A FRESH APPROACH FOR PRIORITISING AND TREATING HIGH RISK CURVES

***Authors*:**

Carl O'Neil (Presenter)
BE(Hons), GIPENZ
Transportation Engineer
Abley Transportation Consultants Ltd
Contact: carl.oneil@abley.com

Paul Durdin
BE(Hons), CPEng, MIPENZ, MInstD
Director
Abley Transportation Consultants Ltd
Contact: paul.durdin@abley.com

Raja Abeysekera
BE (Civil), Grad Dip Mgmt., MIE Aust., CPEng
A/Manager Safer Roads
Transport for NSW: Centre for Road Safety
Contact: Raja.Abeysekera@transport.nsw.gov.au

ABSTRACT

In response to the increasing road toll in New South Wales (NSW), The Centre for Road Safety NSW (CRS) sought to reduce the number of fatal and serious crashes occurring outside of metropolitan areas on high speed (80km/h+) roads, especially on curves.

The Austroads Operating Speed Model for rural roads was used to calculate speeds using a Geographic Information Systems (GIS) based methodology. Using calculated speeds and horizontal curve radii, the methodology allowed the design limit of curves to be assessed. The results of this analysis were used in combination with crash data to identify corridors of road with the highest risk of curve-related crashes. A Treatment Hierarchy was then developed to aid practitioners in choosing appropriate treatments for curves identified as high-risk. The methodology was also used to assess the safety benefits arising from changes to speed limits using a modified form of Nilsson's Power Model.

The methodology used takes account of both safety risk through the GIS analytic techniques developed and economic considerations through the Treatment Hierarchy. This will allow the CRS to target safety spending towards projects which yield the greatest safety benefits.

INTRODUCTION

Statistics from NSW show that the gradual reduction in the road toll from January 2011 through to March 2015 reversed sharply in the 12 months to March 2016. Figure 1 shows that in the 12-month period to date the NSW road toll is up 90 (30%) on the previous 12 months. The sharp spike in the road toll was naturally of serious concern and the Centre for Road Safety NSW (CRS) urgently sought guidance on focussed implementation methods to reverse the trend.

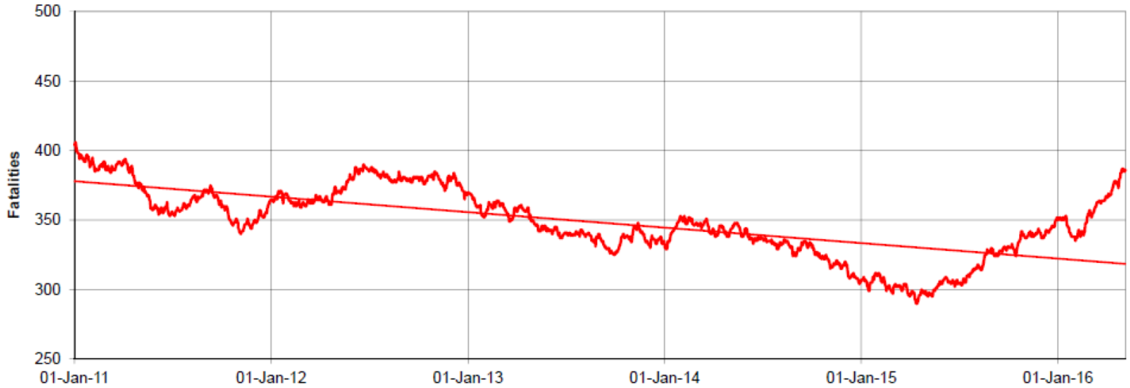

Figure 1 – NSW road fatalities (2011-2016)

One of the identified focus areas was reducing the number of fatal and serious crashes occurring outside of metropolitan areas on high speed (80km/h+) roads, especially on curves. Fatalities are over-represented in rural areas of NSW, particularly on local roads. Current national programs do not focus enough on these safety risks which led the CRS to focus its expenditure on high risk curves and roads with high fatigue risk.

To support funding bids and inform a program of works to address these issues, the Austroads Operating Speed Model for rural roads was used to calculate speeds using a new Geographic Information Systems (GIS) methodology. Using calculated speeds and horizontal curve radii, the model allowed the assessment of the design limit of curves. The results of this analysis were then combined with crash data to identify road corridors with the highest risk of curve-related crashes. A Treatment Hierarchy was also developed to aid practitioners in choosing appropriate treatments for curves identified as high-risk. The methodology was also used to assess the safety benefits arising from changes to speed limits using a modified form of Nilsson's Power Model.

VEHICLE SPEED MODEL AND IDENTIFICATION OF HIGH RISK CURVES

The NSW road network consists of a variety of corridors with various functions and traffic volumes. A particular issue for road safety officials are rural road crashes which occur on curves (48% of all injury rural road crashes 2009-2013[1]). Because crashes occur at random, numerous fatal and serious crashes occur on parts of the network where high-severity crashes have not occurred in the recent past. In these areas, relying on crash history alone to predict where future crashes will occur is unreliable.

A new methodology was applied using Geographic Information Systems (GIS) technology which could identify and assess the risk of all curves on a network independent of crash history. The results of this assessment were used to prioritise corridors in terms of their risk of curve related crashes. A 'treatment hierarchy' was then developed to assist practitioners in choosing appropriate treatment options for corridors highlighted as high risk.

The process used to identify and assess curves on the NSW network is summarised in the following section. Further explanation regarding this methodology can be found in Haris and Durdin (2015).

Identifying and assessing curves on a network

The Austroads (2009) operating speed model predicts the operating (85th percentile) speed of cars travelling in each direction along a section of rural road based on the geometric features of the road. The model mimics the real-world behaviour of drivers based on a large number of car vehicle observations. As such, the model only applies to cars and cannot be used to predict the operating speeds of other types of vehicle. Using calculated speeds and horizontal curve radii, the model allows users to assess the design limit of curves.

With 37,000 km of State and Regional rural roads, manually assessing the risk of each curve in the NSW region using the Austroads model would be time-consuming and cost-prohibitive. As the inputs to the Austroads operating speed model are available in a spatial format, the model was therefore automated using a GIS methodology. This included the use of GIS models that separate a road network into discrete corridors, identify curves, predict vehicle operating speeds along road corridors, and assess curve risk using approach speeds and radius.

