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Providing for Road User Error in the Safe System

Providing for Road User Error in the Safe System

Prepared By
Paul Roberts, Jeremy Woolley and Sam Doecke

Project Manager
Con Stasinos

Abstract

This project investigated the feasibility and cost of moving towards a truly Safe System infrastructure. The key feature of such an infrastructure is that it be designed to preserve safety in the face of driver fallibility. The project first analysed the actual errors that drivers make. This provided an evidence-based means of assessing how effective different types, numbers and combinations of countermeasures are likely to be in mitigating the impact of the errors that drivers make. This in turn allowed an estimate to be made of the plausibility and cost of implementing various models that can be applied as various degrees of approximation to an error tolerant system in a particular road environment.

Keywords

Driver error, Safe System, Countermeasure costs, Safe System infrastructure

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Austroads Ltd.
Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia
Phone: +61 2 9264 7088
austroads@austroads.com.au
www.austroads.com.au

Summary

The central aim of this project was to begin to investigate the feasibility and cost of moving towards a truly Safe System infrastructure. The key feature of such an infrastructure is that it be designed to preserve safety in the face of driver fallibility. For this reason it was important to start with an analysis of the actual errors that drivers make. This provided an evidence-based means of assessing how effective different types and combinations of countermeasures are in mitigating the impact of the actual errors that drivers make. This in turn allowed an estimate to be made of the plausibility and cost of implementing various models that can be applied as approximations to an error-tolerant system in a particular environment.

Crash data was derived from the in-depth crash database at the Centre for Automotive Safety Research (CASR) at the University of Adelaide. Crashes were analysed to derive driver errors, classified at a number of levels of analysis. This allowed the development of a road user error assessment framework. In order to make the task tractable only crashes on high speed rural roads were analysed. Once the error assessment framework was established this was validated by investigating how well it classified a new set of crashes from the CASR database. In general, a satisfactory level of validity was established.

It was found that a surprisingly small number of errors types accounted for the majority of crashes, with overcorrection after straying onto the unsealed shoulder being the most common. Similarly, a relatively small number of treatments types applied in the appropriate location would have protected a large number of drivers who made errors. In particular sealed shoulders, roadside barriers and centre line wire rope safety barriers (WRSBs) would have been effective.

In the second part of the project, defined geographical areas were selected and the identified treatments systematically applied so as to model the feasibility and costs associated with providing varying levels of safety in a rural road network. The approach taken was to compare and contrast a number of models, containing various combinations of the identified treatments, to assess the performance and cost of different approximations to a fully Safe System infrastructure.

The results of these model comparisons suggest that it would be very complicated and very expensive to create a fully Safe System utilising existing infrastructure technologies alone, even in the relatively straightforward rural network examined here. However, it appears that very worthwhile approximations to a Safe System can be achieved more simply and less expensively. For example, implementing only three key treatments (sealed shoulders, roadside barriers and centre line WRSBs) would have provided protection from the consequences of errors in 63% of all the crashes examined in this study while costing one-quarter as much as the fully Safe System model. Furthermore, adding a number of inexpensive treatments to discourage errors (improved delineation and road marking at junctions, curve advisory signs, fatigue warning signs, lower speed limits, stop-controlled junctions, truck-specific warning signs, vehicle-activated signs (other vehicle presence) and warning signs) to these three key treatments only increases cost marginally, but improves the cost-effectiveness of the treatment model significantly.

The research presented here provides an evidence-based account of what would be required to achieve a truly Safe System from an infrastructure perspective using existing technology. It also provides a range of treatment models that can be compared in terms of their complexity, cost and cost-effectiveness; constituting, essentially, a road map for how to move towards a Safe System in the most efficient way.

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1. Introduction

Australian jurisdictions are now firmly committed to the Safe Systems approach to road safety. This approach, which is derived from the Swedish Vision Zero (Johansson 2009), and the Netherlands' Sustainable Safety approaches to road safety (Wegman & Elsenaar 1997), has at its core the recognition that road users are fallible and will make mistakes, even if alert and intending to comply with the road rules. As a result, vehicles and road infrastructure need to be designed to discourage errors and protect against errors when they do occur. Thus road infrastructure must be 'forgiving', in the sense that it should allow for recovery from errors when they occur. In addition, because the human body has a limited ability to resist the impact force from a crash, road infrastructure should also reduce the severity of crashes if they occur.

