
119	57	56	64	62	57	59.8	main	F
120	59	64	58	62	65	62.3	main	F
121	53	61	55	61	44	55.3	main	F
122	67	67	70	58	67	65.5	main	F
123	61	52	53	60	56	55.3	main	F
124	60	56	51	60	55	55.5	main	F
125	57	57	58	61	64	60.0	main	F
127	54	57	57	63	56	58.3	main	F
128	59	65	64	59	61	62.3	main	F
129	65	57	66	59	64	61.5	main	F
130	60	60	71	60	68	64.8	main	F
132	81	59	63	61	64	61.8	main	F
133	64	59	67	54	63	60.8	main	F
135	62	57	51	49	65	55.5	main	F
136	60	53	62	55	58	57.0	main	F
140	38	55	62	62	61	60.0	main	F
141	58	72	71	55	53	62.8	main	F
142	60	61	57	57	60	58.8	main	F
143	58	49	50	64	48	52.8	local	F
144	61	61	65	65	50	60.3	main	F
145	63	58	64	54	50	56.5	main	F
146	62	56	61	62	57	59.0	main	F
147	75	63	65	59	66	63.3	local	F
148	58	59	51	53	62	56.3	main	F
149	73	57	52	63	56	57.0	main	F
150	103	55	64	58	62	59.8	main	F
153	60	67	58	59	63	61.8	main	F
154	68	60	57	67	56	60.0	main	F
155	65	66	53	59	47	56.3	main	F
156	71	63	57	64	60	61.0	main	F
158	55	63	59	64	47	58.3	local	F
159	58	61	59	58	55	58.3	main	F
160	43	60	56	53	71	60.0	main	F
161	56	54	63	61	51	57.3	main	F
162	70	59	61	61	61	60.5	main	F
165	75	50	59	55	64	57.0	main	F
166	58	63	56	60	59	59.5	main	F
168	80	62	58	60	64	61.0	main	F
170	90	65	67	61	64	64.3	main	F
171	74	63	48	54	56	55.3	local	F
172	75	74	56	54	61	61.3	main	F
178	85	66	48	56	61	57.8	main	F
179	78	54	55	48	66	55.8	main	F
180	65	56	48	61	64	57.3	main	F
181	45	61	55	61	54	57.8	main	F
182	57	63	61	70	61	63.8	main	F
183	74	72	67	63	59	65.3	local	F
184	56	51	56	53	64	56.0	main	F
185	65	46	57	57	54	53.5	local	F
186	63	58	61	67	57	60.8	main	F
187	69	51	52	48	59	52.5	main	F
188	91	57	56	47	57	54.3	main	F
189	61	42	58	58	44	50.5	main	F
190	84	52	67	54	59	58.0	main	F

191	47	59	51	64	52	56.5	main	F
192	54	44	47	47	42	45.0	local	F
193	50	73	58	62	46	59.8	main	F
194	54	47	47	50	50	48.5	main	F
195	147	65	58	60	67	62.5	main	F
196	85	60	70	62	49	60.3	local	F
197	73	42	35	42	63	45.5	local	F
198	71	63	62	71	60	64.0	main	F
200	53	64	57	70	60	62.8	main	F
201	57	58	34	45	35	43.0	local	F
203	56	54	52	60	57	55.8	main	F
204	73	57	64	63	60	61.0	main	F
205	65	61	52	65	56	58.5	main	F
207	57	50	56	58	61	56.3	main	F
208	72	50	52	46	47	48.8	local	F
209	77	59	52	68	68	61.8	main	F
210	78	57	62	56	65	60.0	main	F
211	82	56	57	64	58	58.8	main	F
212	68	62	61	57	64	61.0	main	F
213	136	59	62	62	60	60.8	main	F
214	57	60	59	65	56	60.0	main	F
215	66	65	56	60	53	58.5	main	F
216	52	58	58	50	56	55.5	main	F
218	50	54	56	51	50	52.8	main	F
219	66	62	57	63	60	60.5	main	F
069	65	60	63	74	62	64.8	main	FU
107	58	62	58	67	59	61.5	main	FU
114	63	47	58	61	63	57.3	main	FU
206	65	64	64	64	62	63.5	main	FU
055a	83	63	69	68	63	65.8	main	FF
055b	68	60	67	67	68	65.5	main	FF
078a	72	66	64	60	54	61.0	main	FF
078b	80	58	59	60	63	60.0	main	FF
151a	60	60	62	61	57	60.0	main	FF
151b	66	66	58	61	61	61.5	main	FF