Input data

The analysis relied on a number of road and environmental datasets. The most important dataset was a high-quality road centreline sourced from a third-party data supplier. The centreline was cleaned to remove any errors in alignment and visually inspected to ensure that it was fit for purpose. This dataset closely represented actual road alignment and could be used to accurately identify curves and calculate curve radii. Other road datasets, including a road centreline dataset provided by Roads and Maritime Services, were used to extract road characteristics including surface type, speed limits, carriageway width and AADT. A digital elevation model (DEM) with 30 metre resolution provided by the Australian Government was used to extract terrain using advanced analysis in GIS. Crash data from the CRS's Crashlink database was used for risk mapping and speed model validation.

Segmenting the network into corridors

The network was split into logical corridors based on where vehicles would be required to slow or stop at an intersection or where a corridor met an urban boundary. The start speed for each road corridor was then estimated according to the start context. The maximum speed on any road was calculated as a function of curvature and terrain. These values are based on the desired speeds in Austroads (2009) – the maximum speed regarded as acceptable to most drivers for the particular environment. Curvature data, measured as degrees of turn per kilometre, was provided by the CRS with the centreline dataset and terrain data was provided by the Australian Government.

[1] State and regional roads only

Curve identification

Discrete curve sections were extracted and dissolved into single curved segments by adapting the methodology in Cenek et al. (2011). Sections of road with curves of a similar radius separated by short straights (less than or equal to 200m) were identified as discrete sections with an operating speed identified within a narrow range of values (minimum and maximum operating speeds). When drivers travel through a series of curves with similar radii, their speeds stabilise to a level they feel comfortable with (Austroads, 2009). Section operating speeds for single, isolated curves were also calculated.

Identifying out-of-context curves

Once curves had been identified, each road corridor was divided sequentially into a series of curves with known radii, and straights with known lengths. Speeds were then modelled along the road centreline in both directions. The exit speed at the end of each curve or straight is applied as the approach speed for the following section of road. For each curve where deceleration is modelled, the design limit is identified as either out-of-context (unacceptable or undesirable) or within context (desirable or no deceleration). Where a curve is out-of-context, the speed at which a typical driver travels along the straight prior to the curve is higher than the speed required to negotiate the curve safely. A curve is considered within context when a typical driver is already driving close to or at the speed required to negotiate the bend safely. For the purposes of this paper, a 'high-risk curve' is defined as an out-of-context curve (OoCC) identified by the process described above. Vertical alignment was not accounted for in this work due to a lack of available data. While this is a limitation of the work, vertical alignment was not expected to have a large effect on the results of this work on most road corridors.

It is important to appreciate that a curve may be out-of-context in only one direction. This is best demonstrated by Figure 2 where a series of curves before the lowest radii curve slows down the travel speed of southbound drivers. As a result, the lowest radii curve is in-context in the southbound direction but out-of-context in the northbound direction because of the larger radii curves on the northbound approach which support higher operating speeds. In this particular case, the out-of-context curve is exacerbated slightly by a downhill gradient.

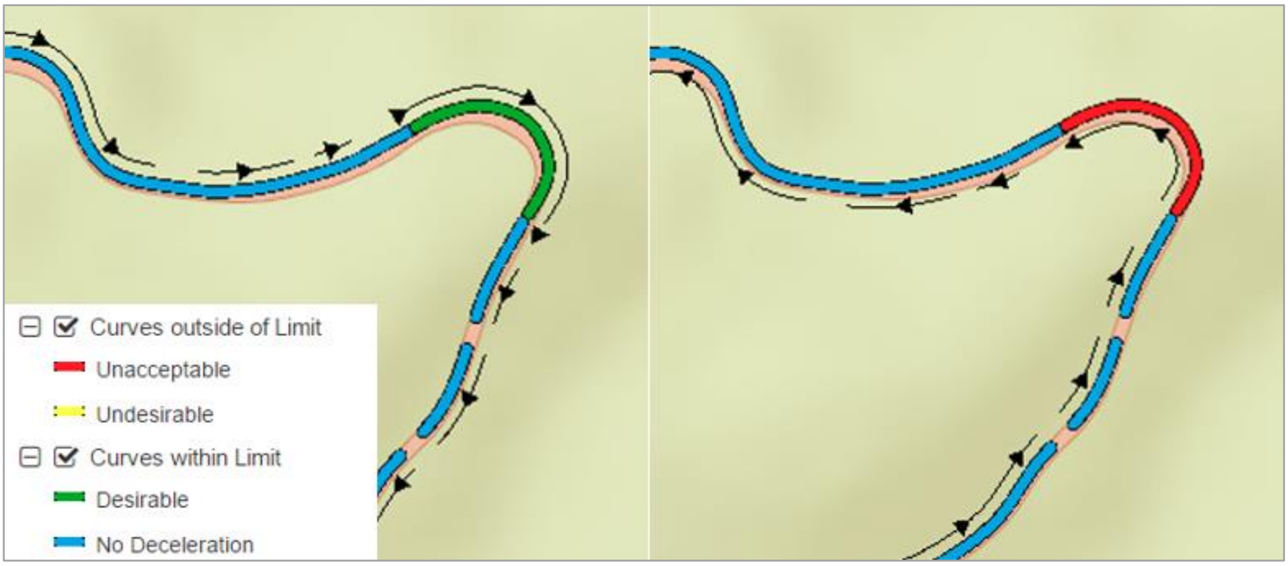

Figure 2: Curve Analysis on Alpine Way, Southwest NSW in southern direction (left) and northern direction (right)

Figure 3 shows a situation where one moderately sharp OoCC is followed by several curves which are within context. This occurs because drivers slow down sufficiently at the first curve and do not have a straight section long enough to accelerate before the following curves. This example highlights a situation where safety interventions are more necessary on the first curve encountered even if subsequent curves have a lower radii and lower negotiation speed.

Figure 3: Curve Analysis on Alpine Way, Southwest NSW in eastern direction

Identifying crashes occurring on curves

For the purposes of this work, all crashes which occur on a curve or within 50m of the curve extents are classified as a curve crash. A distinction is made between crashes occurring on an OoCC and 'all curves'. It should also be noted that the worst curve classification for either direction of travel is taken as the curve rating for the purposes of analysis. This analysis has been undertaken such that a single crash can only be attributed to one curve even if it is within 50m of more than one curve.
By way of example, the 'Undesirable' curve in Figure 4 would be considered to have three non-injury crashes and three serious crashes occurring on it. The fatal crash just south of the curve is more than 50m from the end of the curve so is not considered to have occurred on the curve. The 'No Deceleration' curve would be considered to have one serious crash occurring on it.