Behind this straightforward and uncompromising philosophy however there are many questions that need to be answered to allow a planned and defensible implementation of a Safe System. For example, there is a diversity of views as to how far the Safe System approach should go in accommodating aberrant road user behaviour. Where should the line be drawn between the two key Safe System requirements of alert and compliant road users and the forgiveness of human error? In particular, should the Safe System aim to prevent death and serious injury in fatigue-related crashes, should protection be provided in cases of unintentional minor speeding and what level of user distraction can be tolerated?

The implications of providing a Safe System which accepts different levels of road user non-compliance and error have not been adequately investigated to date. This is particularly relevant in relation to road infrastructure, where the responsibility and cost of improvements rest with the road authorities. In this regard there are many questions to be answered relating to effectiveness, efficiency and cost. For example, while the range of treatments that can be used to create a Safe System may be somewhat self-evident, it is not clear if all of those treatments need to be implemented in a given environment in order to be able to create a worthwhile approximation of a Safe System, or indeed what constitutes a worthwhile approximation to a Safe System. In particular there is currently no information that allows a principled comparison of the relative effectiveness and cost between different potential groups of treatment implementations in particular environments, from a Safe Systems perspective.

This project aims to answer these questions using an evidence-based approach that starts from an analysis of the errors that drivers make. The focus on errors has a number of advantages. Firstly, it provides the means of quantifying the extent to which serious crashes are the result of errors. Secondly, it provides a means of assessing how effective different types and combinations of countermeasures will be in mitigating the impact of the actual errors that drivers make. This in turn will allow an estimate to be made of the plausibility and cost of implementing various approximations to a truly error tolerant system in a particular environment. It is expected that this information will be particularly useful for road authorities by providing principles and tools that can guide the transition into Safe System practice.

Research suggests that the contribution of driver error to crashes is likely to be up to 90% (Treat et al. 1979). Thus while driver error is a contributor in most crashes, and is the focus of this project, the methodology adopted here needs to allow for other causal factors. For this reason the approach in the current project has been to use data pertaining to actual crashes (rather than say reports of errors). Furthermore, using crash data ties the error to an actual example of infrastructure, making it much easier to specify and quantify the relationship between error, crashes and infrastructure. Salmon et al. (2010) have criticised the use of retrospective crash data to study error on the basis that it is often not comprehensive enough to unambiguously identify the critical error and that it is usually driver-centric. It is accepted that, generally speaking, these are valid criticisms. However, the crash data employed in this project avoids these criticisms because it is very detailed and incorporates information about the whole road system. The characteristics of this database are outlined below.

1.1 The CASR In-depth Crash Database

The Centre for Automotive Safety Research (CASR) and its predecessor, the Road Accident Research Unit, both at the University of Adelaide, have conducted in-depth crash investigations for over 40 years. The most recent series began in July 2007 and included both metropolitan and rural crashes to which an ambulance was called and subsequently transported at least one patient to hospital. Crashes where no ambulance transport was required due to an occupant being deceased at scene were also included. Rural crashes were investigated up to 100 kilometres from Adelaide. Rural townships that contained roads within built-up areas were excluded including those roads with speed limits above 80 km/h. The study area also included sections of the South Eastern Freeway and the Southern Expressway.

Crash investigators were notified of a crash by a pager provided by the South Australian Ambulance Service. CASR staff were on call to attend crash scenes between 0900 and 1630 during weekdays. Fatal accidents that occurred at any time on any day were also investigated retrospectively as evidence at the scene was preserved by the South Australian Police Major Crash Investigation Unit.

It was the aim of the investigators to reach the scene of the crash before any of the vehicles involved were moved from their final resting positions. As CASR personnel do not have, nor desire, permission to exceed posted speed limits while en route to a crash scene it was not always possible to achieve this aim. If the vehicles had been removed before the arrival of CASR's investigators and there was insufficient evidence to indicate the final resting positions or the configuration of the accident, the case was abandoned.