APPENDIX B - Fitting an absolute speed risk curve using varying error levels in the case vehicle speeds

Modified logistic regression modelling was used to establish the shape of the casualty crash relative risk curve using the absolute speeds of vehicles (the raw data is presented in Appendix A).

One of the modifications involved allowing for any uncertainty in the estimation of the case vehicle speeds. While the control vehicle speeds were measured very accurately using a laser speed meter, the case vehicle speeds had to be estimated using reconstruction techniques that by their nature cannot give consistently precise results.

Here we consider 4 models that allowed for this uncertainty by assuming a standard error for the case vehicle speeds of 0, 2.5, 5 and 7.5 km/h. The model chosen for the main report used a standard error of 5 km/h which equates to stating that 70 per cent of our estimated case vehicle travelling speeds were within 5 km/h of the actual travelling speed. The others are presented here for reference. See Section 2.2 of the Report for more details on interpreting these Tables.

Table B.1
Vehicle Free Travelling Speed and the
Relative Risk of Involvement in a Casualty Crash
Using a Standard Error for Case Vehicle Speeds of 0 km/h

Speed (km/h)	Relative Risk	Lower Limit	Upper Limit
45	0.66	0.31	1.19
50	0.62	0.41	0.86
55	0.72	0.60	0.82
60	**1**	**1**	**1**
65	1.68	1.48	1.99
70	3.43	2.60	5.07
75	8.45	5.16	17.22
80	25.19	11.52	79.13
85	90.82	28.11	483.36
90	396.08	75.34	4008.31

$$\textbf{Relative risk (V)} = e^{(8.592363214 - 8.592363214V + 8.592363214V^2)}$$

Table B.2
Vehicle Free Travelling Speed and the
Relative Risk of Involvement in a Casualty Crash
Using a Standard Error for Case Vehicle Speeds of 2.5 km/h

Speed (km/h)	Relative Risk	Lower Limit	Upper Limit
45	0.54	0.26	0.99
50	0.56	0.37	0.78
55	0.69	0.58	0.79
60	**1**	**1**	**1**
65	1.71	1.51	2.02
70	3.45	2.61	5.09
75	8.21	5.02	16.73
80	23.11	10.57	72.60
85	76.82	23.78	408.88
90	301.64	57.37	3052.57

$$\textbf{Relative risk (V)} = e^{(6.560246386 - 0.309100819V + 0.00332939V^2)}$$

Table B.3
Vehicle Free Travelling Speed and the
Relative Risk of Involvement in a Casualty Crash
Using a Standard Error for Case Vehicle Speeds of 5 km/h

Speed (km/h)	Relative Risk	Lower Limit	Upper Limit
45	0.27	0.13	0.49
50	0.39	0.26	0.54
55	0.60	0.50	0.69
60	**1**	**1**	**1**
65	1.82	1.60	2.15
70	3.57	2.70	5.28
75	7.63	4.66	15.55
80	17.66	8.08	55.49
85	44.36	13.73	236.10
90	120.82	22.98	1222.70

$$\textbf{Relative risk (V)} = e^{(-0.822957835 - 0.083680149V + 0.001623269V^2)}$$

Table B.4
Vehicle Free Travelling Speed and the
Relative Risk of Involvement in a Casualty Crash
Using a Standard Error for Case Vehicle Speeds of 7.5 km/h

Speed (km/h)	Relative Risk	Lower Limit	Upper Limit
45	0.07	0.03	0.12
50	0.17	0.12	0.24
55	0.43	0.36	0.50
60	**1**	**1**	**1**
65	2.14	1.89	2.53
70	4.25	3.22	6.28
75	7.83	4.78	15.96
80	13.39	6.13	42.08
85	21.26	6.58	113.16
90	31.32	5.96	316.99

$$\textbf{Relative risk (V)} = e^{(-14.949222376 + 0.338714562V - 0.001492681V^2)}$$

APPENDIX C - Fitting a speed difference risk curve using varying error levels in the case vehicle speeds

Modified logistic regression modelling of the difference in speed of the cases and controls from the average control speed at each site was used to establish the shape of the casualty crash relative risk curve using the raw data shown in Appendix A.