Once the number of crashes on each curve is known, the number of crashes occurring on curves along each corridor are totalled. For example, if the small section of road shown in Figure 4 was a corridor, it would be considered that six crashes occurred on an OoCC and seven crashes occurred on 'all curves'.

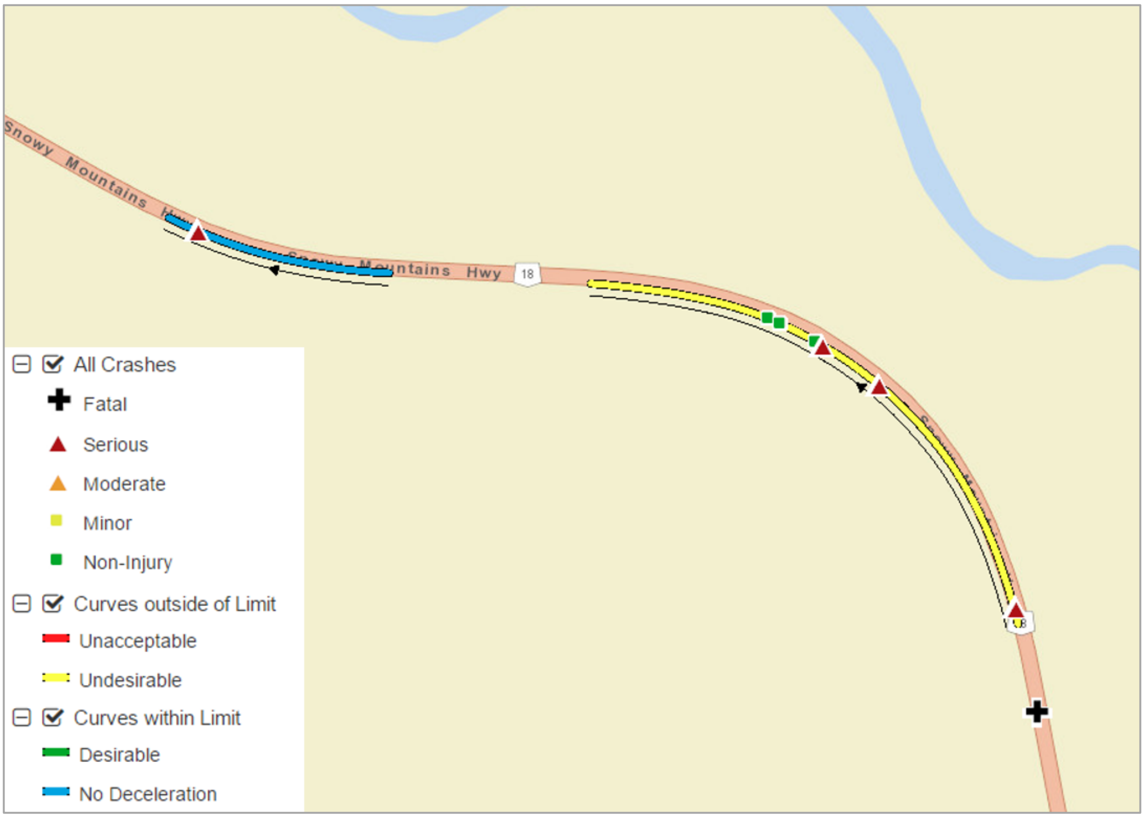

Figure 4: Curve Analysis on Snowy Mountains Highway, Southwest NSW in northern direction

Estimating the Safety Benefits of Speed Limit Changes

While speed management interventions were not the focus of this project, the estimation of death and serious injuries (DSi) that can be saved as a result of speed management interventions has been calculated for all corridors in the NSW region. It is expected that these results will be formalised and published in a guidance document in the near future.

The estimation of death and serious injuries (DSi) that can be saved as a result of speed management interventions is based on a form of Nilsson's Power Model. Recent studies undertaken by Elvik (2009) and Cameron et al. (2010) confirm that speed environment is an important moderator of Nilsson's Power Model. Elvik concluded that in general, changes in speed have a smaller effect at low speeds than at high speeds. Furthermore, the analyses show that the exponents proposed by Nilsson based on speed limit changes in Sweden during 1967-1972 overestimate the expected DSi reductions due to various safety improvements in the last 40 years. However, both authors acknowledge that the Power Model remains a valid model of the relationship between speed and road safety if the exponents are adjusted according to speed environment.

Elvik's study presents separate exponents that are considered to be the best estimate to calculate DSi reductions for rural and urban speed environment. The generic form of Power Model equation for calculating future DSi is:

$$Estimated\ Future\ DSi = Estimated\ DSi \times \left(\frac{Speed\ after}{Speed\ before}\right)^{Exponent}$$

Where the exponent is set to 2.0 for urban environments (speed limit ≤ 70km/h) and 3.5 for rural environments (speed limit ≥ 80km/h). 'Speed after' values derived from the operating speed modelling have been moderated to ensure that potential DSi savings are not overestimated. This has been achieved by limiting the difference between current operating speed and future operating speed to a maximum rate of change of 5km/h for every 10km/h change in speed limit. This is higher than national and international experience where the change in operating speed is rarely found to exceed 5km/h per 10km/h change in speed limit without supporting measures. However, as the rate of change is only used for the assignment and prioritisation of intervention strategies purposes, the implications of the maximum rate value applied is expected to have little impact on the outcomes in a network-wide context.

In practice the use of Nilsson's Power Model has been found to translate to an average DSi reduction of 27% for 100km/h road subject to a proposed 80km/h speed limit, and 9% for a 50km/h road changing to 40km/h.

Road sections where the current operating speed is less than the existing speed limit will attract a lesser percentage reduction in DSi than road sections where the current operating speed is higher. Likewise, road sections where the current operating speed is lower than both the existing speed limit and safe and appropriate speed will generate few DSi savings, as the future operating speed will only reduce by a marginal amount, if at all. Road sections that fall into the latter scenario are most likely to be categorised as 'Self-Explaining' whereas those with a greater difference between current and future operating speeds are more likely to be categorised as 'Challenging Conversations', especially where the road section has an established safety issue. Despite the lack of direct safety benefits that are associated with the 'Self-Explaining' intervention strategy, the classification is important for helping to change the conversation and behaviours with the public around what safe speeds mean. The alignment of speed limits with operating speeds is expected to drive safer travelling speeds on other similar roads and deliver safety benefits across a wider area.