The information collected on each case included:

- photographs of the crash scene and vehicles involved
- video from each road user perspective
- details of the road environment, including traffic control measures
- a site plan of the crash scene including physical evidence (tyre marks etc.) and vehicle positions pre-impact, at impact and final resting positions
- details and measurements of the vehicles involved
- information on the official police vehicle crash report
- crash history of locations and drivers involved
- interviews with crash participants and witnesses
- injury data for crash participants who attended major metropolitan hospitals.

A multidisciplinary review is conducted at CASR when the available data has been obtained and a summary of the crash is created noting mitigating circumstances and factors. A more detailed description of the crash investigation activity is included in Austroads (2012).

1.2 Project Aims

In order to provide an account of the relationship between errors, crashes and infrastructure, some kind of error assessment system is required. Thus, a major component of the current project was to apply an error assessment system to the CASR crash data. This required reviewing and modifying existing approaches to create an assessment framework that would enable identification of a representative sample of errors in such a way that allowed an understanding and quantification of the feasibility and cost of implementing a Safe System.

Specifically, the project aimed to develop a road user error assessment framework based on current knowledge and in-depth crash information from crashes on high speed rural roads so that this framework could be used to assess the feasibility and cost of adapting the road system to protect aberrant road users. Urban crashes are not covered by this project because there is ongoing work in this area, predominantly focussed on intersections (see Salmon, Regan & Johnston 2005; 2006).

A secondary aim was to create a framework that would also be useful in assisting the community to understand and accept Safe System principles.

Key objectives include:

- development of a road user error assessment system
- development of a framework for estimating the cost of providing safe infrastructure for road users under various scenarios
- provision of a clearly defined and quantified account of a Safe System.

1.3 Structure of the Report

The first part of this report reviews existing approaches to error assessment with the aim of modifying and adapting the most useful aspects of these for the current purposes.

The second part of the report utilises the CASR in-depth crash data to derive and test an error assessment model that will have utility in evaluating the feasibility and cost of mitigating the errors that drivers make on high speed rural roads.

The final section of the report compares and contrasts a number of models, containing various combinations of identified treatments, to assess the performance and cost of different approximations to a fully Safe System infrastructure.

2. Approaches to Error Assessment

2.1 Review of Existing Approaches

2.1.1 Person versus System Approaches

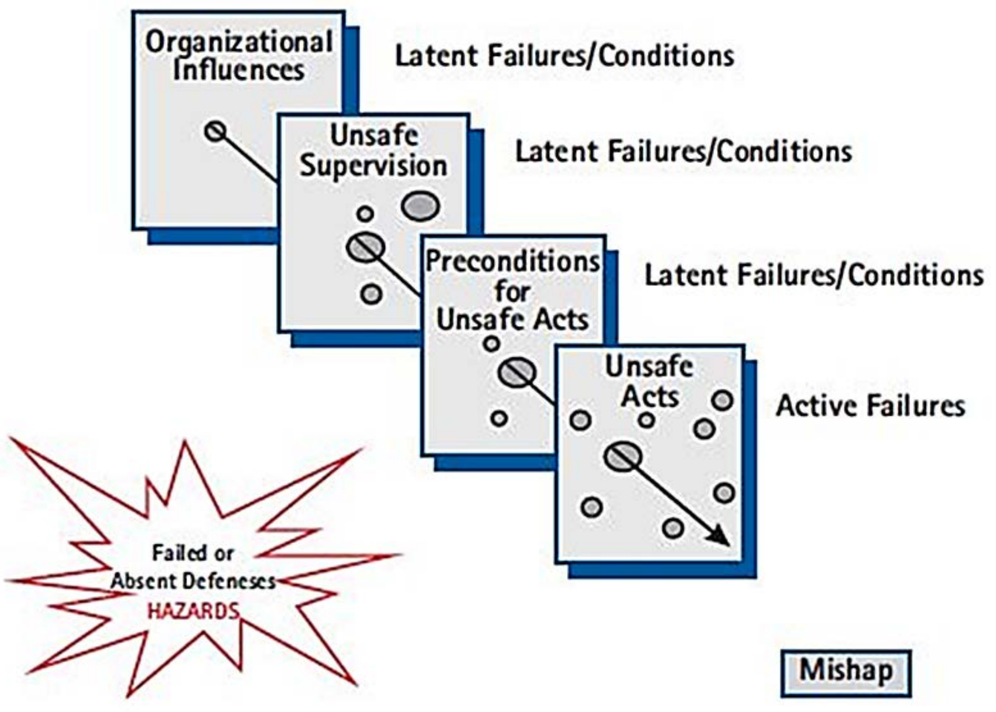
While there are a number of ways of defining human error, for the current purposes a useful definition is:

