FINAL REPORT

R8_Effect of Improved Speed Compliance on Design Speed

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SUMMARY

The purpose of this project was to test if speed limit compliance has improved to the point where design speed could be lowered to match the speed limit, which may result in a reduction in road construction costs. The study reviewed the impacts of adopting a lower design speed on road design, safety, traffic operations and capacity, and on speed limit enforcement.

The study investigated operating speeds on different parts of the Queensland state road network. It was found that the speed compliance was not yet sufficient to recommend adoption of the speed limit as the design speed on any part of the network. A review of point-to-point enforcement evaluations did not produce clear conclusions which could lead to the adoption of reduced design speed under this enforcement regime.

An option of speed limit plus 5 km/h guidance for design speed was considered in detail. It was found that the consistency of speed limit compliance varied across the road network, whole-of-life cost benefits would be marginal, and there would be marginally negative safety and operational impacts.

The report recommends retaining the current approach to design speed selection until speed enforcement reduces operating speeds more consistently across the road network.

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ACKNOWLEDGEMENTS

The authors acknowledge input of Transport and Main Roads staff through provision of data and workshop feedback.

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1 INTRODUCTION

The Queensland Department of Transport and Main Roads engaged ARRB Group to investigate if speed limit compliance has improved to the point where design speed could be lowered to match the speed limit. The rationale was that a lower design speed may be translated into project construction cost savings.

The current road design methodology uses a design speed which is equal to or greater than the operating speed for the road section, or is equal to the speed limit plus 10 km/h. This report investigates the current design guidance and presents the findings of investigations of speed compliance across the Queensland gazetted road network. The investigations tested if there were any parts of the state road network and enforcement scenarios where the design speed could be based on the posted speed limit. The investigation also sought to estimate the extent of any applicable cost savings and impacts on safety in such cases.

The findings of this investigation will also inform the discussion on application of point-to-point speed enforcement in design context to obtain project construction costs.

2 METHODOLOGY

The objectives of the investigation were to:

- document the current design speed guidance
- find out if and what changes to design speed practice in Queensland should be considered
- define under which conditions the changes may be applicable
- what would be impact of the changes on road costs.

The following methodology was undertaken in order to deliver the project objectives.

2.1 Summary of Current Guidance

This part summarised the current design speed guidance in Queensland and in selected other jurisdictions. The task included a detailed review of the Department's *Road Planning and Design Manual (1st edition)*, Chapter 6: Speed Parameters (Department of Transport and Main Roads 2007), VicRoads technical note amendments to Austroads practice, and practitioner statements on the application of design speed policy (phone interviews).

2.2 Literature Review

The aim of this part was to provide background information by reviewing the key available research literature on the effects of:

- speeds, speed uniformity and speed limits on safety outcomes
- design speed and speed uniformity on highway capacity (e.g. issues such as merging, lane changes and arterial flow breakdowns)
- speed limit enforcement and its impacts on speed compliance, observed speeds and speed uniformity.

2.3 Data Analysis

This part consisted of data analysis of speed compliance with the aim of establishing how close the operating speeds are to speed limits on different types of Queensland roads, e.g. freeways and highways in rural and urban areas (subject to data availability).

This was achieved by sourcing recent speed survey and/or instrumented site data collected by the Department and carrying out statistical analysis of mean and operating speeds, including time trend analysis.

2.3.1 Data

The speed data by site, day and hour for the analysis was provided by the Department. The data included:

1. Site ID and location identifier.
2. Mean speed.
3. 85th percentile speed.
4. Compliance levels.
5. Posted speed limit.
6. Road environment (rural or urban).

7. Road standard: divided or undivided.
8. Traffic flow (number of vehicles per hour).

To better capture the differences in operating speeds, the data was classified by the posted speed limit, site location (i.e. rural or urban) and whether the road was divided or undivided. This is because speed profiles differ by speed limit and road environments. Furthermore, the sites were classified into three geographic regions, Metropolitan Brisbane (Metro Brisbane), South East Queensland (excluding Brisbane) and Regional Queensland. The metro Brisbane region included all sites in Brisbane (both urban and some urban fringe), whilst the South East Queensland region included both urban and rural roads. At the same time, Regional Queensland covered regional centres (urban) and the rural highways.

Table 2.1 shows site sample sizes grouped by speed limit, rural or urban environment, divided or undivided road as well as region. From Table 2.1, it is clear that some of the cells had very little data (i.e. number of sites). The limited number of sites meant the analysis outcomes for those road stereotypes were not considered a reliable measure of the operating speed profiles.

Table 2.1: Number of sites analysed for each road stereotype and region

Road stereotype	Metro Brisbane	South East Queensland[1]	Regional Queensland
Urban 60s	15 (divided)	34 (undivided)	26 (undivided)
Urban divided 80s	12	13	11
Urban divided 100s	5	12	N/A
Rural/urban undivided 80s[2]	11	72	N/A
Rural undivided 100s	N/A	60	60
Rural undivided 110s	N/A	N/A	45
Rural divided (100s and 110s)	N/A	11 (110s)	5 (100s)

1 Excludes Brisbane.
2 Urban fringe sites.

2.3.2 Statistical Analysis

The evaluation involved comparing 85th percentile speeds and mean speeds to the posted speed limit. Supplementary analysis also evaluated the mean speeds and levels of speed limit compliance for each road stereotype by region.

T-tests were conducted to determine how close the 85th percentile and mean speeds were to the posted speed limit (Equation Equation 1). The analyses were conducted using IBM's Statistical Package for Social Sciences (SPSS) version 21.

$$t = \frac{\bar{x} - \mu}{s\sqrt{n}} \qquad 1$$

where

t	=	t statistic
$\bar{x}$	=	85th percentile speeds
μ	=	posted speed limit
s	=	standard deviation
n	=	sample size

Given the data in this analysis was aggregated hourly, the evaluation was also based on hourly averages. Only free-flowing speed data with four-second headways was analysed in this study. Also, the data was collected during 2012 and additional data from 2013. These caveats should be considered in interpreting the findings outlined in the report.

Time analysis was also performed to look at long-term trends in operating speeds in Queensland.

2.4 Workshop

Based on the above findings, a preliminary discussion of possible options for selection of design speed in Queensland was prepared, noting the application (e.g. road type) and broad implications on:

- safety
- road design and construction costs
- traffic operations
- speed limit enforcement.

The information was then used to provide broad estimates of construction and whole-of-life cost savings potentially arising from design speed guidance changes.

A practitioner workshop was held in Brisbane in April 2014 to present and discuss the preliminary findings and seek Queensland practitioners' feedback. The workshop was attended by the following:

- Mike Whitehead, Acting Director (Road Design), Queensland Transport and Main Roads
- Mandy Haldane, Manager (Road Geometric Standards), Queensland Transport and Main Roads
- Stephen Cullinan, Principal Designer (Road Geometric Standards)
- Chris Jurewicz, Senior Research Engineer, ARRB Group
- Joseph Affum, Principal Research Engineer, ARRB Group
- David Milling, Senior Advisor (Safe Systems), ARRB Group.

The specific workshop discussion outputs were used to inform the recommendations documented in the report.

3 CURRENT DESIGN SPEED GUIDANCE IN QUEENSLAND

The main document guiding road design in Queensland is the *Road Planning and Design Manual* (the Manual). At the time of the investigation, the 2nd edition of the Manual was being prepared to improve the alignment of Queensland practice with the relevant Austroads guides. During this time, the 1st edition of the Manual took precedence and continued to provide guidance on design speed issues. The following description of Queensland design speed guidance refers to Chapter 6 of the Manual, 1st edition (Department of Transport and Main Roads 2007).

3.1 Design Speed Concept and Selection

Target speed is typically selected for the route as part of the overall road or link strategy. The desired speed can be estimated using Table A 1 and Table A 2. Desired speeds should remain the same over significant sections of the road, even though the operating speed may vary along that length. The desired speed is typically set 10 km/h over the speed limit where speeds are largely unaffected by the horizontal alignment (e.g. high-speed roads and urban roads). Lower desired speeds can be selected where speeds are constrained by horizontal alignment.

Design speed adopted for individual elements along the section may be the same or lower than the desired speeds. Design speed is used to coordinate other design parameters, e.g. sight distance, vertical curvature, horizontal radius, superelevation and side friction demand.

Design speed must be equal to or greater than the operating speed for the particular horizontal geometric element. Operating speed should be measured on existing roads. Where horizontal alignment is constrained and operating speeds are variable, it may be calculated using the Austroads Operating Speed Model,. Where operating speed cannot be measured (e.g. new roads), or is not constrained by horizontal alignment, the common practice is to adopt desired speed as the design speed (i.e. speed limit plus 10 km/h).

Design speeds can vary between consecutive design elements on variable speed roads. However, it is preferable that they be as consistent as possible along the length of the road. The Manual emphasises that roads should be designed in such a way that it is relatively simple for drivers to choose a safe speed and position for their vehicle. Geometric inconsistencies that bring about large changes in speed or direction should be avoided. The Manual provides guidance on the maximum speed decreases between successive geometric elements.

Appendix A summarises a step-by-step process to determine the design speed. It also describes the process of applying the Operating Speed Model.

3.2 Effect of Design Speed on Design Elements

Appendix B provides a listing of different road design elements affected by the design speed with reference to the relevant chapters of the manual. This listing assists in understanding the impacts of lowering the design speed on other road design elements, construction and whole-of-life costs.

The key design elements which are determined using design speed are:

- lane width, kerb and channel type
- pavement crossfall, superelevation
- horizontal and vertical curve radii, side friction, sight distance, sag curve length
- clear zones
- safety barrier test levels, run-out lengths, deflections and flare angles

- intersection deceleration distances, turn warrants, sight distances, dimensions of turning treatments and auxiliary lanes, corner radii
- interchange ramps and loops
- maximum permissible variations in alignment through at-grade rail crossings.

If the design speed was ‘assumed’ or estimated to be lower than the actual operating speed, the effect would be a reduction in standard of many of the above design elements. In practice this would translate to potentially shorter lengths (e.g. turning lanes, sight distances), narrower widths (lanes, clear zones), tighter curves and interchanges, and lower vehicle containment ability of safety barriers. Overall, this would result in a lower overall road standard particularly in terms of safety. The extent and perception of changes would depend on the amount of design speed reduction, its absolute value, and the design element in question.

Most design speed information in the Manual is presented in increments of 10 km/h. The change in design speed policy would have to be of this order, or greater, to have any noticeable impact on the design practice, and potentially, on the road costs.

4 OTHER JURISDICTIONS

Interviews were conducted with managers of design or standards teams in state road agencies from NSW, Victoria, South Australia and Western Australia in the late 2013. The same set of questions relating to design speed policy was posed to each manager:

1. Is policy of applying design speed of less than SL+10 used in your jurisdiction? Where and when is it used?
2. What has the implementation been like?
3. If used, have any cost savings been identified? Of what order? In which areas?
4. Other issues.

The responses to each question varied. Only Victoria had set a policy of using the speed limit as a design speed in metropolitan areas, speed limit plus 10 km/h was to be used on rural roads and freeways (see Appendix C). Risk-assessment and an Extended Design Domain (EED) approval were necessary from VicRoads Technical Consulting arm before a lower design speed could be adopted on these roads.

VicRoads noted that the policy was enthusiastically adopted by VicRoads and consulting designers due to savings in construction and land acquisition costs. This typically affected minor projects such as developer-funded access or intersection remodelling works. The policy has not been evaluated at the time.

It was noted that the policy was open to abuse by designers working for developers seeking to minimise costs, especially on the urban fringe. Consultation with VicRoads was often not done early enough resulting in delays at EED approval stage.

New South Wales still used the Austroads approach of speed limit plus 10 km/h but was permissive of using the speed limit on case-by-case basis. There was a recognition that some cost savings could be achieved this way, but not at the cost of safety. This often resulted in adoption of a lower design speed and using other features to compensate for a tighter design. It was noted that a policy position was being debated internally and a lower design speed may become part of a future NSW supplement to the Austroads (2010).

At the time, South Australia and Western Australia both used the speed limit plus 10 km/h design speed policy. Main Roads WA investigated making a change to a speed limit-only policy, but decided that full investigation of travel speeds would be required before making a commitment.

5 REVIEW OF RESEARCH LITERATURE

This section provides a summary of available research evidence on the main issues relating to the design speed policy. This information was collated to inform decisions relating to the review of the design speed policy in the context of improved speed limit compliance. The available research literature was reviewed on the effect of:

- speeds, speed uniformity and speed limits on safety outcomes
- design speed and speed uniformity on highway capacity (e.g. issues such as merging, lane changes and arterial flow breakdowns)
- speed limit enforcement and its impacts on speed compliance, observed speeds and speed uniformity.

The details of the reviewed research literature are provided in Appendix D. The following sections summarise the key findings.

5.1 Effect of Speeds, Speed limits and Speed Uniformity on Safety Outcomes

5.1.1 Speed Uniformity/Variation and Safety

All identified research refers to speed variability rather than uniformity, i.e. parameters of speed standard deviation, variance, or derivatives of these. The relationship between speed variation and safety outcomes has had little research. Three seminal projects looked at the issue in the context of urban roads (Taylor, Lynam and Baruya 2000) and on rural roads (Garber and Gadiraju 1988, Taylor, Lynam and Kennedy 2001).

On urban roads there was a strong association between speed variation and increased risk of casualty crashes. Roads with high standard deviation compared to the mean speed were observed to have relatively more casualty crashes (Taylor, Lynam and Baruya 2000). It should be noted that the study was based on limited UK data and a number of assumptions, hence the observations are at best indicative of what may happen elsewhere.

A US study by Garber and Gadiraju (1988) found a strong link between standard deviation of speed and observed crash rates on rural interstate and state highways.

The reviewed studies showed a strong observed association between the road stereotype and the amount of speed variation. It is likely that road design and adjacent land use play an important role in the amount of speed variation and the crash outcomes.