Results

The curve identification methodology recognised 45,078 curves across the NSW region. Each curve was classified by design limit (in both directions) according to the Austroads speed model (Austroads, 2009). The number of curves identified by category are displayed in Table 1. Where curves were classified differently in opposing directions, the worst (most out-of-context) classification has been applied. For example, a curve that is 'undesirable' in one direction but 'within limit' in the reverse direction would be categorised as 'undesirable'.

Curve Category	Total Curves	% of all Curves
Unacceptable	6890	15.3%
Undesirable	9141	20.3%
Desirable	9453	21.0%
Within Limit	19594	43.5%

Table 1: NSW curve categorisation

Correlation between curve category and loss-of-control crashes

Analysis of the number of loss-of-control crashes by curve category (Figure 5) demonstrates that curves rated 'unacceptable' or 'undesirable' in either direction have a far higher incidence of loss-of-control crashes compared to curves that are within context ('desirable' or 'within limit'). This demonstrates that the relative risk of a rural curve is a function of the extent to which the curve is out-of-context with the approach speed.

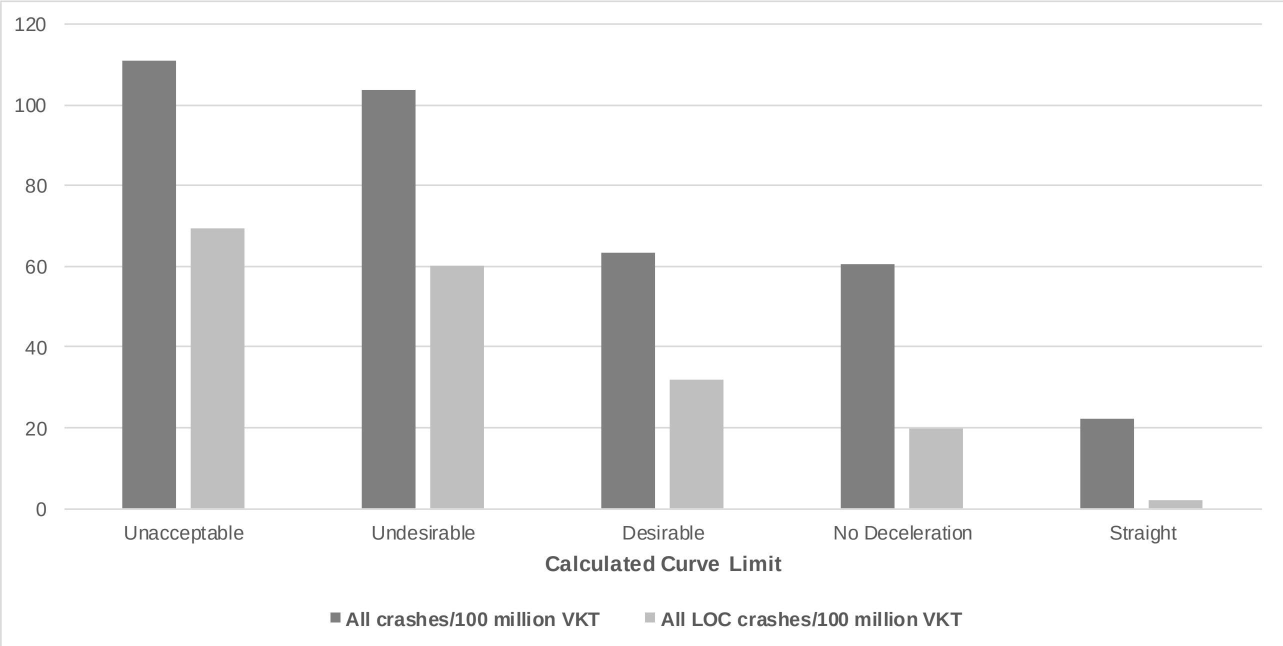

Figure 5: Loss-of-control crashes per 100 million VKT by curve limit class

Figure 5 shows that crash rates on OoCCs are approximately 380% higher than straights, and 80% greater than curves that are within context (No Deceleration or Desirable). Focusing on LOC injury crash rates the relativity becomes more pronounced at approximately 3000% and 160% respectively.

The remainder of this paper utilises the results of the modelling to develop a strategy and implementation process for identifying and prioritising road safety improvements on high-risk rural curves.

PRIORITISING HIGH RISK CURVES FOR TREATMENT

A detailed corridor-based analysis was undertaken on all regions in NSW to develop risk thresholds for prioritising corridors for mass action curve investigation and improvement programmes. The prioritised corridor based approach was preferred over isolated curve prioritisation, as it can provide better route consistency outcomes from a road user perspective.

The analysis identified two measures of risk to target LOC (loss-of-control) crashes on OoCCs. The first metric, **Out-of-Context Curve Risk**, measures the number of injury crashes occurring on OoCCs per OoCC. This is considered a good proxy for the number of crashes that can be targeted if OoCCs along a section are improved to an appropriate standard. All injury crashes are used as opposed to just LOC as some other types of crash are likely to be attributable to the curve being out of context e.g. cutting the corner resulting in a head-on.

The second metric, **Overall Curve Risk**, measures the number of injury crashes occurring on all curves (not just OoCCs) normalised for traffic volume. The second metric is useful as it filters out roads which have a high number of crashes relative to the number of curves on the section but a low crash rate considering the traffic volumes traversing the section. Low crash rates indicate that safety improvements may not yield as much safety benefit when compared to sections with high crash rates. An additional benefit of the second metric is that it highlights sections with a poor record on all curves rather than just OoCCs. This metric helps to show sections where mass action corridor treatments, such as the installation of audio tactile edge lines may improve safety.

The greatest safety savings were considered to be achieved when both **Out-of-Context Curve Risk** and **Overall Curve Risk** were high.

Out-of-Context Curve Risk was calculated using the following equation:

$$\boldsymbol{Out-of-Context\ Curve\ Risk} = \frac{Injury\ crashes\ occuring\ on\ OoCCs\ (previous\ 5\ years)}{Number\ of\ OoCCs}$$

Overall Curve Risk was calculated using the following equation:

$$\boldsymbol{Overall\ Curve\ Risk} = \frac{Injury\ crashes\ occuring\ on\ all\ curves\ (previous\ 5\ years)\ \times\ 10^8}{Number\ of\ curves\ \times\ AADT\ \times\ 365\ \times\ 5}$$

The unit for **Overall Curve Risk** is equivalent to the number of injury crashes occurring per 100 million curves traversed.

A five-tiered risk structure was used to classify corridors in terms of both **Out-of-Context Curve Risk** and **Overall Curve Risk**. The thresholds are set at levels designed to achieve the target percentage of network length to fall within each risk band. Table 2 shows the risk band thresholds for both **Out-of-Context Curve Risk** and **Overall Curve Risk**.