> the failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event. (Reason 1997, p.71)

In the past this commonsense definition of error has been taken to imply that these failures of planned actions are caused by failures of the individual making the error with psychological factors such as carelessness or inattention being invoked as explanatory constructs. However, more recently, it has been appreciated that there are wider ‘systemic’ causes of such failures and that these may in fact be legitimately seen as responsible for the manifestation of psychological factors, such as carelessness and inattention.

For example, within this systems framework, because it is well known that humans are error prone, a failure in the system could be construed as occurring at the level of the road authority which has not designed road infrastructure to take account of the errors that road users make. These kinds of failures are termed ‘latent failures’ in Reason’s model (see Section 2.1.2).

Figure 2.1: Accident trajectory diagram



Source: Reason (1997).

2.1.2 Reason's Model

Despite being a systems approach, Reason's model is difficult to apply to road safety in a systemic way, especially from an infrastructure perspective. There are at least two key reasons for this.

Firstly, there is no clearly defined classification of latent failures specific to road safety. While it can be imagined what many of these latent failures might be, and while there is some work in road safety that is relevant to some of the different levels, this information has not been integrated in any way that would provide a coherent framework for application.

Secondly, while there is work on unsafe acts in driving, this does not easily translate into infrastructure countermeasure recommendations. For example, much of the work in this area has utilised the Driver Behaviour Questionnaire (DBQ). As can be seen from Figure 2.2 below, the questions are answered from the person perspective. Thus there is no infrastructure context to the questions that would help provide clues about how these behaviours might be minimised or avoided by infrastructure countermeasures.

Figure 2.2: Driver behaviour questionnaire

Lajunen, T., Parker, D., & Summala, H. (2004). The Manchester Driver Behavior Questionnaire: A cross-cultural study. *Accident Analysis, and Prevention, 36,* 231-238.

Respondents were asked to indicate how often they themselves do each of the violations and errors when driving. Responses were on a six-point scale from "Never" to "Nearly all the time".
1=Never 2=Hardly Ever 3=Occasionally 4=Quite Often 5=Frequently 6=Nearly All The Time

Aggressive Violations
7. Sound your horn to indicate your annoyance to another road user
17. Become angered by another driver and give chase with the intention of giving him/her a piece of your mind
25. Become angered by a certain type of a driver and indicate your hostility by whatever means you can
"Ordinary" Violations
10. Pull out of a junction so far that the driver with right of way has to stop and let you out
11. Disregard the speed limit on a residential road
18. Stay in a motorway lane that you know will be closed ahead until the last minute before forcing your way into the other lane
20. Overtake a slow driver on the inside
21. Race away from traffic lights with the intention of beating the driver next to you
23. Drive so close to the car in front that it would be difficult to stop in an emergency
24. Cross a junction knowing that the traffic lights have already turned against you
28. Disregard the speed limit on a motorway
Errors
5. Queuing to turn left onto a main road, you pay such close attention to the main stream of traffic that you nearly hit the car in front of you
6. Fail to notice that pedestrians are crossing when turning into a side street from a main road
8. Fail to check your rear-view mirror before pulling out, changing lanes, etc.
9. Brake too quickly on a slippery road or steer the wrong way in a skid
13. On turning left nearly hit a cyclist who has come up on your inside
14. Miss "Give Way" signs and narrowly avoid colliding with traffic having right of way
16. Attempt to overtake someone that you had not noticed to be signaling a right turn
27. Underestimate the speed of an oncoming vehicle when overtaking
Lapses
1. Hit something when reversing that you had not previously seen
2. Intending to drive to destination A, you "wake up" to find yourself on the road to destination B
4. Get into the wrong lane approaching a roundabout or a junction
12. Switch one thing, such as the headlights, when you meant to switch on something else, such as the wipers
15. Attempt to drive away from the traffic lights in third gear
19. Forget where you left your car in a car park
22. Misread the signs and exit from a roundabout on the wrong road
26. Realize that you have no clear recollection of the road along which you have just been traveling

2.1.3 Stanton and Salmon (2009)

In a recent paper Stanton and Salmon (2009) provide an excellent overview of driver error and a generic taxonomy of driver error incorporating many of the existing models and taxonomies (Figure 2.3).