The work of Kloeden et al. (2001, 2002) suggested that only the part of the speed variation which is above the mean speed contributes to casualty crashes. The risk for drivers travelling below the mean speed is not increased. These findings may explain why speed enforcement initiatives have been successful in improving safety by only reducing those speeds above the limit.

5.1.2 Design Speed and Operating Speed

Several studies investigated the relationships between design speed and operating speed. The studies confirmed that driver speed selection could be influenced by the:

- physical road environment: the level of roadside development, carriageway width, road geometry (curve radius, 'bendiness' of the route), sight distance and road smoothness, roadside hazard proximity and density

- traffic factors: volume, the number of intersections, parked vehicles and presence of pedestrians)
- general conditions: time of day, weather and traffic flow.

A study by Turner and Tate (2009) found a strong correlation between curve crash rates and the positive differential between driver speeds and the design speed. This highlights the importance of both speed enforcement and consistent road design.

Intersection speed studies focussed on roundabout design findings that roundabouts where visibility and geometry were restricted were more effective in crash reduction (Turner and Roozenburg 2006, Zirkel et al. 2013).

5.2 Effect of Design Speed and Speed Uniformity on Highway Capacity

A review of the US *Highway Capacity Manual*, or the HCM (Transportation Research Board 2010a, 2010b) provided a number of research-based inputs relating to the relationship between design speed, mean speed and capacity under free-flow conditions (Appendix D.1.1). At lower design speed, lesser standards of these elements would be selected resulting in potential geometric restraint on the mean free speed of the uninterrupted flow (e.g. rural roads or freeways).

According to the research supporting the HCM, there is a well-proven causal link between reduction in mean free speed (e.g. due to enforcement, or geometric restriction) and a reduction in capacity. The magnitude of the change is typically small and depends on a number of roadway design and operational factors, which are also correlated with capacity and driver selection of speed. According to the HCM, these include:

- narrow clear zones
- narrow lane widths
- steep grades and their length
- higher percentage of heavy vehicles
- hilly terrain
- overtaking opportunities
- greater ramp density.

The studies included in the review suggested a limited capacity reduction of up to several percent as a result of a range of reductions in the mean free speed.

A substantial design speed reduction, which results in mean free speed restriction, is likely to have a limiting effect on capacity. This is likely to be an issue on urban freeways and some arterials, where traffic volumes often approach capacity under uninterrupted flow conditions.

On roads with interrupted flow, lower design speed may affect intersection capacity more directly through traffic flow disruption. Bonneson et al. (2005) showed an association between lower speed limit and reduced signalised intersection lane saturation flow. The authors noted the correlation of lower speed limits with other factors such as parking, pedestrians, driveway density and segment length.

There has been little research on the effect of speed uniformity (or variability) on road capacity. Speed uniformity should increase as uninterrupted traffic flow approaches capacity due to high flow density (vehicles per lane kilometre). Under high density conditions, heavy platooning and low headways restrict speed differences between vehicles and the opportunity for lane changes.

It would be difficult to draw a definitive conclusion about the effect of speed uniformity on capacity from the available information.

5.3 Effect of Speed Limit Enforcement on Speed Compliance, Observed Speeds and Speed Uniformity

Elliott (2001) identified enforcement as one the four main determinants of driver speed, along with the driving environment, behaviour of other drivers and societal norms. Enforcement is most effective in reducing speeds when drivers have a perceived high risk of detection, thus reducing the perceived benefits of speeding (Oxley and Corben 2002; Elliott et al. 2003).

There has been a significant amount of published research on the effects of different speed limit enforcement approaches on speeds and on safety outcomes. Table 5.1 provides a summary of the research reviewed in Appendix D.2.

Transport for New South Wales (2013) reported preliminary findings on the effectiveness of the point-to-point speed limit enforcement technology for heavy vehicles for New South Wales only. There were observed mean speed reductions, reduced number of infringements and increased compliance levels among heavy vehicle traffic as well as a reduction in the number of heavy vehicle crashes.

Point-to-point enforcement technology appears to have delivered comparable speed reductions to other speed camera technologies, but applied over a road section. Available studies suggested improved speed uniformity through reports of increased speed compliance. The findings in Table 5.1 suggest that the speed reductions were not uniform and varied between different road sections.

There was an insufficient body of research to form a consistent view on the possible translation of point-to-point speed reductions to the selection of lower design speed.

A review of studies on intelligent speed adaptation (ISA), however, provided consistent information on speed uniformity effects. The standard deviation of speeds was generally reduced in line with a reduction in mean speeds.

Table 5.1: Effects of speed limit enforcement/feedback

Enforcement type	Speed compliance	Observed speeds	Crash and injury reductions	References
Fixed speed cameras	▪ Proportion exceeding speed limit reduced by 35–71% ▪ Proportion of extreme speeding (30 km/h over speed limit) reduced by 76%	▪ Average speeds reduced by 3.4–13% ▪ 85th percentile speeds reduced by 4–20%	▪ Total crashes reduced by 16% ▪ 33% reduction in injury crashes ▪ 23–51% reduction in casualty crashes ▪ 30–51% reduction in the number of injuries ▪ Fatal crashes reduced by 39–90%	Austroads project ST1768 (unpublished), Elvik et al. (2009), Gains et al. (2004), Mountain et al. (2004), Diamantopoulou and Corben 2002 (VIC)
Mobile speed cameras	▪ Proportion exceeding speed limit reduced by 21% ▪ 59% reduction in number of drivers	▪ Average speeds reduced by 9.8%	▪ 12–61% reduction in all crashes ▪ 10–36% reduction in casualty crashes ▪ 16–45% reduction in fatal crashes	Avrenli et al. (2011), Elvik et al. (2009), Cunningham et al. (2005), Gains et al. (2004), Christie et al. (2003), Newstead and Cameron

Enforcement type	Speed compliance	Observed speeds	Crash and injury reductions	References
	exceeding speed limit by ≥10 km/h ▪ 55% reduction in number of drivers exceeding speed limit by > 16 km/h			(2003), Anderson and Edgar (2001)
Point-to-point speed cameras	▪ Proportion exceeding speed limit by less than 10 km/h reduced by 13% and 38% (different sections) ▪ Proportion exceeding speed limit by more than 10 km/h reduced by 3% and 33% (different sections)	▪ Average speed reduced by 15 km/h initially, and 10 km/h six months after implementation ▪ 85th percentile speeds reduced 6–21 km/h ▪ Average speeds reduced by 3 – 18 km/h in different sections ▪ Reduced speed variability.	▪ 33% reduction in injury crashes ▪ 33–85% reduction in casualty crashes ▪ 55.6% reduction in severe crashes ▪ 26.6% reduction in non-severe crashes	Speed Check Services (n.d.), Stefan (2006), Department of Public Works Management (2003), Ragnøy (2011), Montella et al. 2012 (Italy)
Combined speed and red light cameras	-	-	▪ 26% reduction in all crashes ▪ 34% reduction in injury crashes ▪ 26–47% reduction in casualty crashes	Budd et al. (2011), Centre for Road Safety (2010)
Non-enforcement approaches				
Feedback signs	-	▪ Average speeds reduced by 3.5–8.0 km/h ▪ Slightly higher for 85th percentile speeds	-	Mabbott and Cairney (2002)
Intelligent speed adaptation (ISA)	▪ 6.6–94% reduction in number of vehicles speeding on 30 km/h	▪ Average speeds reduced by 2.5–5 km/h	-	Hjälmdahl et al. (2002), Váhelyi et al. (2002), Lind (2000)

6 DATA ANALYSIS OF SPEED COMPLIANCE IN QUEENSLAND

This section provides the results on analysis carried out using speed data provided by the Department.

6.1 Operating Speeds

The 85th percentile speeds were averaged for all available sites for each road stereotype defined by speed limit, divided/undivided design and urban/rural area, across three geographic regions: metropolitan Brisbane, the remainder of S.E. Queensland, and the rest of regional Queensland. This approach makes it easy to compare operating speeds with the speed limit across typical road scenarios.

The key finding of the analysis, shown in Table 6.1, is that operating speeds were generally less than 5 km/h above the speed limit across the range of road stereotypes and geographic regions. The only exceptions were:

- Urban 60 km/h roads in metropolitan Brisbane where operating speeds exceeded the speed limit by more than 6 km/h. The data for this sample came exclusively from divided multilane arterials, and does not represent other, lower standard 60 km/h roads.
- The semi-rural undivided 80 km/h roads in S.E. Queensland, where the operating speeds for this road category exceeded the posted speed limit by 5 km/h.

For some road stereotypes, the average operating speeds were below the speed limit (e.g. urban divided roads in metropolitan Brisbane, rural undivided 110 km/h roads).

All the differences between operating and maximum legal speeds were statistically significant at $p \leq 0.05$ because of the large numbers of vehicles at each site (see Appendix E, Table E 1 for detailed results). This being true, the operating speeds for some road stereotypes were based on only several sites (shown in italics in Table 6.1)

Table 6.1: Comparing average operating speeds with speed limits

Road stereotype	Metro Brisbane	S.E Queensland excluding Brisbane	Regional Queensland
Urban 60 km/h	66.4[1]	64.1	61.1
Urban divided 80 km/h	79.8	82.7	83.4
Rural/urban undivided 80 km/h [2]	83.0	85.3	-
Rural/urban divided 100 km/h	*99.9*	102.4[3]	*102.5*
Rural undivided 100 km/h	-	93.3	103.3
Rural divided 110 km/h	-	112.4	-
Rural undivided 110 km/h	-	-	108.3

3 Based on a sample of divided roads due to lack of other data.
4 These are many of the lower quality rural roads close to urban areas.
5 Based on SEQ urban and rural divided 100 km/h roads.

Figure 6.2 shows the individual plots of recorded operating speeds at different sites vs. their speed limit. It is clear that standard deviation was significant (5–15 km/h). Many sites recorded much higher or much lower operating speeds than the applicable limit. The deviation was much greater for 100 km/h sites as these represented a very broad range of road standards and alignments.

Operating speeds on 110 km/h roads showed clustering around the average value reflecting the strict guidelines for the selection of this speed limit.

Figure 6.1: Operating speeds and the posted speed limit

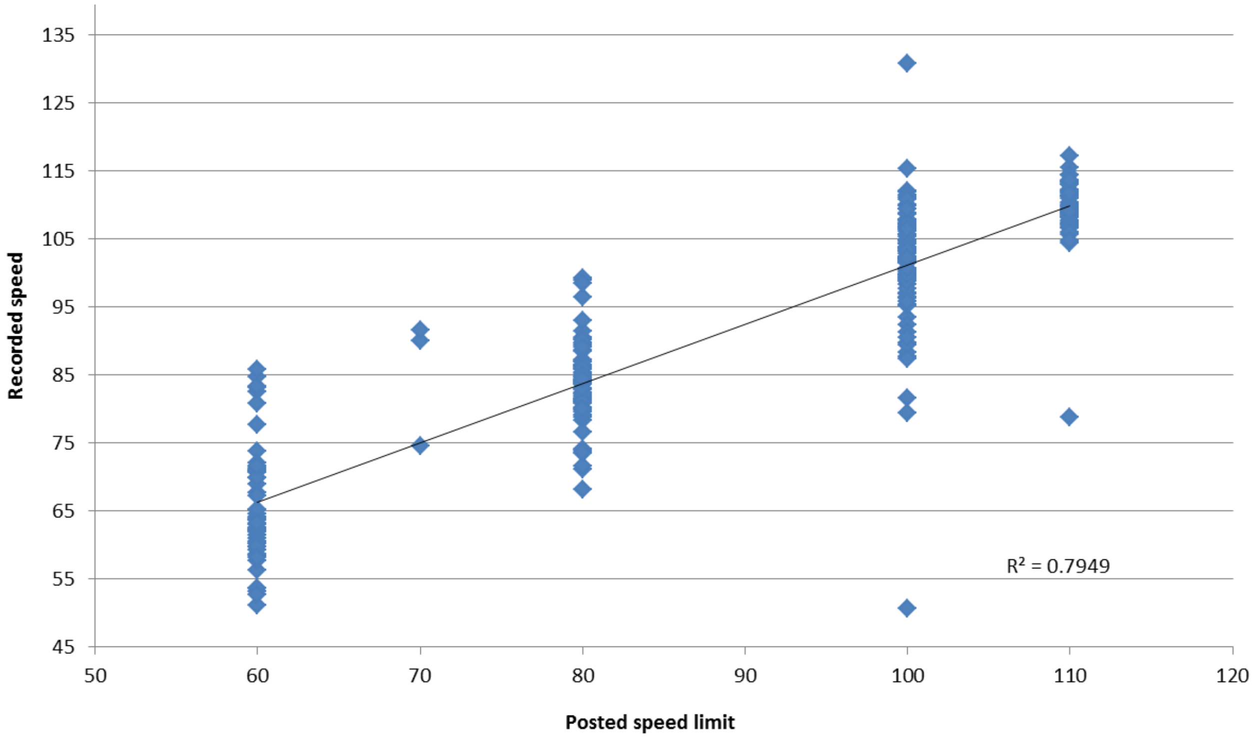
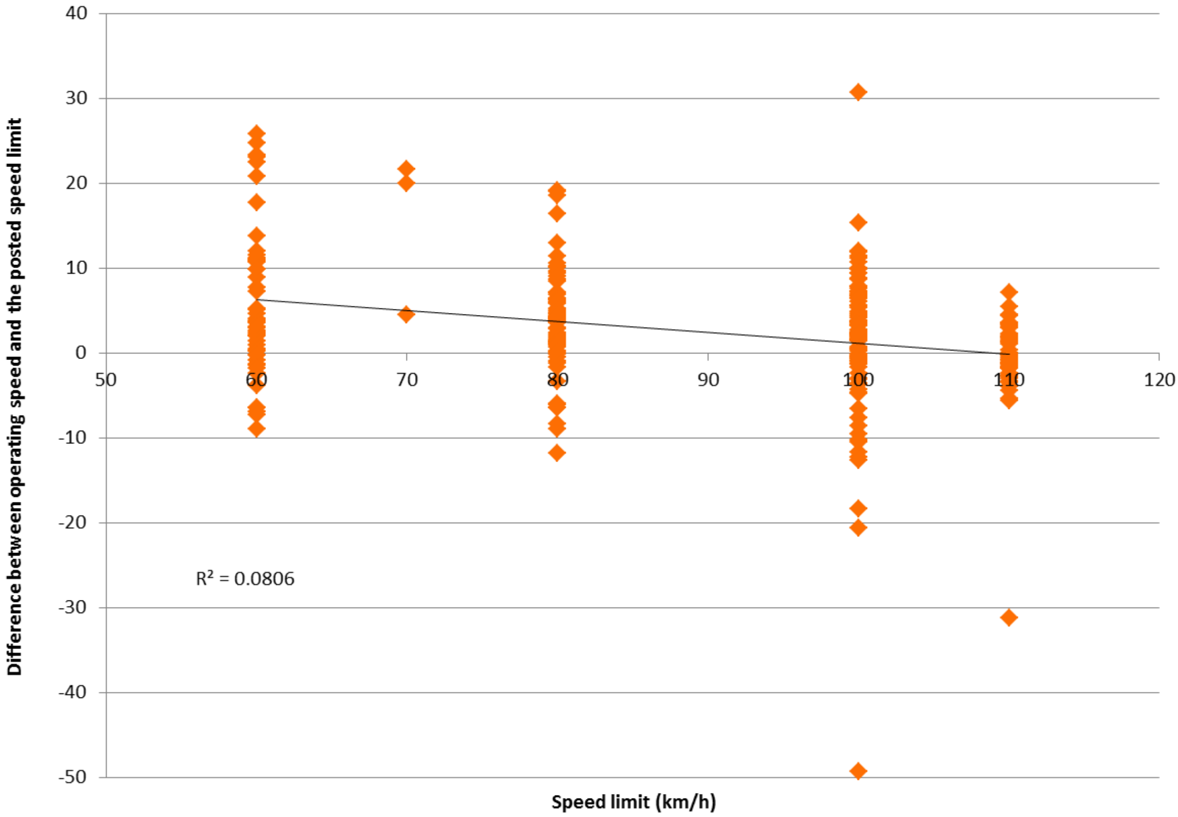