Risk Band	**OoCC Risk Thresholds (Injury crashes on OoCCs per OoCC)**	**Overall Curve Risk Thresholds (Injury crashes on all curves per 100 million curves traversed)**
HIGH	0.43+	17.0+
MEDIUM HIGH	0.214 – 0.43	11.3 - 17.0
MEDIUM	0.067 – 0.214	5.48 – 11.3
LOW MEDIUM	0 – 0.067	3.65- 5.48
LOW	0	0 – 3.65

Table 2: OoCC Risk and Overall Curve Risk Thresholds

The combined metric used to prioritise corridors for treatment accounts for both **Out-of-Context Curve Risk** and **Overall Curve Risk**. The combined metric has been formulated such that approximately 10% of corridors are flagged as HIGH RISK. Table 3 shows how the combined metric is calculated.

		Out-of-Context Curve Risk				
		LOW	**LOW MEDIUM**	**MEDIUM**	**MEDIUM HIGH**	**HIGH**
Overall Curve Risk	**HIGH**	MEDIUM	MEDIUM HIGH	MEDIUM HIGH	HIGH	HIGH
	MEDIUM HIGH	MEDIUM	MEDIUM	MEDIUM HIGH	MEDIUM HIGH	HIGH
	MEDIUM	LOW MEDIUM	MEDIUM	MEDIUM	MEDIUM HIGH	MEDIUM HIGH
	LOW MEDIUM	LOW MEDIUM	LOW MEDIUM	MEDIUM	MEDIUM	MEDIUM HIGH
	LOW	LOW	LOW MEDIUM	LOW MEDIUM	MEDIUM	MEDIUM

Table 3: Combined metric calculation

Restrictions were placed on the combined metric to ensure that a single crash on a short section of low volume road would not flag a section of road as HIGH RISK without sufficient crash data.The restrictions dictate that:

- A corridor classified as HIGH RISK must have had at least 3 fatal or injury LOC crashes during the analysis period.
- A corridor classified as MEDIUM HIGH risk must have had at least 2 fatal or injury LOC crashes during the analysis period.

Table 4 shows the target percentage of network length sought for each band, and the calculated percentage of total network length which falls within each band of the combined metric.

Risk Band	Target Percentage of Network Length	Calculated Percentage of Network Length
HIGH	10%	10.3%
MEDIUM HIGH	15%	17.5%
MEDIUM	20%	23.7%
LOW MEDIUM	25%	18.8%
LOW	30%	29.8%

Table 4: Percentage of network within each risk band

RESULTS

Table 5 shows the length and percentage of network identified as high risk in each sub region of NSW. The table shows that less populated regions, such as the Western and South West regions have a lower percentage of state network identified as high risk. By contrast, the Hunter and Southern regions have the highest percentage of network identified as high risk, and by comparison have significantly denser population than the western regions, as well as more winding roads. While the Sydney region has the highest population of any region by far, the number of rural roads in the region is low and the standard of rural roads (mainly motorways) is generally high.

Region	Length of network identified as HIGH RISK	% of network identified as HIGH RISK
Western	718 km	5%
Northern	888 km	16%
Hunter	490 km	21%
Southwest	671 km	8%
Sydney	158 km	13%
Southern	709 km	20%

Table 5: Length and percentage of network by sub region

Table 6 shows the number of crashes on curves and OoCCs within each risk band as a percentage of the total. This shows that the prioritisation process effectively targets crash risk on curves.

Risk Band	% of all crashes on curves	% of all crashes on OoCCs
HIGH	25%	38%
MEDIUM HIGH	28%	33%
MEDIUM	25%	21%
LOW MEDIUM	16%	5%
LOW	6%	3%

Table 6: Number of crashes on curves by risk band

HIGH RISK CURVE TREATMENT HEIRARCHY

A 'Treatment Hierarchy' was developed to help practitioners identify appropriate curve treatments on corridors prioritised for improvements. The purpose of the Treatment Hierarchy is to ensure that a standardised approach is applied when identifying treatments for sections of road with a number of high-risk curves. The Treatment Hierarchy complements Section 19 of the Delineation guide published by Roads and Traffic Authority NSW (RTA, 2008).

A literature review was undertaken to inform the development of a high-risk curve Treatment Hierarchy. The review examined a range of existing NSW, Australian and New Zealand guidelines, including the RTA Delineation Guideline, and other relevant publications. One of the key findings of the literature review that has been carried through as a fundamental component of the Treatment Hierarchy is the need for treatment strategies to reflect the different function each road performs within a network context.

Categorisation of treatment strategies

Treatment strategies have been grouped into four categories from Type A to Type D.

Type A is the minimum baseline specification that should be applied to all high-risk curves independent of road function. Specifications in this category cover the minimum level of delineation features that should be present on all roads[2]. Treatments in this category include painted centre and edge lines, edge marker posts and vegetation maintenance.

Type B defines a suite of delineation-based treatments that can be introduced to reduce the likelihood of motorists losing control on high-risk curves. Treatments specified in this category are typically of low to moderate cost and are likely to be funded from maintenance or minor safety improvement budgets. Type B treatments are applicable to all high-risk curves except for the lowest order roads carrying very low traffic volumes. Treatments in this category include curve and advisory speed signs, chevron alignment markers, no overtaking lines, retro-reflective road pavement markers and low-cost innovative treatments such as speed activated warning signage.

Type C defines a suite of physical infrastructure treatments that can be introduced to reduce the likelihood and/or consequence of motorists losing control on high-risk curves. Treatments specified in this category are highly variable in cost. Type C treatments are mainly applicable to higher order roads and roads carrying moderate to high traffic volumes. Treatments in this category include curve widening, hazard removal, roadside and median barriers and costlier innovative treatments such as transverse rumble strips.

Type D treatments cover physical works to the road pavement, including superelevation corrections, shoulder widening and realignments. Type D treatments are mainly applicable to higher order roads and roads carrying moderate to high traffic volumes.

Identifying an indicative treatment strategy

The purpose of this step was to identify the treatment strategy most likely to be appropriate for addressing high-risk curves along a corridor. Table 7 shows how an indicative strategy type can be selected based on road hierarchy and existing treatments.