Figure 2.3: Generic driver error taxonomy with underlying psychological mechanisms

Underlying psychological mechanism	External error mode	Taxonomy source	Example
Action errors			
Action execution	Fail to act	Tables 1, 4, 2, 8, 10	Fail to check rear view mirror
Action execution	Wrong action	Tables 2, 4–6, 8, 9	Press accelerator instead of brake
Action execution	Action mistimed	Tables 1 and 2	Brake too early or too late
Action execution	Action too much	Tables 5 and 6	Press accelerator too much
Action execution	Action too little	Table 5	Fail to press the accelerator enough
Action execution	Action incomplete	Table 1	Fail to turn the steering wheel enough
Action execution	Right action on wrong object	Tables 1 and 2	Press accelerator instead of brake
Action execution, planning, and intention	Inappropriate action	Tables 1, 2 , 4–6, 8, 9	Following too close, race for gap, risky overtaking etc.
Cognitive and decision-making errors			
Perception	Perceptual failure	Table 2	Fail to see pedestrian crossing
Perception	Wrong assumption	Table 2	Wrongly assume a vehicle will not enter path
Attention	Inattention	Tables 5, 6, 8, 9	Nearly hit car in front when queuing
Attention	Distraction	Table 4, 5, 8, 9	Distracted by secondary task e.g. mobile phone conversation
Situation assessment	Misjudgement	Tables 1, 4–6, 8–10	e.g. misjudged speed of oncoming vehicle, misjudge speed and distance, misjudge gap
Perception	Looked but failed to see	Tables 6 and 9	Looked at road ahead but failed to see pedestrian
Observation errors			
Memory and recall	Failed to observe	Tables 1, 2, 4, 5, 8, 9	Failed to observe area in front of vehicle
Memory	Observation incomplete	Tables 4, 6, 10	Failed to observe offside mirror when changing lanes
Situation assessment	Right observation on wrong object	Tables 4 and 10	Failed to observe appropriate area
Memory and recall	Observation mistimed	Tables 1 and 2	Looked in drivers side mirror too late when changing lane
Information retrieval errors			
Situation assessment	Misread information	Table 10	Misread road sign, traffic control device or road markings
Situation assessment	Misunderstood information	Tables 1 and 10	Perceive information correctly but misunderstand it
Situation assessment	Information retrieval incomplete	Table 10	Only received part of information required
Situation assessment	Wrong information retrieved	Table 10	Read wrong information from road sign
Violations			
Action execution, planning and intention	Intentional violation	Tables 4, 6, 8, 10	Overtake on the inside, knowingly speed
Action execution	Unintentional violation	Tables 4, 6, 8, 10	Unknowingly speed

Source: Adapted from Stanton and Salmon (2009).

While they do consider road infrastructure in the list of causal factors leading to errors (see Figure 2.4 below) their paper is primarily concerned with intelligent transport systems (ITS) solutions that would help to mitigate these errors. Thus, while their approach to error is useful for the current purposes, we need to extend the analysis of potential mitigating solutions to road infrastructure.