Figure 6.2 shows the differences between the operating speed and the speed limit. The trend is clearly downwards, indicating that the speed limit and operating speeds are more aligned on the higher speed roads. This suggests a confirmation of the literature findings that speeds tend to be more uniform on high speed roads. Also, Figure 6.2 closely resembles similar analysis based on Victorian roads (unpublished analysis for VicRoads).

Both figures indicate that there was a significant spread of operating speeds and that speed compliance was varied across the road network.

Figure 6.2: Differences between operating speeds and the posted speed limit



The same differential data was aggregated by speed limit and road design type (divided/undivided), without the geographic split, in Table 6.2. Again, most operating speeds were within 5 km/h of the speed limit, with only the urban 60 km/h divided roads being 6 km/h above.

Table 6.2: Operating speed – speed limit differences by speed limit and road type

Speed limit (km/h)	Difference b/w avg. operating speed and speed limit (km/h)	
	Divided roads	Undivided roads
60	6.4	2.6
80	1.9	4.2
100	1.6	-1.7
110	2.4	-1.7

6.2 Speed Compliance

Another important factor in determining the design speed is an overall understanding of speed compliance. This study analysed the overall percentage of vehicles exceeding the speed limit, the percentage exceeding the speed limit by less than 10 km/h and the percentage exceeding by 10 km/h or more.

The lowest levels of compliance, indicated by the high percentage of vehicles exceeding the speed limit, were on urban 60 km/h roads where an overall 47.6% of vehicles exceeded the posted speed limit, followed by urban fringe undivided 80 km/h roads (37.1%). Rural undivided 100 km/h roads also had low levels of compliance with 32% of the vehicles exceeding the posted speed limit. The highest overall level of compliance was on rural 110 km/h roads (both divided and undivided roads).

Overall, it could be said that while the operating speeds were close to the speed limit, compliance levels were low.

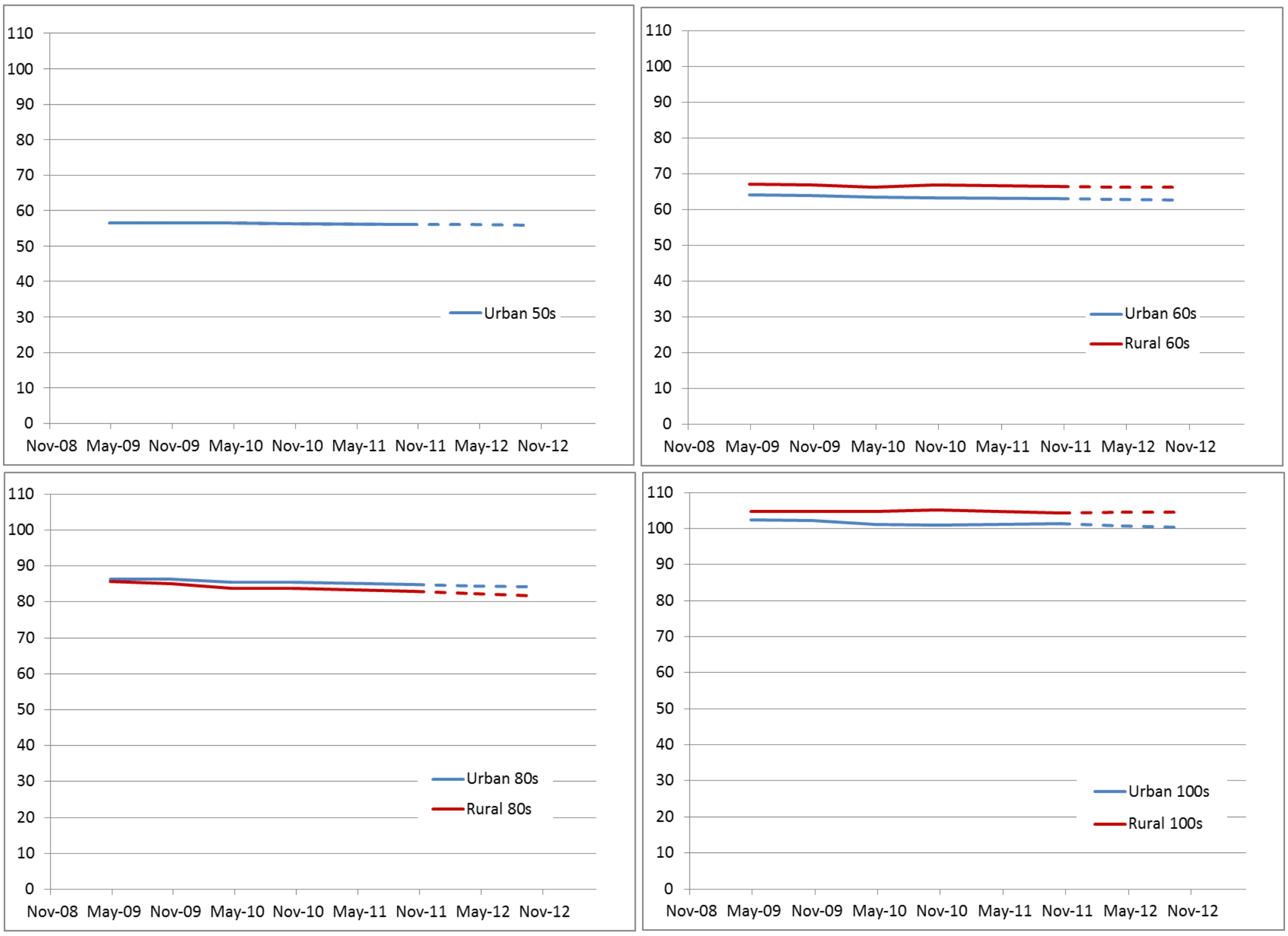
6.3 Time Trend Analysis

One of the objectives of the analysis was to identify the long-term trends in operating speeds on different roads in Queensland. Historical data was available until November 2011 and then extrapolated for the year November 2012 to continue the trends as shown in Figure 6.3. The speed data from this project could not be appended due to a different sampling regime.

For all cases in Figure 6.3 the trends were downward, although very slight. The average rate of operating speed reduction was 0.16 km/h per annum, with the maximum reduction of 0.53 km/h per annum shown for rural 80 km/h roads, and the smallest reduction of 0.04 km/h per annum on rural 100 km/h roads. Urban 60 km/h roads showed a declining trend of 0.21 km/h per annum.

These rates suggest that operating speeds have stabilised and further operating speed decreases would take a long time, or may be periodically reversed if future speed compliance rates fall.

Figure 6.3: Extrapolated time trends for operating speeds in Queensland



7 DISCUSSION

The project reviewed current design speed guidance (Section 3 and Section 4), the relevant research literature (Section 5), and carried out speed data analysis (Section 6). This section summarises and discusses these inputs and proposes options for guidance on selection of design speed. The discussion notes the application (e.g. road type), broad implications on road design, construction costs, safety, traffic operations and speed limit enforcement. It provides broad estimates of construction and whole-of-life cost savings potentially arising from design speed guidance changes.

A practitioner workshop was held in Brisbane in April 2014 to present and discuss the preliminary project findings and to seek feedback. The workshop outputs were used to inform the recommendations documented in Section 8.

7.1 Current Design Guidance

A review of the current guidance in Queensland suggested that design speed had relatively limited effect on the most costly elements such as cross-section, presence of medians and type of intersection control. The aspects of horizontal and vertical alignment and lengths of auxiliary lanes were affected by the design speed. Design speed change to match the speed limit would impact these through a reduction in material quantities and labour. The extent of this impact on road construction costs would depend on many other factors not directly associated with design speed, e.g. type of project, terrain, AADT and design accommodations for heavy vehicles.

7.2 Point-to-point Speed Limit Enforcement

The review of the relevant literature in Section 5.3 suggested significant speed reductions and compliance improvements. Yet, there was no clear evidence that point-to-point speed limit enforcement brought the speeds down to an appropriate level where design speed could be reviewed downwards. The findings suggest this could be the case, but further evaluations of point-to-point would be required to confirm this.

7.3 Analysis of Speed Data and Compliance

The key findings from the speed data analysis were that:

- The rate of operating speed decline was very slow (average of 0.17 km/h per annum, 0.04 to 0.53), thus it is not likely that such a change could be made soon. There was a significant margin for future improvement through continuing speed limit enforcement.
- There were strong differences between operating speeds at survey sites with the same speed limit and road stereotype (standard deviation of 5–15 km/h). This meant that speed limit compliance was inconsistent across the road network.
- For most investigated road stereotypes, where speed data was available, the average operating speeds were close to the speed limit and below the speed limit plus 5 km/h mark.
- Urban divided 60 km/h arterials in Brisbane and the undivided 80 km/h roads in S.E. Queensland were the two exceptions, with operating speeds 5–6 km/h above the speed limit. These road stereotypes had reasonable rates of operating speed decline and should be monitored (-0.21 and -0.53 km/h per annum respectively).
- The accuracy of the results was satisfactory.

The conclusion from this analysis is that typical operating speeds in 2012 and 2013, where data was available, were below the current assumption of speed limit plus 10 km/h, but not sufficiently low to recommend the speed limit as the revised design guidance. Most available average operating speeds were below speed limit plus 5 km/h.

7.4 Speed Limit Plus 5 km/h Option

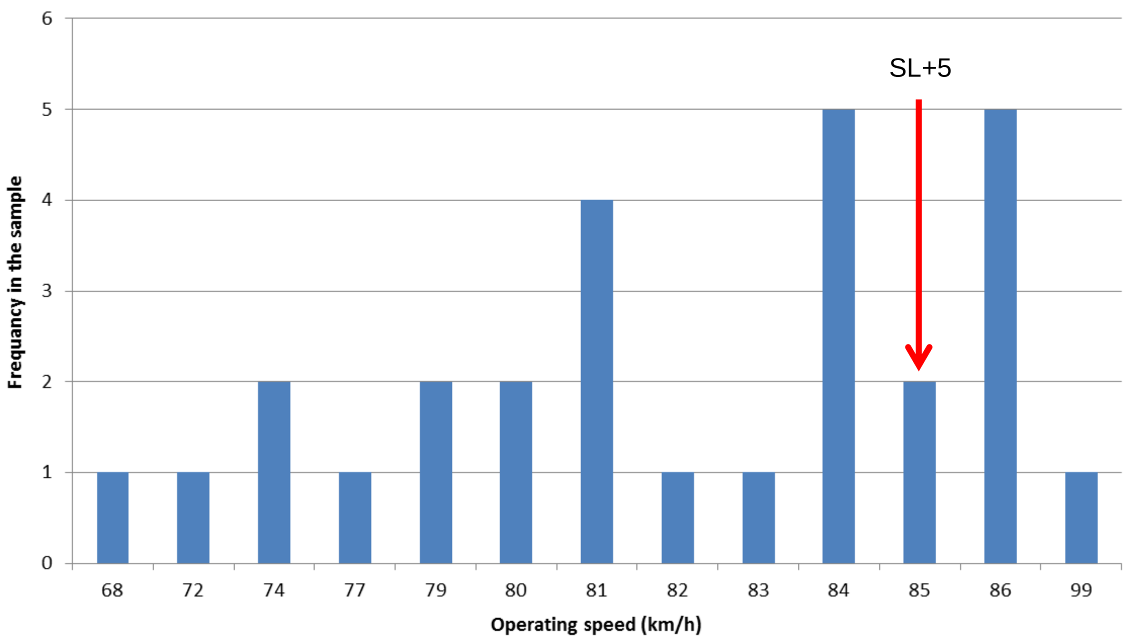
Based on the speed data analysis, the design speed assumption of speed limit plus 5 km/h was considered, where measured operating speed is not available or not constrained by alignment.