[2] Where sufficient width exists

		Traffic volume (vehicles per day)				
		<300	>300	>750	>3000	>5000
Treatment Class	A					
	B					
	C					
	D					

Categories
Very likely to be appropriate
Likely to be appropriate
May be appropriate
Unlikely to be appropriate
Very unlikely to be appropriate

Table 7: Indicative treatment strategies

The AADT thresholds in Table 7 are based on Section 19 of the Delineation guide published by the Roads and Traffic Authority NSW. The indicative treatment order acknowledges that more expensive treatments are generally reserved for more traversed roads where road user expectations are higher. It also indicates that lower cost interventions should generally be used before more expensive treatments are implemented. It is possible that a Type A or Type B treatment could be an effective solution on any corridor (regardless of AADT) if no treatments have yet been applied.

In the case of lower volume roads, only extreme situations would see the use of Type C or Type D treatments. This may be the case if many Type B options have already been implemented without a reduction in crash rate and crash rates remain very high. It should be noted that numerous Type B treatment strategies exist which can be very effective at improving safety when installed properly. Higher volume roads may see Type C or Type D treatments used more readily however lower cost treatments should still be considered and installed if appropriate.

Judgement is required when selecting a treatment strategy, as it is unlikely that any curve will have all Type B treatments installed before moving on to a Type C or Type D treatment. If a major road already has a number of Type B treatments in addition to Type A treatments, then it may be prudent to apply a Type C or Type D treatment. Conversely, if a major road is deficient of a number of desired basic treatments and has not trialled any other Type B treatments, it may be advisable to apply these first before applying more expensive treatments.

Identifying specific treatments

To aid practitioners with selecting specific treatments, a brief breakdown of both common and more innovative treatment methods was provided. The breakdown included:

- an outline of what the treatment involves, an indicative cost of implementing the treatment,
- an indicative timeframe for how long the treatment will last before it requires replacement or maintenance,
- whether the treatment will reduce the consequence or likelihood of a crash,
- and an indication of the type of LOC crashes which will be prevented/reduced in consequence, and;
- a reference for information regarding design standards.

Treatment options were then selected based on:

- the indicative treatment strategy to be applied to the section,
- any crash trends for the particular section, and;
- any other site-specific factors.

Specific guidance relating to the design of each treatment strategy was beyond the scope of this work. An inspection checklist was included which takes account of the performance and state of existing assets, thus enabling maintenance activities to be scheduled where necessary to maximise the value and safety potential of existing assets. The intention of the checklist was that it be completed for each high-risk curve along a corridor identified as high-risk before improvements are planned, designed and implemented. Speed limit changes were not considered as part of the Treatment Hierarchy but will be explored further as part of ongoing work for the CRS.

APPLICATION

To demonstrate how the results can be applied, two HIGH RISK corridors near the town of Windsor, New South Wales have been selected. Windsor is located approximately 50km northwest of Sydney as shown in Figure 6. The selected exemplar corridors are shown in more detail in Figure 7.