One of the modifications involved allowing for any uncertainty in the estimation of the case vehicle speeds. While the control vehicle speeds were measured very accurately using a laser speed meter, the case vehicle speeds had to be estimated using reconstruction techniques that by their nature cannot give consistently precise results.

Here we consider 4 models that allowed for this uncertainty by assuming a standard error for the case vehicle speeds of 0, 2.5, 5 and 7.5 km/h. The model chosen for the main report used a standard error of 5 km/h which equates to stating that 70 per cent of our estimated case vehicle travelling speeds were within 5 km/h of the actual travelling speed. The others are presented here for reference. See Section 2.3 of the Report for more details on interpreting these Tables.

Table C.1
Differences Between Case Vehicle Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed Using a Standard Error for Case Vehicle Speeds of 0 km/h

Speed Difference (km/h)	Relative Risk	Lower Limit	Upper Limit
-15	1.91	0.43	3.12
-10	1.07	0.47	1.39
-5	0.86	0.63	0.95
0	**1**	**1**	**1**
+5	1.68	1.50	2.10
+10	4.07	2.94	6.45
+15	14.25	7.10	30.99
+20	71.99	20.69	240.46
+25	525.14	70.65	2953.74
+30	5529.93	281.28	59363.48

Relative risk (D) = $e^{(0.0669597V + 0.0073435V^2)}$

Table C.2
Differences Between Case Vehicle Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed Using a Standard Error for Case Vehicle Speeds of 2.5 km/h

Speed Difference (km/h)	Relative Risk	Lower Limit	Upper Limit
-15	1.32	0.30	2.15
-10	0.88	0.39	1.14
-5	0.80	0.58	0.88
0	**1**	**1**	**1**
+5	1.71	1.53	2.14
+10	4.03	2.91	6.38
+15	12.96	6.46	28.20
+20	57.21	16.44	191.07
+25	346.00	46.55	1946.10
+30	2868.10	145.89	30788.90

Relative risk (D) = $e^{(0.0762415V + 0.0063046V^2)}$

Table C.3
Differences Between Case Vehicle Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed Using a Standard Error for Case Vehicle Speeds of 5 km/h

Speed Difference (km/h)	Relative Risk	Lower Limit	Upper Limit
-15	0.34	0.08	0.56
-10	0.43	0.19	0.55
-5	0.61	0.44	0.67
0	**1**	**1**	**1**
+5	1.89	1.69	2.36
+10	4.12	2.97	6.52
+15	10.32	5.14	22.44
+20	29.77	8.56	99.44
+25	98.90	13.31	556.27
+30	378.22	19.24	4060.15

Relative risk (D) = $e^{(0.1133374V + 0.0028171V^2)}$

Table C.4
Differences Between Case Vehicle Travelling Speed and Average Control Speed and the Risk of Involvement in a Casualty Crash Relative to Travelling at the Average Control Speed Using a Standard Error for Case Vehicle Speeds of 7.5 km/h

Speed Difference (km/h)	Relative Risk	Lower Limit	Upper Limit
-15	0.03	0.01	0.05
-10	0.11	0.05	0.15
-5	0.36	0.26	0.40
0	**1**	**1**	**1**
+5	2.47	2.20	3.09
+10	5.40	3.90	8.56
+15	10.47	5.22	22.77
+20	17.97	5.16	60.01
+25	27.32	3.68	153.67
+30	36.80	1.87	395.06

Relative risk (D) = $e^{(0.1929169V - 0.0024244V^2)}$