The speed analysis in Section 6 was based on average operating speeds at the sampled sites. For most road stereotypes, the speed limit plus 5 km/h design speed guidance would be a higher value than these average operating speeds (with the exceptions noted previously). It is worth noting, that the standard deviation from the average was high for some road stereotypes. Thus, the new guidance would not be inclusive of all scenarios.

Further detailed analysis of operating speed distributions indicated that a significant percentage of sites would have had operating speeds above the design speed set by the considered guidance (Table E 4 in Appendix E). This is clear in the example shown in Figure 7.1, where 21% of the divided 80 km/h sites had operating speed above 85 km/h. This percentage was higher for other road stereotypes, as high as 58% for 60 km/h divided roads. In essence, compliance with speed limits was not sufficiently consistent on large parts of the road network.

This presents a challenge in setting the new guidance of speed limit plus 5 km/h, as it may not be sufficiently robust at this time. A more conservative approach of retaining the current guidance of speed limit plus 10 km/h, would be more inclusive of sites where speeding is still a significant problem.

Figure 7.1: Distribution of operating speeds for 80 km/h divided roads



7.5 Potential Impacts of Speed Limit Plus 5 km/h as Operating Speed Estimate

Based on the data analysis, a change in design speed selection advice from speed limit plus 10 km/h to speed limit plus 5 km/h could be considered on most parts of the Queensland gazetted road network, with the exception of urban divided 60 km/h arterials in Brisbane and possibly undivided 80 km/h roads in S.E. Queensland.

This project analysed the impacts of such change on:

- road design and construction costs
- safety
- traffic operations (capacity)
- speed limit enforcement.

An assessment was also made of whole-of-life cost savings potentially arising from the lower design speed guidance.

7.5.1 Road Design and Construction Cost Impacts

The assumption of operating speed being speed limit plus 5 km/h is only 5 km/h lower than the current assumption of speed limit plus 10 km/h. In most cases the reduction in design speed needs to be interpolated between existing values. Table 7.1 provides the breakdown of these impacts using the Manual, 1st edition for two typical scenarios. The impacts were very minor or even difficult to detect. One exception was the differences in minimum vertical curve radii which could translate to sharper crests and sags in isolated situations – these elements are generally influenced by many other geometric constraints such as maximum grade and its length.

Table 7.1: Examples of design impacts of reducing design speed by 5 km/h

Design elements	Effect on urban roads, assume 60 km/h speed limit	Effect on rural roads, assume 100 km/h speed limit
Lane width, kerb and channel type	No impact on traffic or bicycle lane widths, shoulder width or provision, median and verge widths, crossfall. No impact on kerb and channel type.	No impact on traffic or bicycle lane widths, shoulder width or provision, median and verge widths, crossfall. No impact on kerb and channel type.
Pavement crossfall, superelevation,	Desirable maximum coefficient of side friction – increase from 0.19 to 0.22. Adverse superelevation would be allowed for curves with radius down to 248 m, instead of 295 m.	Desirable maximum coefficient of side friction – no change. Adverse superelevation would be allowed for curves with radius down to 2500 m, instead of 3000 m.
Horizontal and vertical curve radii, side friction, sight distance, sag curve length	Stopping sight distance (SSD) requirement would reduce by 10 m (assumes reaction time of 2.0 sec). Minimal impact on general maximum grades in flat and rolling terrain only (+0.5%). No impact on maximum lengths of grade. The minimum vertical crest curve radius reduced by about 350 m (applicable only if length of crest curve is greater than the sight distance). Minimum sag curve radius reduced by about 100 m.	Stopping sight distance (SSD) requirement would reduce by 20 m (assumes reaction time of 2.5 sec). Minimal impact on general maximum grades in flat and rolling terrain only (+0.5%). No impact on maximum lengths of grade. The minimum vertical crest curve radius reduced by about 1600 m (applicable only if length of crest curve is greater than the sight distance). Minimum sag curve radius reduced by about 150 m.
Clear zones	Current guidance is not precise enough for such small change to have any meaningful impact. Minor impact on curves – 2–3% narrower. No impact on roadside batters (earthworks).	Current guidance is not precise enough to specify the effect, but potentially less than 1 m narrower. Minor impact on curves, only 2–3% narrower. No impacts on roadside batters (earthworks).
Safety barrier test levels, runout lengths, deflections and flare angles	Current guidance is not precise enough for such small change to have any meaningful impact. Barrier runout length may be 5 m shorter. No difference for lateral clearance to objects on bridges.	Current guidance is not precise enough for such small change to have any meaningful impact. No change for minimum lateral clearance to barriers (shy line).** Barrier runout length may be 5–7.5 m shorter.

Design elements	Effect on urban roads, assume 60 km/h speed limit	Effect on rural roads, assume 100 km/h speed limit
		No difference for lateral clearance to objects on bridges.*
Intersection deceleration distances, turn warrants, sight distances, dimensions of turning treatments and auxiliary lanes, corner radii	Sight distances about 15 m shorter. No impact on medians and traffic islands. Deceleration length at auxiliary lanes 10 m shorter. Diverge lengths 5 m shorter. Minimally tighter corner radii can be used. Length of acceleration may be 28 m shorter. Guidance on channelised turn treatments reduces this difference to about 10 m.	Sight distances about 15-20 m shorter. No impact on medians and traffic islands. Deceleration length at auxiliary lanes 15 m shorter. Diverge lengths 5 m shorter. Minimally tighter corner radii can be used. Length of acceleration may be 80 m shorter. Guidance on channelised turn treatments reduces this difference to about 10 m.
Interchange ramps and loops	Desirable minimum radius of horizontal curvature may be 30 m less. Acceleration distance for a merge ramp may need to be 20 m longer (disbenefit).	Major road sight distance to the nose (exits and diverges) reduced by 50 m. Desirable minimum radius of horizontal curvature may be 30 m less.
Maximum permissible variations in alignment through at-grade rail crossings	Negligible differences.	Negligible differences.

* Would have a difference of 0.5 m on 80 km/h roads.

** Would have a difference of 0.25 on 80 km/h roads.

Overall, the effect of the design speed being speed limit plus 5 km/h on construction costs would be negligible. Many design elements would not be affected, form a small proportion of the road network, or of a major construction project (deceleration and acceleration lanes, less than 10% change), or simply have no appreciable impact on costs (coefficient of friction, superelevation).

Discussions with the Department practitioners and managers at the project workshop resulted in an estimate of less than a 1% impact on construction costs. The cost impacts on maintenance would be even lower.

7.5.2 Safety Impacts

The minor changes in design element diameters would only have a marginal impact on crash risk. This would be through the roads being less forgiving of driver error and vehicle fleet differences. Some of the specific examples include:

- Narrower clear zones on high-speed roads will increase the risk of run-off-road crashes.
- Overtaking lane diverging and merging may be riskier.
- Shorter sight distances will increase the risk of intersection and pedestrian crashes.
- Overtaking/head-on crash risk may be higher as lower overtaking sight distance requirements would permit the manoeuvre more frequently in constrained conditions.
- Higher risk of heavy vehicle driver error due to lesser design values (e.g. curve widths, overtaking, intersection sight distance).

Many roads in this study were shown to operate at speeds much higher than the average operating speed, or the current speed limit plus 10 km/h design speed. Crash risk changes may be more than marginal there.

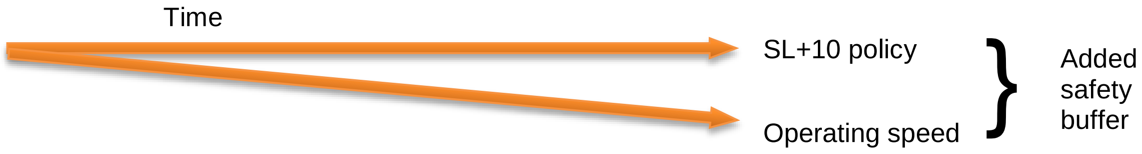
Such marginal changes to road standards are not likely to cause speed reductions or greater speed uniformity. Hence no safety effects could be expected from this measure.

Analysis of data in Section 6 shows that drivers are not encouraged to drive any faster than in the past. In fact, combination of enforcement, cultural change and more vehicles present on the road are likely to continue providing the benefit of lower speeds.

If the current guidance of speed limit plus 10 km/h was retained, existing and new roads being designed would become safer as the operating speeds slowly decline. Roads would become more forgiving of road user error without any additional intervention from the designers (e.g. more sight distance than absolutely needed).

Figure 7.2 attempts to demonstrate how the added safety buffer develops in presence of speed enforcement and more forgiving design standard. Reduction in design speeds would negate all or some of this buffer.

Figure 7.2: Synergy of retaining the current design speed guidance with declining operating speeds



7.5.3 *Capacity and Traffic Operations Effects*

As outlined in the literature reviews in Section 5.2 the effect of reducing free speed has a limited effect on capacity. There was little actual evidence regarding design speed. None of the marginal design impacts of speed limit plus 5 km/h guidance, listed in Table 7.1, would have an impact on free speeds or capacity of a road.

Some factors may have operational impacts resulting in a higher chance of delays, e.g.:

- High speed/rural roads:
  - marginal reduction in forward sight distance and overtaking opportunities, and merging opportunities (travel time increase)
  - slightly steeper maximum grade may marginally increase speed variation between heavy and passenger vehicles
  - marginally shorter deceleration and acceleration lengths may cause other vehicles to slow down
  - potential for greater driver frustration.
- Urban roads:
  - shorter auxiliary and merge lanes may *theoretically* reduce intersection capacity, and have impact on average network speeds
  - reduced sight distances may increase incidents/flow breakdown
  - potential for greater driver frustration.

7.5.4 *Speed Limit Enforcement Effects*

There were no identified effects of the speed limit plus 5 km/h guidance on the effectiveness of speed limit enforcement. It was noted in Section 0 that speeding levels were still high throughout Queensland. Further speed limit enforcement and cultural change should continue to address this issue.

7.5.5 Whole-of-life Costs

Overall, the whole-of-life impacts of changing the current guidance on design speed to speed limit plus 5 km/h would be between marginal and negligible. Small capital costs (quantities and labour) could be occasionally achieved on isolated design components. As noted earlier the most likely saving would be less than a 1% cost difference on large projects. Table 7.2 incorporates inputs from the practitioner workshop.

Table 7.2: Matrix of whole-of-life cost changes from speed limit plus 5 km/h guidance

Element	Effect	How?
Capital costs	Marginal reduction	Marginally lower quantities, sometimes Marginally shorter construction times Lesser impact on other infrastructure
Routine maintenance	Negligible reduction	Negligibly narrower, shorter, smaller maintenance responsibilities
Periodic maintenance	Negligible reduction	Negligibly lower pavement areas to resurface, rehabilitate
Replacement	Marginal reduction	As per the capital costs

8 SUMMARY AND RECOMMENDATIONS

The project tested if there were any parts of the road network, and enforcement scenarios, where the design speed could be based on the posted speed limit. The findings did not support this concept at this time.

The review of available point-to-point enforcement evaluations showed an insufficient state of knowledge to translate the observed speed reductions into changes to design speed guidance.

Where measured operating speed is not available, or not constrained by alignment, the design speed assumption of speed limit plus 5 km/h was considered for most parts of the Queensland state road network.

Further evaluation suggested that a significant percentage of the network would continue to register operating speeds above design speeds set using this guidance. This is due to inconsistent compliance with speed limits. This presents a potential challenge in using the speed limit plus 5 km/h guidance, as it could be insufficiently robust at this time.

Analysis of the design and construction cost impacts found that speed limit plus 5 km/h design speed guidance would have a marginal impact on design elements (occasionally slightly shorter, tighter and steeper), and hence a marginal effect on construction costs. The whole-of-life cost estimations found the effect to be between marginal and negligible.

The safety effects would be negative but also marginal. Retaining the current design speed guidance would be more supportive of the current Safe System approach in Australia (Austroads 2013). This would occur gradually through providing a more forgiving road network, at no additional cost, as operating speeds decline slowly.

There were concerns that the speed limit plus 5 km/h guidance could result in more frequent delays, even though capacity was not likely to be affected. No impacts on speed enforcement were identified.

Based on the findings of the study, it is recommended to retain the existing guidance for the selection of design speed, i.e. the speed limit plus 10 km/h, where measured operating speed is not available and not constrained by alignment. This guidance is more appropriate given the current levels of speed limit compliance, and leads to a more forgiving road environment.

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APPENDIX A SUMMARY OF QUEENSLAND DESIGN SPEED GUIDANCE

A.1 Introduction

Under the Road Planning and Design Manual (1st edition), design issues relating to speed are detailed in Chapter 6: Speed Parameters (Department of Transport and Main Roads 2007). The chapter aligns with the Austroads Guide to Road Design Part 3: Geometric Design, and in particular Section 3 of that guide: Speed Parameters (Austroads 2010).

The update of the Road Planning and Design Manual was underway during the project, including a review of how the Manual aligns with the updated versions of the Austroads Guide to Road Design. Until that review was complete, guidance contained in the Road Planning and Design Manual (1st edition) was to be used in lieu of the Austroads Guide to Road Design - Part 3. This included the entirety of Chapter 6 (Speed Parameters). This procedure differs from that in other states, whom largely adopt the guidance contained in the Austroads Guides and publish supplements to these guides where required.

The following is a summary of Chapter 6, focussing on issues relating to design speed guidance in Queensland.

The following is a summary of Chapter 6, focussing on issues relating to design speed guidance in Queensland.

A.1.1 Speed Prediction Models

The Speed Environment Model, as introduced in Australia from 1980 until 2003, predicted the speed along a road where the operating speed varied. This method was not well implemented in Australia and was replaced by the Operating Speed Model. Main Roads has adopted the Operating Speed Model with some minor enhancements.

A.1.2 Definition/Explanation of Key Terms

Six key terms relating to the selection of speeds for geometric design are defined. A visual representation of these terms and how they fit together is shown in

Target Speed

Target speed is the indicative operating speed for a road link (or a significant part of the road link). Target speeds at set at the network planning level, so as to establish a target geometric design standard for the road.