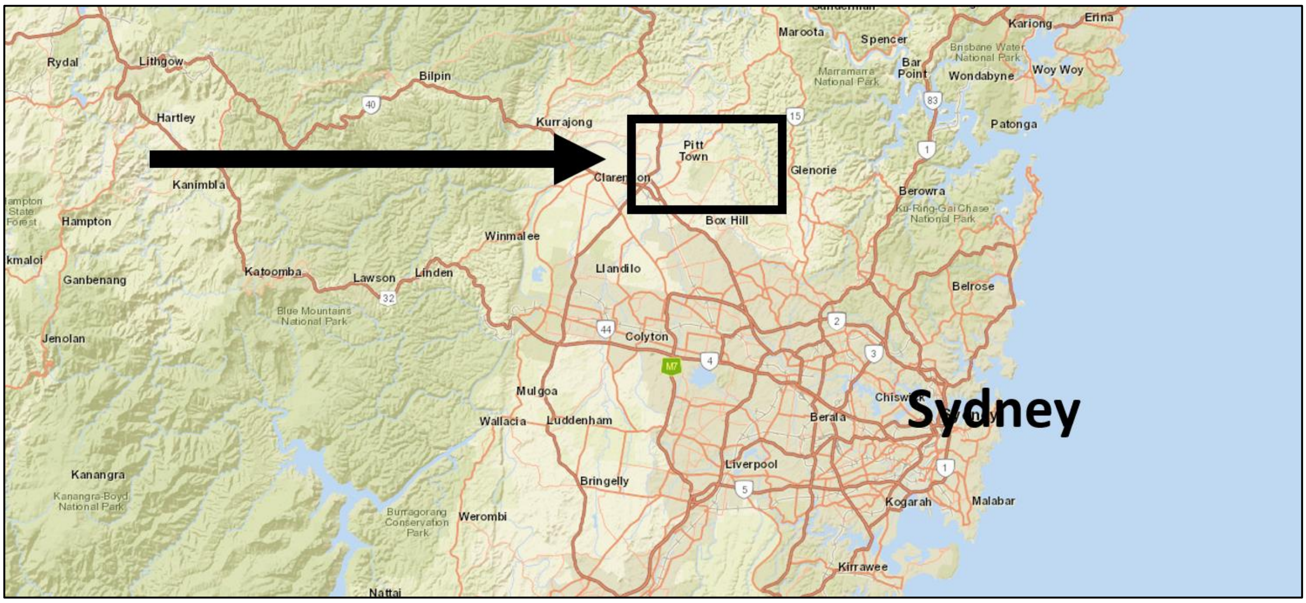

Figure 6. Location of Windsor, New South Wales

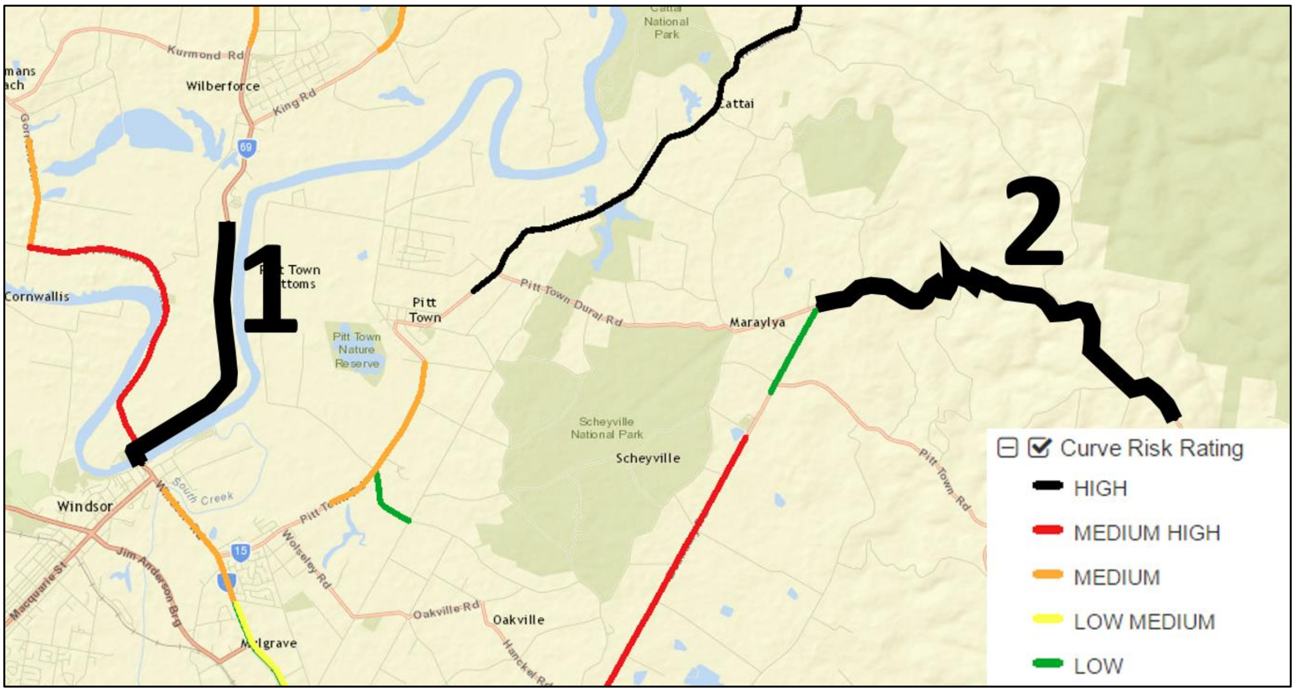

Figure 7. Location of exemplar corridors

The first corridor (1) connects Windsor with the town of Wilberforce to the north and has a traffic volume of approximately 5,500 vpd. Figure 8 shows that the curve directly north of the Hawkesbury River bridge is out-of-context in one direction and has a particularly poor safety record. Other curves along the corridor are considered 'within limit'. For this corridor, a site specific treatment on the out-of-context curve may be more appropriate to address curve safety issues.

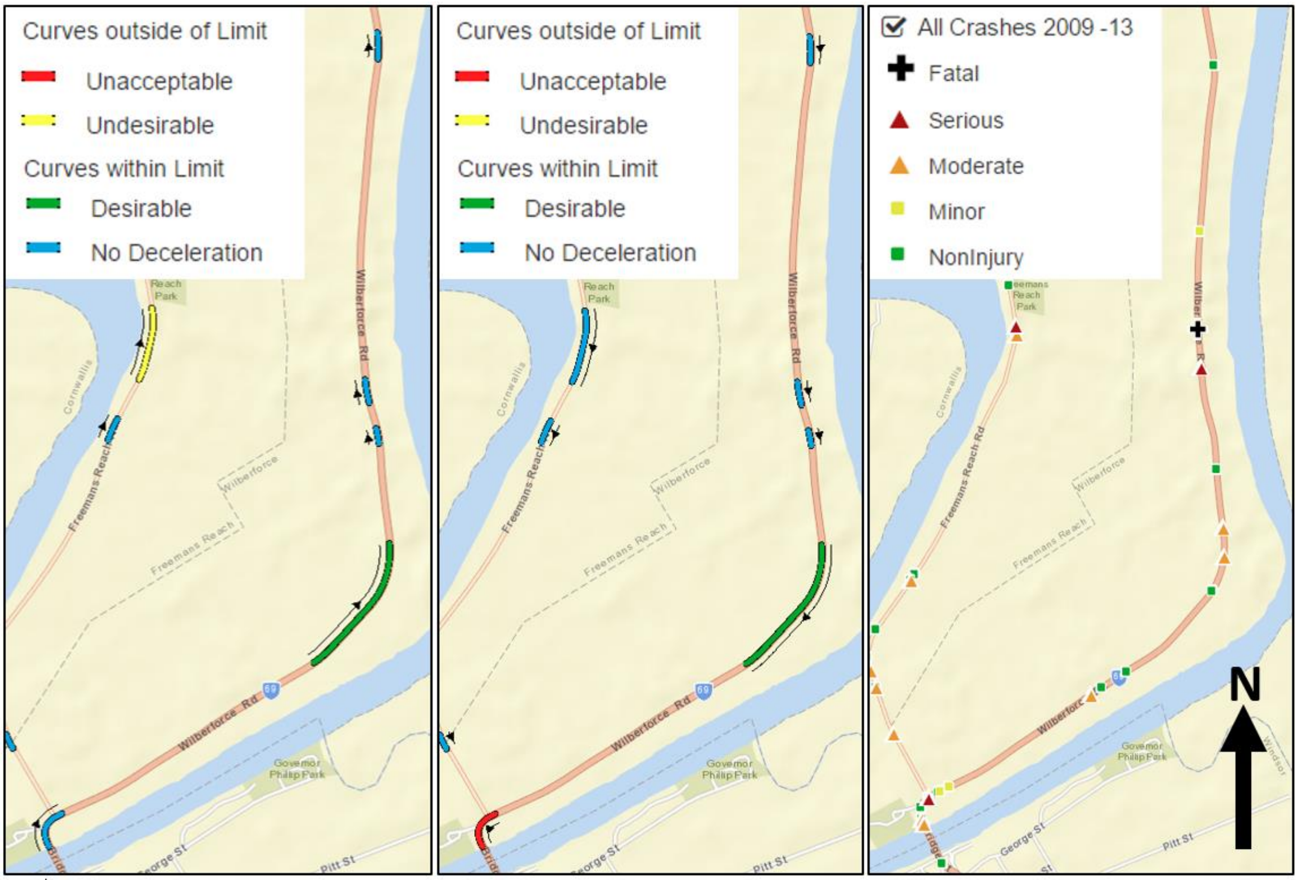

Figure 8: Exemplar Corridor 1: Wilberforce Road, Wilberforce, NSW (Left: curves in ascending direction, Centre: curves in descending direction, Right: Recorded crashes)

Given the traffic volume traversing the corridor, all classes of treatment shown in Table 7 are appropriate for consideration on this corridor. The out-of-context curve already has all Type A treatments and has a number of Type B treatments including curve and advisory speed signs, chevron alignment markers and a wide median with no overtaking lines.