It is not always practical to design a road to its target speed over its entire length.

Operating Speed / 85th Percentile Speed

Operating speed is the 85th percentile speed (under free-flow conditions) at some point on the road. Designs based on the 85th percentile speed will cater for the majority of drivers, and that those 15% exceeding this speed are considered to be aware of the increased safety risk of their higher speed.

Operating speed may be different in each direction of travel, or may even vary from lane to lane on multi-lane carriageways.

Desired Speed

This is the operating speed that drivers will adopt on less constrained elements, i.e. straights and large radius curves of a reasonably uniform section of road when not constrained by other vehicles. The desired speed is influenced by:

- Roadside environment
- Road characteristics
- Speed limit
- Road function – drivers less willing to accept lower speeds on important roads (freeways etc.)

In practice, the desired speed is often about 10 km/h above the posted speed limit.

The desired speed does not vary over a road section, but the road section can still have isolated features that are not consistent with the desired speed (e.g. tight curves, roundabouts, overtaking lane). The desired speed only changes if the road environment varies over a significant length of roadway.

With the previous Speed Environment Model, the Speed Environment was numerically equal to Desired Speed, so this concept is still valid under the Operating Speed Model.

Design Speed

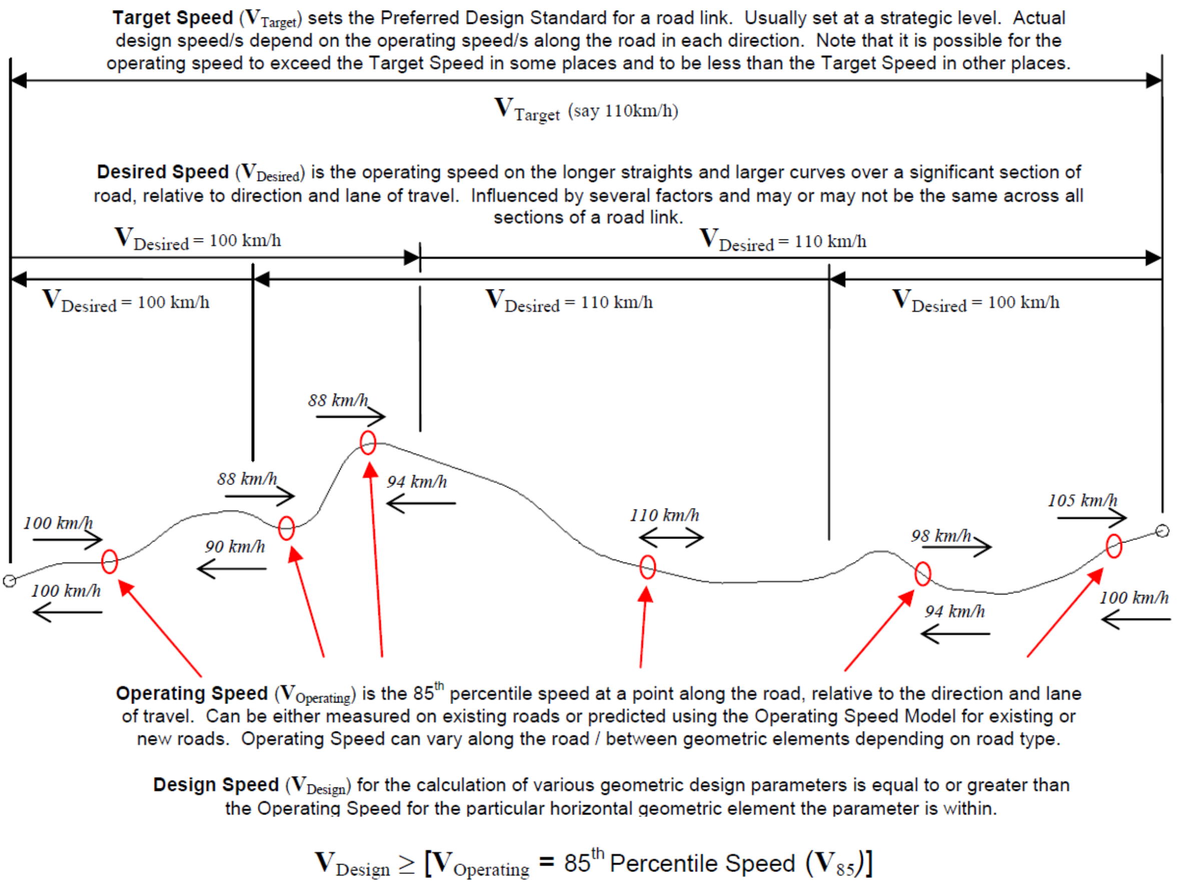
Design Speed is defined as the speed that is adopted for the calculation of the various geometric design parameters. Design speed must be equal to or greater than the operating speed (85th percentile) for the particular horizontal geometric element.

Determination of Design Speed is covered in Section 6.2 and 6.4 of Chapter 6, and is outlined in Section A.4 of this summary.

Limiting Curve Speed

The limiting curve speed is the speed at which a vehicle travelling on a curve of given radius and superelevation, will have a side friction demand equal to the absolute maximum recommended value for that speed (available in Chapter 11 of the Manual). The operating speed should not exceed the limiting curve speed for that particular curve.

Figure A 1: General overview of the relationship between speed parameters



Source: Department of Transport and Main Roads (2007)

A.2 Warrants for Geometric Assessment

A geometric assessment determines whether a road project is ‘fit for purpose’ or a ‘context sensitive design’. New projects, as well as restoration projects, must include a geometric assessment of the alignment.

A.3 Operating Speed Characteristics and Geometric Standard of Different Road Types – Including Determination of Desired Speed

A.3.1 Rural Roads

The desired speed on rural roads is largely determined by their stereotype and horizontal alignment. Rural roads can be classified in terms of their general operating characteristics. Table A 1 and Table A 2 show typical desired speeds for different road stereotypes with and without horizontal alignment limitations.

High Speed Rural Roads

These roads are designed for speeds in excess of 100 km/h. On these roads, operating speeds are not constrained by road geometry but by a number of other factors, including:

- The degree of risk that drivers are willing to take
- Speed limits and the level of policing of these limits
- Vehicle performance

These roads have a high desired speed and uniform operating speeds, so should have a single design speed.

Intermediate Speed Rural Roads

These roads are designed with a minimum operating speed of 80 km/h, at which vehicles are generally constrained by geometry. Drivers will accelerate up to their desired speed (up to 110 km/h) on straights. The speed limit is likely to be 80 to 100 km/h.

Low Speed Rural Roads

These roads have many curves and generally have operating speeds between 50 and 70 km/h. Such rural roads exhibit these characteristics when difficult terrain and costs prevent the road from reaching a higher standard geometry. These roads often have a reduced speed limit of 60 km/h. In these cases, it is pragmatic to design individual elements to the best practicable standard. Speed reduction treatments may be required if these standards cannot be met.

Determining Desired Speed on Existing Rural Roads

For restoration projects on existing rural roads, or short sections being realigned, operating speeds should be measured from speed studies on suitable sections of existing road. The desired speed can be measured directly as the 85th percentile speed on longer straights or large radius curves.

Determining Desired Speed on New Rural Roads

The speed on similar roads nearby can be used to estimate the likely desired speed on the new road. When realigning a section of road, the desired speed assessment should take into account the curvature on at least 1.5 km of road beyond each end of the realignment.

Desired Speed on Steep Grades

Relative speed differences between lighter and heavier vehicles can occur on steep grades. It may be necessary to limit the desired speed to minimise the potential relative speed differential.

Table A 1: Typical Desired Speed for roads on which vehicle speeds are largely unaffected by the horizontal alignment

Road Type	Proposed Speed Limit (km/h)	#Typical Desired Speed and Design Speed (km/h)	*Typical Minimum Radius (m) that will not reduce Desired Speed
Motorways	80	90	450
	100	110	600
	110	120	800
High Speed Rural Roads	100	110	600
	110	120	800
Urban Arterial and Sub-arterial Roads	60	70	200
	70	80	275
	80	90	300

* Used for identifying those roads on which vehicle speeds are unaffected by the horizontal alignment. Normally, there should be no curves that require vehicles to operate at less than the desired speed and the minimum preferred radii are greater than these radii.
# For a speed zoned road, desired speed is usually speed limit + 10km/h.

Source: Department of Transport and Main Roads (2007)

Table A 2: Typical Desired Speed for rural roads on which vehicle speeds are influenced by the horizontal alignment

Approximate Range of Horizontal Curve Radii (m)[a]	Desired Speed (km/h)[b, c] Terrain Type			
	Flat	Undulating	Hilly	Mountainous
Less than 75			75	70
75-300		90	85	80
150-500	110	100 - 110	95	90
over 300-500	110	110		
over 600-700	110 - 120			

a. Value selected as representative of the road section's general geometric standard. These are not to be used as design values.

b. Desired Speed as a function of overall geometric standard and terrain type. It is the speed regarded as acceptable to most drivers in the particular environment, and represented by the 85th percentile speed on unconstrained sections, eg straights, curves with radii well above those listed.

c. On roads with a speed limit < 100km/h, the desired speed is typically equal to the speed limit + 10km/h.

Source: Department of Transport and Main Roads (2007)

A.3.2 Motorways and Interchange Ramps

Motorways

The desired speed on motorways is largely influenced by the speed limit and by having a consistent and relatively high geometric standard.

Interchange Ramps

Interchange ramps allow vehicle to move between side streets and major roads or from one major road to another without stopping. On ramps between major roads, the Operating Speed Model must be used. Section 6.3.2 of Chapter 6 has more detail on the special considerations relating to other interchange ramps.

A.3.3 Urban Roads

On urban roads, speeds are limited during the peak hours of the day by the high volume of traffic. Outside the peak, speeds are governed by the speed limit, mid-block friction (lane changes and merging vehicles) and intersection friction. Table A 1: should be used as a guide for selecting the design speed.

A.3.4 Temporary Tracks (including side tracks)

Temporary tracks must still be designed to suit the operating speeds that occur in practice. There may be trade-offs between cost, safety and efficiency.

A.4 Determination of Design Speeds

The design speed applies to individual geometric elements and is the speed used to coordinate design parameters (sight distance, vertical curvature, horizontal radius, superelevation and side friction demand). The design speed must be equal or greater than the 85th percentile speed.

As well as on new roads, operating speeds need to be assessed on existing roads due to changes brought about by driver perception, changes to vehicle performance, driver expectation and driver behaviour. It is important that the correct operating speed in order to find the design speed.

A.4.1 Roads on which Vehicle Speeds are Largely Unaffected by the Horizontal Alignment

On these roads, the desired speed is influenced by the speed limit and road environment rather than the presence of horizontal curvature. A single design speed will acceptable for calculating the various design parameters.

A.4.2 Roads on which Vehicle Speeds are Largely Influenced by the Horizontal Alignment

Operating speeds can vary due to horizontal alignment on roads including:

- Low and intermediate speed rural roads
- Where there is a change in desired speed
- Short and constrained road sections that need a speed reduction but are not long enough to influence desired speed. It is important that the reason for reduced operating speed is apparent to drivers. Operating speeds will quickly revert to the desired speed beyond these sections.
- Urban roads that do not have sufficient curvature or roadside environment such that vehicle speeds vary between geometric elements along the road.

Vehicle operating speeds will vary depending on the horizontal alignment, and the operating speed model can be used to calculate operating speeds at points along the road. The selected design speed must be equal to or greater than the operating speed for the element. While this can vary, it is preferable that it be as consistent as possible along the length of the road.

Using the Operating Speed Model to Predict Operating Speeds

After selecting a horizontal alignment and desired speed, the Operating Speed Model is used to predict the operating speed of cars along the road in each direction.

Predictions using this model are usually within 5 km/h of the actual speed, and that when in doubt it pays to err in favour of the higher possible operating speed. The Operating Speed Model can be used ‘manually’ or with the assistance of the ‘OSroad’ computer program.

A.4.3 Truck Speeds

While cars are the major focus of the operating speed model, trucks should also be considered in the design process, especially in hilly terrain, on tight curves and where sight distance may be insufficient for truck drivers.

A.5 Driver Behaviour and Road Design

Section 6.5 of Chapter 6 touches on some themes relating to driver behaviour, with the overall message emphasising that roads are designed in such a way that they relatively simple for drivers to choose a safe speed and position for their vehicle. Geometric inconsistencies that bring about large changes in speed or direction should be avoided.

A.6 Potential Relative Speed between Vehicles

It is important that the potential relative speed between vehicles is minimised at points of potential conflict. This is covered in Section 6.6 of Chapter 6.

A.7 Decrease in Speed between Successive Elements

Section 6.7 in Chapter 6 outlines the importance of providing consistency in successive geometric elements, and gives guidance as to maximum decreases in speed on various road types.

A.8 Speed Parameters in the Design Process

This section outlines how speed parameters are applied in the geometric design process for new and upgraded roads.

A.8.1 Select Target Speeds

The target speed is determined as part of the overall road or link strategy.

A.8.2 Determine Trial Horizontal and Vertical Alignment

Trial horizontal and vertical alignment should be produced with as large radii as possible. The minimum geometric standards used must be appropriate for the terrain, consistent with the hierarchy of the road and equal or greater than the 85th percentile operating speed.

A.8.3 Determine Desired Speed/s

The desired speed can be estimated using Table A 1 and Table A 2. Desired speeds should remain the same over significant sections of the road, even though the operating speed may vary along that length. The desired speed will typically be 10 km/h over the speed limit.

A.8.4 Check Desired Speed against Target Speed

This helps ensure consistency in the geometric standard at the road link level.

A.8.5 Determine Operating Speeds / Design Speeds

The operating speeds at points along the road determine the design speeds of individual geometric elements. Where operating speeds vary in each direction, the higher speed is used to determine superelevation and side friction for a horizontal curve. The higher operating speed is also used for the design of the vertical alignment element. Sight distance requirements on horizontal curves may be calculated using the respective speed for each direction.