Further Type B treatments such as speed activated warning signage and retro-reflective road pavement markers may be effective treatments in this case. Given the constrained built environment, Type C treatments which demand physical changes to the road environment may be unachievable. However, median and roadside barriers, hazard removal (poles/trees) and an increased maintenance standard (to improve skid resistance) may be appropriate on the out-of-context curve.

The second corridor (2) begins approximately 10km northeast of Windsor and connects the rural suburbs of Maraylya and Glenorie. This corridor has a traffic volume of approximately 500 vpd. Figure 9 shows that there are a number of crashes scattered along the corridor with clusters on several out-of-context and in-context curves. In this case, a corridor-wide rather than site specific treatment may be more appropriate to address curve safety issues.

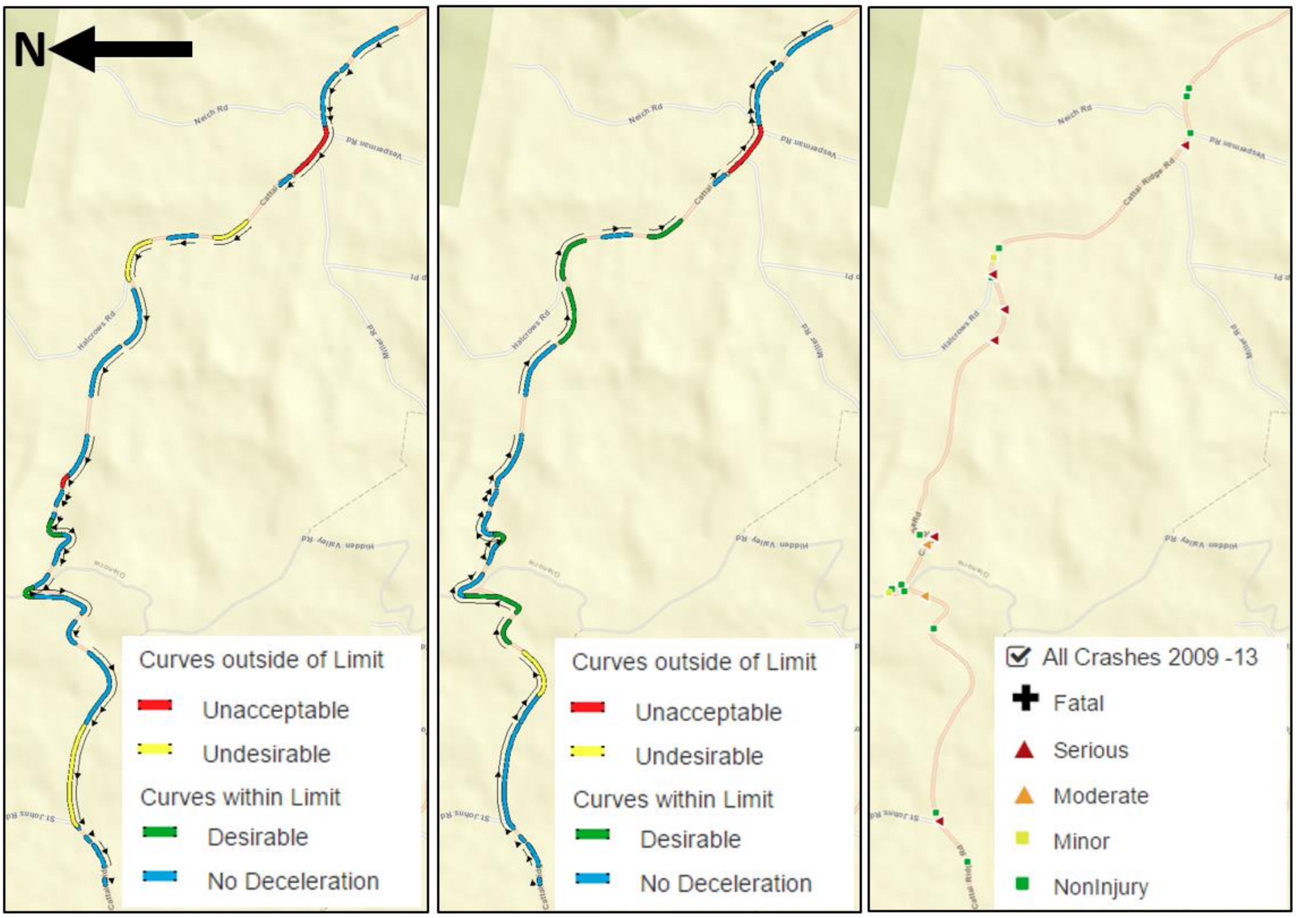

Figure 9: Exemplar Corridor 2: Cattai Ridge Road, Glenorie, NSW (Left: curves in ascending direction, Centre: curves in descending direction, Right: Recorded crashes)

Given the traffic volume traversing the corridor, only Type A and B treatments shown in Table 7 are appropriate for consideration on this corridor. The corridor already has all Type A treatments and has a number of Type B treatments including curve and advisory speed signs, chevron alignment markers, retro-reflective road pavement markers and no overtaking lines.

Further Type B treatments such as speed activated warning signage, 'SLOW' pavement markings ahead of curves and optical speed bars[3] may be effective treatments in this case. Type C treatments are not likely to be appropriate for this corridor given the low traffic volumes, they may however become advisable if the corridor continues to exhibit a poor safety record after further Type B treatments have been applied.

[3] Optical Speed Bars are transversely painted strips spaced at gradually decreasing distances. The rationale for using them is to increase drivers' perception of speed and cause them to reduce speed. The Optical Speed Bar name comes from this intended visual effect on drivers' speed as they react to the spacing of the painted lines (US Department of Transportation, 2011).

CONCLUSION

The Treatment Hierarchy developed in this project helped the CRS to prioritise corridors and identify treatment strategies which can reduce the number of loss of control crashes occurring on high-risk curves. The process takes account of both safety risk through the GIS analytic techniques developed and economic considerations through the Treatment Hierarchy. This will allow the CRS to target safety spending towards projects which yield the greatest safety benefits.

Funding bids are being lodged by the CRS to treat high-risk roads through the Safer Roads Program. Additional countermeasures at high risk curves will also be implemented. Scope also exists to reduce speed limits on numerous high risk rural (undivided) roads. In 2016/17, each region of NSW is targeting increased speed zone reviews on rural roads with a number of high-risk curves.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Joyce Tang from the CRS for her help in sourcing data for the project. The team would also like to thank Subodh Dhakal and the wider team at Abley Transportation Consultants for their work on this project.

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