Roads on which Vehicle Speeds are Largely Unaffected by the Horizontal Alignment

On these roads, a single design speed, equal to or greater than the operating speed, is to be used.

Roads on which Vehicle Speeds are Largely Influenced by the Horizontal Alignment

These roads require the Operating Speed Model to predict operating speeds in each direction. This also involves consistency checking and taking into account various other factors including relative speeds between vehicles and speed changes between geometric elements. In cases of complex road alignment, some refinement of the road design may be required.

Interchange Ramps

Speed profiles for the transition between low speed terminals and high speed terminals are covered in Chapter 16 of the Road Planning and Design Manual. Interchanges between two high speed terminals can be designed using the Operating Speed Model.

A.8.6 Relative Speed Checks

Relative speed checks may require another iteration of the alignment design, however experienced designers should minimise relative speed differences early in the process.

A.8.7 Complete Vertical Alignment and Review Horizontal Alignment

After refining the vertical alignment, it may be necessary to review the horizontal alignment.

A.9 Using the Operating Speed Model

The operating speed model is used to predict the operating speed of cars along a road in each direction.

A.9.1 Basic Concepts

Section Operating Speed

Vehicle speeds tend to stabilise if a series of horizontal curves and short straights are 'reasonably similar'. This speed is dependent on the general curve radii and will not exceed the desired speed for that section. This speed is known as the "Section Operating Speed".

Sections

A Section is a geometric element or a chain of closely space elements with similar characteristics.

Driver Behaviour and Road Characteristics

Driver behaviour by car drivers and truck drivers, as well as various road characteristics can impact on the operating speed on a road section.

Desired Speed

The Operating Speed Model does not explicitly encompass the concept of desired speed. Under the Operating Speed Model, there is an implicit desired speed of 110 km/h, which historically been the case for high, intermediate and some low speed rural roads. However, on urban roads and lower speed rural roads, a lower desired speed must be taken into account. This is done by 'capping' the Section Operating Speed at the desired speed.

A.9.2 Operating Speed Model Components

The Operating Speed Model requires dividing the road into sections, and calculating the operating speed using the curve radii and appropriate tables and graphs.

An example of how to follow the Operating Speed Model process is available in Section 6.9.3 of Chapter 6.

A.9.3 Additional considerations when using the Operating Speed Model

Increase in desired speed

The desired speed can increase due to a changed speed limit and/or a change in geometric standard.

Decrease in desired speed

A lowered speed limit can bring about a decrease in desired speed, but this reduction takes place over some time and distance. Changes to road alignment will only change the desired speed if they occur over a sufficient distance.

Increase in speed on a chain of 'short' elements

A number of factors need to be considered when predicting the operating speed through a combination of increasing curve radii. Chapter 6 Section 6.9.4 covers this in detail.

A.9.4 Effect of Grades

Designers are not provided with firm guidance on the effect of grades, but should consider the road grade and make adjustments accordingly.

A.9.5 Effect of Cross-Section

Speeds are typically reduced by about 3 km/h when traffic lanes are 3 m or less. The Operating Speed Model assumes 3.5 m lane width, so adjustments need to be made when this is not the case.

A.9.6 Effect of Pavement Condition

On roads with high roughness or poor quality surfaces, speeds can be reduced by 5 – 10 km/h. The Operating Speed Model assumes the pavement is in good condition.

APPENDIX B EFFECT OF DESIGN SPEED ON DESIGN ELEMENTS

The design speed is used throughout the design process described by the Manual. Knowledge of design speed determined in Chapter 6 of the Manual is required in other chapters of the manual as shown in Table B 1. This sort of analysis helps in understanding the effect of changing the design speed guidance on other design elements.

Table B 1: How design speed affects other design elements, by chapter of the Manual

Chapter in the Manual	Which design elements are affected by design speed?
Chapter 1: Planning and design framework (August 2004)	-
Chapter 2: Design philosophy (December 2005)	-
Chapter 3: Road planning and design fundamentals (December 2005)	-
Chapter 4: Application of design principles and standards (December 2005)	Sets out design speed expectations for different categories of roads; prominent throughout the document with references to Chapter 6 when required.
Chapter 5: Traffic parameters and human factors (August 2004)	-
Chapter 7: Cross section (September 2004)	Design speed used to calculate lane width, kerb and channel, cross-fall and median clearance.
Chapter 8: Roadsides (June 2005)	Selection of clear zones, barrier test levels, run-out lengths, deflections and flare angles for barriers.
Chapter 9: Sight distance (January 2002)	Calculation of manoeuvre sight distance and stopping sight distance.
Chapter 10: Alignment design (August 2001)	-
Chapter 11: Horizontal alignment (May 2002)	Calculation of superelevation, curve radii, side friction, sight distance and other components of alignment.
Chapter 12: Vertical alignment (July 2002)	Calculation of vertical curve length, sag curve length and vertical curve sight distance.
Chapter 13: Intersections at grade (October 2006)	Needed to determine deceleration distances at intersections, turn warrants, intersection sight distance, design adjustments due to grade and in calculating the dimensions of various turning treatments.
Chapter 14: Roundabouts (January 2006)	Used in determining stopping and sight distances at roundabout approach.
Chapter 15: Auxiliary lanes (April 2002)	Lengths, sight distances and tapers of auxiliary lanes.
Chapter 16: Interchanges (December 2005)	Used in the design of ramps, loops and interchanges
Chapter 17: Lighting (August 2004)	-
Chapter 18: Traffic signals (July 2002)	Design speed is specified for design of corner radii at intersections.
Chapter 19: Intelligent Transport Systems (June 2009) is superseded by the Road Planning and Design Manual (2nd edition) Volume 5: Intelligent Transport Systems.	-
Chapter 20: Roadside amenities (March 2002)	-
Chapter 21: Railway and cane railway level crossings (March 2002)	Used to determine maximum superelevation, grade and alignment variations at level crossings.
Chapter 22: Bridges and retaining walls (June 2006)	Referenced in determining the minimum offset to barriers.
Chapter 23: Tunnels (June 2006)	One of the key determining variables in tunnel design – typically between 60–80 km/h.

APPENDIX C VICTORIAN PRACTICE

The following update was issued by VicRoads Design Department to clarify application of the revised design policy. The text has been reproduced with permission from VicRoads.

Update 6: 19 January 2012: Operating Speed for Road Design

The following information is especially pertinent to people involved with preparing road project proposals and deals with the issue of appropriate Operating Speed to use for road design on projects. As you may be aware, this has been a subject of discussion at a number of project specific PRC meetings over the last 12 months or so.

A Project Review Committee (PRC) Meeting was held on 19 December 2011 to review current practice around the use of Operating Speed and how it impacts on road design solutions, review available data and consider changes in current VicRoads design references to clarify design expectations in the use of Operating Speed for the purpose of road design.

The report collated much of the thinking from NAP, RS&NA, Regional staff who have all been dealing with GAA submissions and Technical Consulting.

This Design Alert summarises the discussion held at PRC and decisions made in relation to operating speed and some related matters.

Definition: Operating Speed – 85th percentile speed of cars during daylight hours at a time when traffic volumes are low and drivers are free to choose the speed at which they travel. Generally only vehicles with a minimum of four seconds headway are included in data for determination of 85th percentile speed.

It is important to note that determining Operating Speed only considers vehicle driver behaviour that is not classed as being constrained by surrounding vehicles (i.e. not all vehicles included in sample), hence the nomination of four seconds minimum headway for vehicles surveyed.

Decisions made at the PRC

There were a number of recommendations relating to Operating Speed that were endorsed at the PRC:

Adopt Operating Speed equivalent to the posted speed limit for:

- **Melbourne urban arterial area; and**
- **Major rural cities**

It was considered reasonable that a similar approach (to the Melbourne metropolitan area) be adopted for major rural cities that have an established arterial network and an appropriate speed enforcement program. Appropriate judgement is needed when applying the second recommendation.

Adopt Operating Speed equivalent to the posted speed limit plus 10 km/h for:

- **high speed rural roads (for the time being; subject to further review); and**
- **metropolitan freeways**

Speed study results for these roads do not indicate the same change in driver behaviour as was demonstrated on the urban arterial network. In addition, there is a current Austroads study being undertaken to validate the Operating Speed model in the rural area so further review will be carried out when the study is complete.

In the meantime, when necessary, designers may adopt a risk-based approach using the available speed data to assist in choosing an appropriate Operating Speed (less than 10 km/h greater than the posted speed limit) for a project where design controls warrant an alternative approach to ensure that a value-for-money design solution can be developed. The current Extended Design Domain (EDD) approval process should be used to document decisions made to adopt Operating Speed less than 10 km/h greater than the posted speed limit in high speed rural areas and for existing metropolitan freeways.

Where car Operating Speed equivalent to the posted speed limit has been adopted, adopt Truck Operating Speed equivalent to the posted speed limit for:

- **urban areas; and**
- **major rural cities**

The Austroads Guide to Road Design suggests that a truck operating speed of 10 km/h less than the car operating speed be adopted for design but is silent for cases where the car operating speed is equivalent to the posted speed limit. Review of this requirement was required as a result in the change to car Operating Speed adopted in urban areas.

Continue to adopt 2.5 seconds reaction time as usual practice. Where use of 2.0 seconds reaction time is contemplated, use Austroads Guide to Road Design to assist assessment of risk.

The use of longitudinal friction factor and reaction time in the design process was also discussed at PRC as there have been some changes in approach as a result of adopting the Austroads Guide to Road Design. The decision above clarifies how VicRoads should use the Guide.

Summary

Obviously the main change for VicRoads will be to the minimum design speed values generally permitted to be adopted in the urban area. As always, care needs to be taken when using design guides to ensure that context sensitive designs are produced. Care should be taken with preparation of design briefs and Design and Construct specifications to ensure that the intent of the PRC decisions are met. Further review of specification shells will be carried out.

It is important that designs are approached with an objective of optimising the safety outcome within the design constraints/controls (which can include budget to varying degrees) identified for a particular site - design is not about adopting minimum numbers in a Guide. A key part of this is the development of skills supporting use of appropriate judgement during the design process.

APPENDIX D LITERATURE REVIEW DETAILS

D.1 Effect of Design Speed and Speed Uniformity on Highway Capacity

The subject was divided into the effects of design speed on road capacity, and effects of speed uniformity on road capacity.

D.1.1 Design Speed and Capacity

Design speed influences the selection of values and categories of all major road design elements as noted in Appendix B. At lower design speed, lesser standards of these elements would be selected resulting in potential geometric restraint on the free flowing speed of the uninterrupted flow (e.g. rural roads or freeways).

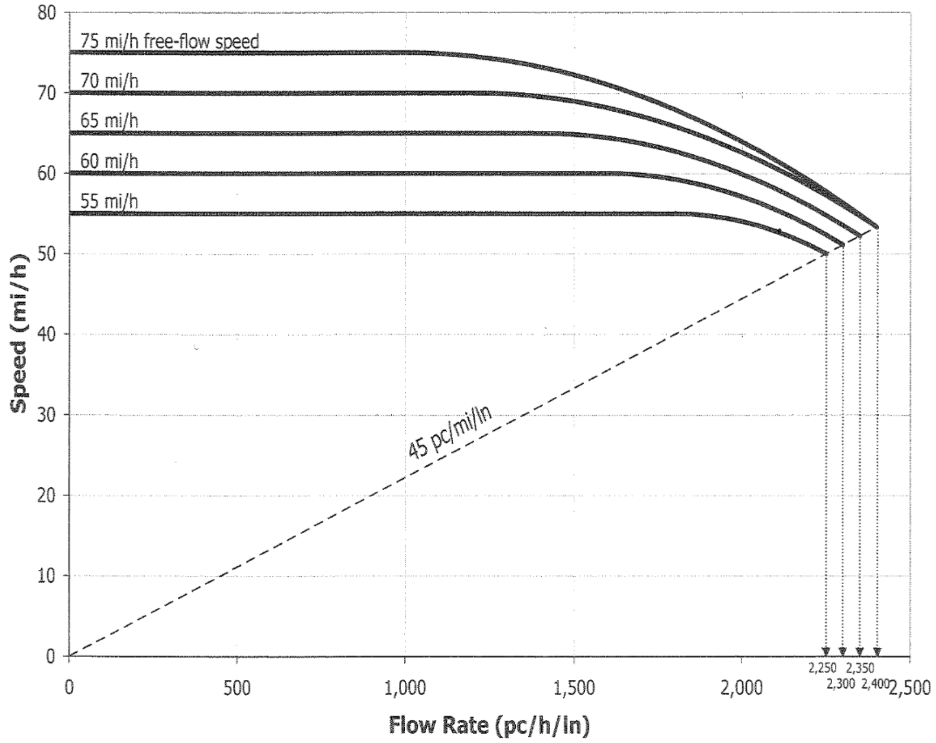
The US Highway Capacity Manual (HCM) Volume 2 (Transportation Research Board 2010a), provides many empirical relationships governing these principles. The key one, relating to free flow speed and capacity is shown in Figure D 2 (freeway segments). As free flowing speed is reduced, the capacity of the segment reduces. It is noted that a very substantial reduction is speed would be needed to make a significant impact on capacity. For instance, Figure D 2 suggests that a drop of 20 mi/h would result in only a 6% reduction in capacity. Such capacity in reduction is only relevant if the traffic volumes are high (e.g. urban freeways). Further, Avrenli et al. (2011) show that capacity was reduced by about 5.5% due to free flow speed reduction of 6 mi/h, caused by enforcement at a roadworks site (lower capacity than suggested by HCM due to local conditions). The authors demonstrated that mobile camera van had a greater effect on capacity than a police vehicle. This is shown on Figure D 3.

The key design elements related to design speed which could reduce free-flowing speed and capacity on freeway segments are:

- clear zone, expressed as ‘lateral clearance’ to objects; matters only if < 2 m
- average lane width; matters only if less than 3.7 m
- grades and their length

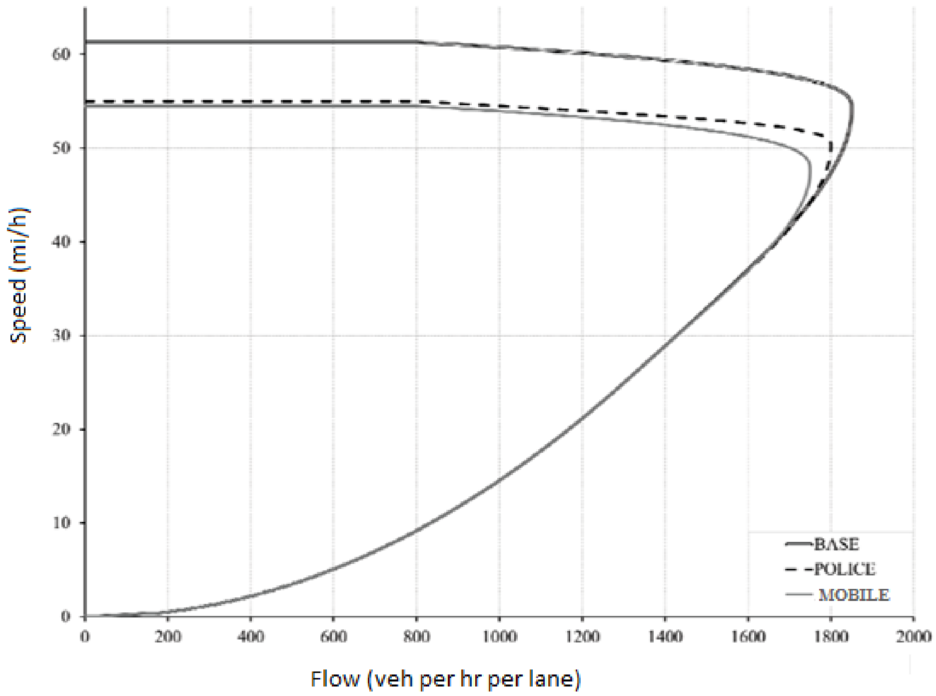
Other significant factors affecting capacity, not directly related to design speed selection, include percentage of heavy vehicles, terrain and ramp density.

Figure D 2: Typical freeway free flowing speed vs. flow rate relationship



Source: Transportation Research Board (2010)

Figure D 3: Average speed-flow curve under general deterrence, police presence and mobile camera enforcement regimes



Source: based on Avrenli et al. (2011)

HCM Volume 2 does not propose any explicit design speed dependent parameters in estimating capacity and operational parameters of freeway weave zones and ramps. It could be speculated, however, that a ramp with a small radius would have reduce the free flowing speed and restrict its capacity. Also, low speed ramp designs can lead to sight distance issues causing increased delays due to incidents. Examples of such ramps can be found on most urban freeways in Australia.

HCM Volume 2 does not suggest that capacity of rural highways is affected by free flowing speed. Rather, it provides capacity correction factors based on terrain, grade and its length, traffic flow, overtaking opportunities and heavy vehicles. All of these indirectly affect the actual traffic speeds. Curve radius is not explicitly noted, but there is a clear effect of hilly terrain on reduced capacity.

The information provided by HCM Volume 2 and 3 (Transportation Research Board 2010a, 2010b) suggests that capacity[1] of other road segment types will be reduced by any factors which reduce the free flowing speed. Relationships similar in nature to that in Figure D 2 are presented for interrupted flow conditions.

Where the traffic flow is interrupted, the road capacity is controlled by the parameters of intersections. HCM Volume 3 does not explicitly list design elements affected by design speed as factors limiting road segment capacity or intersection saturation flow.

It would be reasonable to speculate that severe constraint of design speed and some design elements would negatively affect saturation flow/capacity through introduced delays or flow disruption. These could include:

- lower sight and stopping sight distance requirements – delays due to gap selection
- tighter horizontal curve radii – as above
- tighter turning radii – slower turning movements, lower efficiency
- shorter auxiliary lanes and reduced merge requirements – interruption of free flow and loss of through lane utilisation
- additional permissible road activities adding to traffic friction, e.g. parking
- introduction of signalised intersections on some high-speed roads – delays to the major road
- relaxation of direct access restrictions - more driveways and minor intersections

This point was demonstrated by Bonneson et al. (2005) who developed a model to estimate the effect of several previously unaccounted factors influencing the saturation flow rate of a signalised intersection. The authors showed that speed limit was one of the explanatory variables. The predicted effect of a 20 km/h lower speed limit (80 vs. 60 km/h) was a 7% reduction in the saturation flow rate. The authors noted this was not a causal relationship, but an observation of speed limit’s correlated with the physical characteristics of the street environment, e.g. driveway density, roadside development, footpaths, parking and road segment length. As discussed throughout this report, there is a strong link between speed limit and design speed.

I can be concluded, that a reduction in free flow speed is likely to translate to a reduction in capacity of a roadway segment under uninterrupted flow conditions. Hence, substantial design speed reduction, which results in free flow speed restriction, is likely to have a limiting effect on capacity. This is likely to be an issue on urban freeways and some arterials, where traffic volumes often approach capacity under uninterrupted flow conditions. On roads with interrupted flow, lower design speed may affect intersection capacity more directly through traffic flow disruption.

[1] Or a point at which level of service is severely degraded.

D.1.2 Speed Uniformity and Capacity

The impact of speed uniformity on capacity has not been broadly examined. Speed uniformity should increase as uninterrupted traffic flow approaches capacity due to high flow density (vehicles per lane kilometre). Under high density conditions heavy platooning and low headways restrict the opportunity for speed differences between vehicles and lane changes.

It is also noted by Burley and Gaffney (2010) that one of freeway flow breakdown causes is speed differential between vehicles, e.g. due to a slow heavy vehicle. Many other listed reasons for flow breakdown were also directly related to difference in vehicle speeds, e.g. police presence, driver behaviour (‘rubber-necking’, excessive speeding), and sudden flow spikes. All of these are unusual events rather than parts of a normal speed distribution. No references to this issue could be found in the HCM.

Seminal research by Olcot (1955) showed that limiting the slow end of the speed distribution appeared to increase capacity. This was achieved by banning underpowered trucks and installing minimum speed limits in the Lincoln Tunnel in New York.

It is difficult to draw a definitive conclusion from the available information on the effect of speed uniformity on capacity.

D.2 Effect of Speed Limit Enforcement on Speed Compliance, Observed Speeds and Speed Uniformity

D.2.1 The Effects of Speed Limit Enforcement

Speed limit enforcement is one of the tools for driver speed management. Other tools include setting of appropriate speed limits, road design (local and arterial traffic calming) and driver education. The literature reviewed in the following sections shows speed limit enforcement to be an effective tool in moving towards compliance with speed limits, lower mean and operating speeds, and greater speed uniformity. Safety improvements are also quantified.

Increased levels of speeding often occur when speed limits do not match driver expectations given the road environment. In the Netherlands where some rural speed limits were set in accordance with the harm minimisation principles, additional police enforcement was required to reduce the large numbers of speeding vehicles (SWOV 2012a). This and other learnings show that enforcement may be required if the new speed limit is a reduction of 10 km/h or more from the existing mean speed and no changes to existing infrastructure are being made (Jurewicz and Turner 2009).

Elliott (2001) identified enforcement as one the four main determinants of driver speed, along with the driving environment, behaviour of other drivers and societal norms. Enforcement is most effective in reducing speeds when drivers have a perceived high risk of detection, thus reducing the perceived benefits of speeding (Oxley and Corben 2002; Elliott et al. 2003). This is achieved through widespread, highly visible and constant presence of speed limit enforcement.

There are a number of different types of speed limit enforcement that achieve varying degrees of compliance. The main types and their effectiveness will be discussed in the following sections.

D.2.2 Fixed Speed Cameras

The effectiveness of fixed speed cameras was assessed after installation in the Domain Tunnel in Melbourne (Diamantopoulou and Corben 2002). Average vehicles speeds were reduced by 3.4%, but more notably the proportion of drivers exceeding 80 km/h (the speed limit) was reduced by 66% and extreme speeding (30 km/h over the speed limit and higher) was reduced by 76%.

In 2005, fixed speed cameras were studied by ARRB Group at 28 locations in both rural and urban NSW over a two year period. Vehicle speeds were found to have reduced by approximately 6 km/h, and 85th percentile speeds had reduced between four and 20% over the locations. Some increases in speed was consequently experienced on adjacent roads to the speed cameras. Casualty crashes were reduced by 23% and fatal crashes by almost 90% (current Austroads project ST1768).

Elvik et al. (2009) performed a meta-analysis of the effectiveness of fixed speed cameras from a number of studies. Crashes were estimated to have been reduced by 16% and fatal crashes by 39%. The analysis corrected for publication bias.

A study of the national safety camera program in the UK was studied during its implementation in 2000 and 2003 (Gains et al. 2004). It was found that vehicle speeds reduced by 8% and speeding vehicles by 71% in all urban camera locations. There was a 33% reduction in injury crashes (statistically significant) and a 51% reduction in the number of casualties at the locations.

It should be noted that most studies fail to account for general crash trends, regression-to-mean (RTM) and crash migration effects when measuring the speed and safety impact of speed cameras. Mountain et al. (2004) attempted to control for these factors when studying 62 fixed speed cameras in the UK on 30 mph (48 km/h) roads displaying problematic speeding issues. Data was collected for three years prior to camera installation and up to three years after. Across all sites, the mean speeds dropped from 32.8 mph (52.8 km/h) to 28.4 mph (45.7 km/h) and 85th percentile speeds reduced from 38.9 mph (62.6 km/h) to 33.0 mph (53.1 km/h). This equated to a 35% reduction in speeding drivers. After controlling for crash trends, it was established that there was an injury crash reduction of 30% and a casualty crash reduction of 29%

D.2.3 Mobile Speed Cameras

Mobile speed cameras allow speed enforcement to be implemented both broadly and at individually-identified problem locations. A number of studies have found similar positive results:

- An evaluation of Queensland’s mobile speed camera program found a 45% reduction in fatal crashes within 2 km of camera sites and significant reductions of other crash types. This was calculated to be an overall reduction of 32% in fatal crashes across Queensland when the speed camera program was at maximum coverage (Newstead and Cameron 2003).
- A similar study on urban arterials in the ACT found a 59% reduction in the number of drivers exceeding 10 km/h above the speed limit, but also a 39% reduction in the same drivers at control sites. Fatal and serious injury crashes reduced by 36% at camera locations, and no change was detected at the controls (Anderson and Edgar 2001).
- A before and after study of mobile speed cameras at 101 treatment sites compared to 101 control sites found a statistically significant reduction (61%) in crashes within 100 metres of the site, with particular reductions in crashes during daylight hours, on 30 mph (48 km/h) roads and involving pedestrians and passengers (Christie et al. 2003).
- A before and after study of mobile speed camera usage in the city of Charlotte (USA) found a drop in mean speeds of 0.88 mph (1.4 km/h, statistically significant) and a drop of 0.99 mph (1.6 km/h) drop in 85th percentile speeds. There was a 55% reduction in the number of drivers exceeding the speed limit by more than 10 mph (16 km/h) and a 12% reduction in total crashes (Cunningham et al. 2005).

Gains et al. (2004), in their assessment of the UK national safety camera program, compared the effectiveness of fixed and mobile speed cameras. It was suggested that mobile cameras were less effective on speed and casualty crash reduction, as the number of casualties fell by 28% at mobile sites in comparison to 51% at fixed camera sites. Similarly, speeding drivers were reduced by 21% at mobile sites and 71% at fixed sites.

Elvik et al. (2009), similar to their study on fixed cameras, performed a meta-analysis of mobile speed camera studies. The authors found a 10% reduction in all injury crashes and 16% in fatal crashes (not statistically significant). It was also concluded that pairing a speed camera program with a publicity campaign yielded a small but non-significant benefit.

Avrenli et al. (2011) show the effect of various levels of speed limit enforcement on a US freeway capacity under uninterrupted flow conditions. During roadside works, the speed limit was reduced to 88 km/h (55 mph). Speed and capacity were measured under:

- typical enforcement conditions (i.e. general deterrence)
- visible police vehicle presence
- mobile speed camera van.

Drivers' response to direct speed limit enforcement with a police vehicle or mobile camera was in the reduction in speed to match the speed limit (from approximately 61 mi/h to 55 mi/h). The authors observed that the mean speed reduction was comparable for the police vehicle and the mobile camera van. They did not analyse other speed compliance parameters.

D.2.4 Point-to-point Speed Cameras

Point-to-point cameras measure vehicle speeds over a known distance by taking timestamps at two locations. The average speed can then be calculated of a selected vehicle using number plate recognition technology (ANPR). Point-to-point cameras can be used for enforcing speed limits, gathering travel time data and criminal investigations (Austroads 2012). The Austroads (2012) guide to point-to-point speed enforcement provides a broad overview of implementations throughout Australia and New Zealand. A number of trials were in progress at the time of writing, however no point-to-point speed enforcement studies have been completed in Australia or New Zealand since the publication of this guide. This type of speed camera is generally considered on controlled access roads due to the need to minimise entry and exit points along the section (e.g. freeways, links, and rural road sections).

The Department of Public Works Management (2003) carried out an evaluation of a speed limit reduction from 100 km/h to 80 km/h combined with point-to-point enforcement on the A13 motorway near Overschie, the Netherlands. The results showed higher speed compliance and reduced mean speeds, and in the same study and a follow-up modelling study of other motorways it was established that mean speeds were reduced under free-flowing conditions using this enforcement method (Department of Public Works Management 2003; Olde et al. 2005).

A point-to-point speed enforcement system in a 2.3 km urban tunnel in Vienna, Austria, showed a mean speed reduction of 15 km/h initially, and 10 km/h six months after implementation (5 km/h below the posted speed limit) (Stefan 2006). The system also yielded a 33% and 49% reduction in injury and casualty crashes respectively after controlling for general trends.

Speed Check Services (n.d.) is the system operator of many point-to-point systems in the UK. It is well established that the system is particularly effective in reducing vehicle speeds and crashes, with 85^{th} percentile speeds reduced between 4 mph (6.4 km/h) and 13 mph (20.9 km/h) (Speed Check Services 2010). Austroads (2012) established that this gave a reduction of 33–85% in casualty crashes.

The Norwegian Public Roads Administration evaluated a trial of point-to-point speed limit enforcement technology at three different sites (Ragnøy, 2011). At the first site, mean speed fell from 76.7 km/h to 74 km/h 10 weeks after implementation of the point-to-point speed limit enforcement followed by a further slight reduction to 73.6 km/h 25 weeks after implementation. At the same time, the percentage of vehicles exceeding the posted speed limit (80 km/h) fell from

36.8% to 23% while the percentage of vehicles exceeding the speed limit by 10 km/h or more fell from 4.1% to 1.4%. However, there were reductions in traffic volume at this site. The study also reported reductions in average speed at the second and third sites as well as increases in compliance and reductions in speed variability.

Montella et al. (2012) evaluated the application of point-to-point enforcement on sections of the Milan-Naples Motorway in Italy. The study was designed as a before-after empirical Bayes analysis. The findings of this evaluation indicated overall crash reductions of 31.2% with severe crashes falling by 55.6% and non-severe crashes by 26.6%. They also found that the effectiveness in terms of crash reductions fell slightly with time. While this study indicated overall safety benefits, it did not outline the speed changes.

D.2.5 Combined Speed and Red Light Cameras

Red light cameras are installed to detect vehicles that cross the control line at an intersection after the traffic lights have turned red. Often they are installed in combination with fixed speed cameras. There are a number of studies that have investigated the effectiveness of red light cameras on their own (e.g. Austroads 2004; Radalj 2001; Thoresen et al. 2008), however this section will predominantly look combined speed and red light camera studies:

Crash reductions were assessed at 87 sites with combined speed and red lights in Victoria (Budd et al. 2011). Casualty crashes were reduced by 47% on camera approaches and 26% across the intersection. Minor crashes showed similar reductions. There was no statistically significant increase in rear-end crashes. It was suggested that without the presence of the speed camera drivers are tempted to accelerate to beat the red light.

The Centre for Road Safety (2010) assessed the crash reductions at 13 new sites and 44 sites previously with old red light cameras after new combined speed and red light cameras were installed. There was a recorded 34% reduction in injury crashes and a 26% reduction in all crashes.

D.2.6 Non-enforcement Approaches

Feedback signs

Feedback signs are a type of vehicle activated sign that commonly use radar to measure vehicle speeds and present it back to the driver on a digital display. This makes drivers aware if they are speeding and to what extent, and encourages conformity through the perceived risk that they will get caught doing so (Mabbott and Cairney 2002). Mabbott and Cairney (2002) studied the effect of feedback signs across multiple countries and found mean speed reductions between 3.5 and 8.0 km/h, and slightly higher reductions for 85^{th} percentile speeds. Some treatment sites saw benefits in the surrounding streets to the feedback signs.

Intelligent Speed Adaptation (ISA)

Intelligent speed adaptation (ISA) is a type of in-vehicle technology that is used to assist drivers in conforming to posted speed limits. ISA systems generally use global positioning systems (GPS) or satellite navigation technology to assess whether a driver is speeding in comparison to the local speed limit and to inform the driver if that is the case. The Euro NCAP Safety Assist Assessment Protocol (Euro NCAP 2012) now includes ISA technologies.

ISA can include the following systems:

- advisory – audio or visual information about local speed limits
- supportive – provides information and warns the driver when the driver is exceeding the speed limit

- limiting – interacts with vehicle, e.g. by providing resistance on the accelerator pedal when the driver attempts to exceed the speed limit.

ISA technologies can be voluntary or mandatory. Voluntary means the system provides advice about speeding but the driver ultimately has control to drive at any chosen speed. Mandatory systems override driver control and limits the ability for a driver to speed (Cartsen et al. 2006).

Table D 2 provides a summary of the effects of ISA on mean speed, standard deviation of speed and speed violations from a number of studies (SWOV 2010).

Table D 2: Summary of ISA evaluation studies

Study	Methodology	Country	Effect on mean speed	Effect on standard deviation of speed	Speed violations
Comte (2000)	Driving simulator	United Kingdom	Decrease	Decrease	?
Peltola and Kulmala (2000)	Driving simulator	Finland	+	Decrease	?
Hogema and Rook (2004)	Driving simulator	Netherlands	Decrease	Decrease	Decrease
Van Nes et al. (2007)	Driving simulator	Netherlands	Decrease	Decrease	Decrease
Brookhuis and De Waard (1999)	Instrumented vehicle	Netherlands	Decrease	Decrease	Decrease
Päätalo et al. (2001)	Instrumented vehicle	Finland	Decrease	?	Decrease
AVV (2001a; 2001b)	Field trial	Netherlands	Decrease	Decrease	?
Lahrmann et al. (2001)	Field trial	Denmark	Decrease	?	?
Biding and Lind (2002)	Field trial	Sweden	Decrease	Decrease	Decrease
Regan et al. (2006)	Field trial	Australia	Decrease	Decrease	Decrease
Vlassenroot et al. (2007)	Field trial	Belgium	Decrease	Decrease	Decrease

Notes: + increase, ? not investigated.
Source: SWOV (2010).

Various other studies have demonstrated the benefits of ISA systems:

- SWOV (2012b) claimed that ISA improves driver compliance with speed limits that are set significantly below driver expectations due to the road environment and that better results are achieved through the use of 'limiting' ISA systems.
- Vägverket (2002) reported reduced approach speeds at intersections, reduced speed variance and reduced fuel consumption.
- Lind (2000) reported a reduction from 94% to 6.6% in the number of vehicles speeding on 30 km/h speed limited roads in Borlänge.
- Two studies demonstrated midblock mean speed reductions of 2.5–5 km/h on 70 and 50 km/h roads, as well as improved driver behaviour (giving way to pedestrians, slower approaches to intersections, increase following distances) (Hjälmdahl et al. 2002; Váhelyi et al. 2002).

ISA usage is gaining momentum in certain sectors in Australia, particularly in small private companies using ISA in truck fleets (Crackel and Toster 2007). Advisory ISA are available to the public in NSW and most new cars equipped with navigation systems. NSW is also undertaking a speed limit database project which will facilitate the future usage and adoption of ISA technologies. The Road Safety Council in Western Australia has previously demonstrated the usage of advisory ISA through qualitative trials on driver experiences using the technology. Crackel (2009) reported that during Phase 1 the drivers generally felt positively towards the ISA usage.

APPENDIX E DETAILED DATA ANALYSIS

Table E 1: Comparing operating speeds with the speed limit – detailed results

Region	Road type	No. sites	No. vehicles	85th percentile speed	95% confidence interval		Standard deviation
					Lower	Upper	
Metro Brisbane	Brisbane urban divided 60 km/h	15	4715	**66.4**	66.17	66.69	9.00
	Brisbane urban divided 80 km/h	12	3887	**79.8**	79.58	79.94	5.71
	Brisbane urban divided 100 km/h (urban freeway)	5	7352	**99.9**	99.74	99.97	4.92
	Brisbane urban/rural undivided 80 km/h[1]	11	3518	**83.0**	82.79	83.16	5.50
South East Queensland[1]	SEQ ex. Brisbane urban undivided 60 km/h	34	18144	**64.1**	63.91	64.20	10.02
	SEQ ex. Brisbane urban divided 80 km/h	13	3487	**82.7**	82.46	82.84	5.83
	SEQ ex. Brisbane urban divided 100 km/h	12	9049	**102.1**	101.92	102.35	10.34
	SEQ ex. Brisbane rural/urban undivided 60 km/h[2]	2	945	**84.6**	84.08	85.14	8.31
	SEQ ex. Brisbane rural/urban undivided 70 km/h	3	1819	**85.5**	85.00	85.93	10.10
	SEQ ex. Brisbane rural/urban undivided 80 km/h[2]	67	25002	**85.3**	85.82	86.04	9.04
	SEQ ex. Brisbane rural undivided 100 km/h	58	56659	**93.3**	93.19	93.45	15.79
	SEQ ex. Brisbane rural divided 100 km/h	1	987	**105.6**	105.51	105.71	1.58
	SEQ ex. Brisbane rural divided 110 km/h	10	7302	**112.4**	112.36	112.47	2.45
Regional Queensland	Regional urban undivided 60 km/h	26	96352	**61.1**	61.06	61.14	6.00
	Regional urban divided 80 km/h	11	10338	**83.4**	83.38	83.49	2.84
	Regional rural undivided 100 km/h	60	66273	**103.3**	103.19	103.38	12.55
	Regional rural undivided 110 km/h	45	182041	**108.3**	108.21	108.31	10.63
	Regional rural and urban divided 100s	5	8866	**102.5**	102.48	102.59	2.58

Bold statistically significant at $p<0.05$
6 excludes Brisbane
7 urban fringe sites

Table E 2: Comparing mean speeds with the posted speed limit – detailed results

Region	Road type	No. sites	No. vehicles	Mean speed	Speed limit	95% confidence interval		Standard Deviation
						Lower	Upper	
Metro Brisbane	Brisbane urban divided 60 km/h	15	4715	**58.5**	60	58.23	58.75	9.05
	Brisbane urban divided 80 km/h	12	3887	**70.9**	80	78.23	78.75	8.04
	Brisbane urban divided 100 km/h (urban freeway)	5	7352	**87.8**	100	87.53	88.06	11.60
	Brisbane urban/rural undivided 80 km/h[1]	11	3518	**74.4**	80	74.19	74.58	6.00
South East Queensland[1]	SEQ ex. Brisbane urban undivided 60 km/h	34	18144	**55.6**	60	55.49	55.79	10.11
	SEQ ex. Brisbane urban divided 80 km/h	13	3487	**73.1**	80	72.79	73.32	7.88
	SEQ ex. Brisbane urban divided 100 km/h	12	9049	**93.4**	100	93.19	93.58	9.37
	SEQ ex. Brisbane rural/urban undivided 60 km/h[2]	2	945	**73.9**	60	73.60	74.28	5.34
	SEQ ex. Brisbane rural/urban undivided 70 km/h[2]	3	1819	**75.1**	70	74.62	75.52	9.74
	SEQ ex. Brisbane rural/urban undivided 80 km/h[2]	67	25002	**76.5**	80	76.39	76.60	8.53
	SEQ ex. Brisbane rural undivided 100 km/h	58	56659	**82.1**	100	81.95	82.22	16.09
	SEQ ex. Brisbane rural divided 100 km/h	1	987	**94.4**	100	94.25	94.63	3.06
	SEQ ex. Brisbane rural divided 110 km/h	10	7302	**103.7**	110	103.66	103.84	3.99
Regional Queensland	Regional urban undivided 60 km/h	26	96352	**54.2**	60	54.17	54.25	6.37
	Regional urban divided 80 km/h	11	10338	**76.2**	80	76.12	76.26	3.65
	Regional rural undivided 100 km/h	60	66273	**93.0**	100	92.93	93.11	12.44
	Regional rural undivided 110 km/h	45	182041	**96.6**	110	96.55	96.65	11.34
	Regional rural and urban divided 100s	5	8866	**93.5**	100	93.41	93.56	3.71

Bold statistically significant at p<0.05
8 excludes Brisbane
9 urban fringe sites

Table E 3: The percentage of vehicles exceeding the posted speed limit by road stereotype

Region	Road type	Exceeding speed limit (%)	No. vehicles	Exceeding speed limit by 1-10 km/h (%)	No. vehicles	Exceeding speed limit >10 km/h (%)	No. vehicles
Metro Brisbane	Brisbane urban divided 60 km/h	45.4	4707	29.9	4704	15.5	4271
	Brisbane urban divided 80 km/h	20.1	3887	17.6	3887	2.5	3681
	Brisbane urban divided 100 km/h (urban freeway)	25.4	7350	22.5	7350	2.9	7324
	Brisbane urban/rural undivided 80 km/h[1]	32.7	3468	25.8	3448	6.9	3393
South East Queensland[1]	SEQ ex. Brisbane urban undivided 60 km/h	29.3	17619	17.6	17547	11.7	12230
	SEQ ex. Brisbane urban divided 80 km/h	27.2	3483	21.5	3482	5.7	3439
	SEQ ex. Brisbane urban divided 100 km/h	30.7	8876	22.1	8810	8.6	8330
	SEQ ex. Brisbane rural/urban undivided 60 km/h[2]	91.3	944	31.6	837	59.7	938
	SEQ ex. Brisbane rural/urban undivided 70 km/h[2]	71.6	1747	33.6	1649	38.0	1591
	SEQ ex. Brisbane rural/urban undivided 80 km/h[2]	41.4	23620	26.5	23070	14.9	20536
	SEQ ex. Brisbane rural undivided 100 km/h	22.5	42007	16.8	40438	5.7	31326
	SEQ ex. Brisbane rural divided 100 km/h	36.0	987	30.1	987	5.9	987
	SEQ ex. Brisbane rural divided 110 km/h	23.9	7302	21.1	7302	2.8	7209
Regional Queensland	Regional urban undivided 60 km/h	24.5	94361	20.5	93783	4.0	72941
	Regional urban divided 80 km/h	32.5	10337	28.7	10337	3.8	10212
	Regional rural undivided 100 km/h	41.7	54722	32.9	51496	8.8	42923
	Regional rural undivided 110 km/h	24.5	130819	19.5	123029	5.0	88415
	Regional rural and urban divided 100s	24.2	8859	20.2	8854	4.0	8539

10 excludes Brisbane
11 urban fringe sites

Table E 4: Percentage of sites which would have operating speeds above speed limit plus 5 km/h threshold

Road type	% above SL+5
60 km/h undivided	23%
60 km/h divided	58%
80 km/h undivided	47%
80 km/h divided	21%
100 km/h undivided	54%
100 km/h divided	38%
110 km/h undivided	3%
110 km/h divided	17%