Figure 2.4: Driver error causal factors

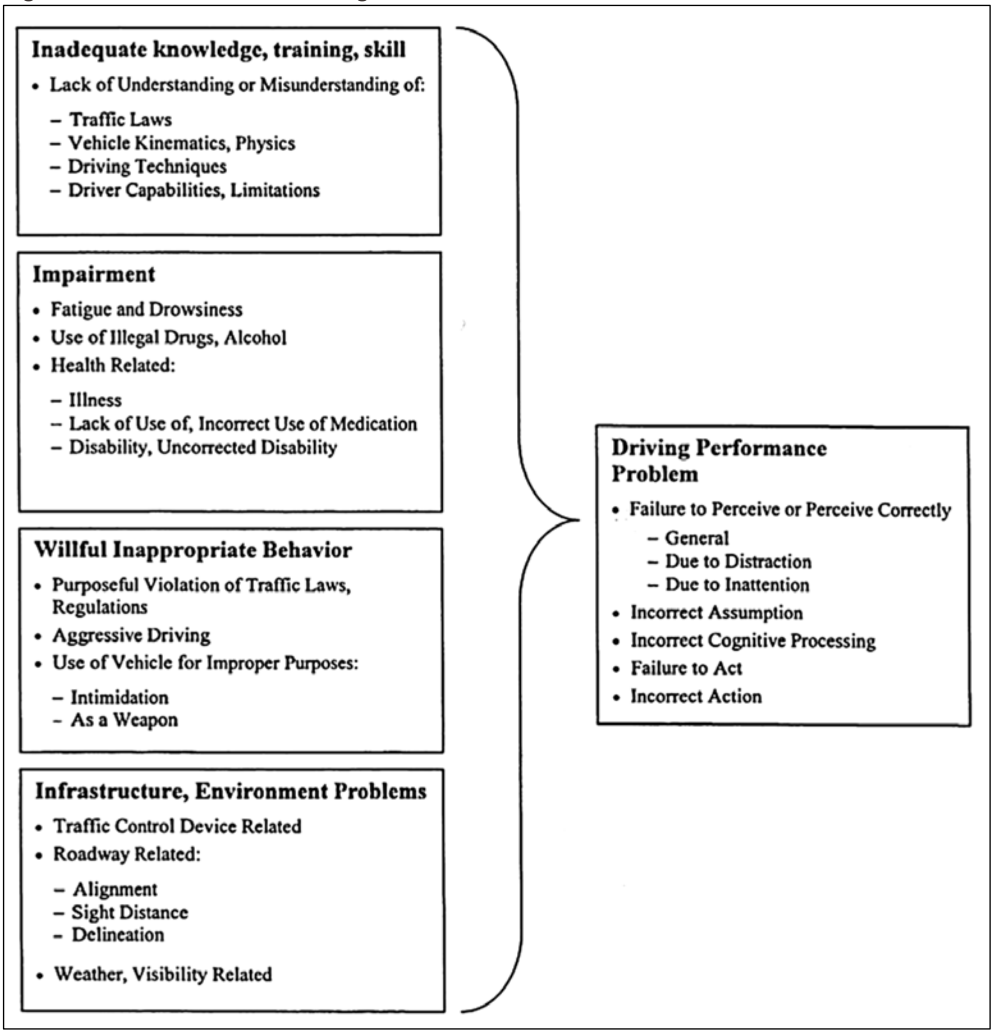
Casual factor group	Casual factor	Source
Road infrastructure	Road layout	Tables 5, 9, Figure 3
	Road furniture	Tables 5 and 9
	Road maintenance	Tables 5 and 9
	Road traffic rules, policy and regulation	Figure 3
Vehicle	Human machine interface	Table 5
	Mechanical	Table 5
	Capability	Table 5
	Inappropriate technology usage	Table 5
Driver	Psychological state	Tables 5 and 9, Figure 3
	Mental state	Table 5
	Training and experience	Tables 5 and 9
	Knowledge, skills and attitudes	Figure 3
	Context	Table 5
	Non-compliance	Figure 3
Other road user	Other driver behaviour	Table 9
	Passenger influence	Table 5
	Pedestrian behaviour	Table 5
	Law enforcement	Table 5
	Other road user behaviour	Table 9
	Weather conditions	Table 5 and 9, Figure 3
Environmental conditions	Lighting conditions	Table 5
	Time of day	Table 5
	Road surface conditions	Tables 5 and 9

Source: Adapted from Stanton and Salmon (2009).

2.1.4 Wierwille et al. (2002)

In their project for the FHWA Wierwille et al. (2002) employed crash reports, focus groups with crash investigators, driver interviews and video surveillance to develop a driver error taxonomy, to investigate the causes of these errors (Figure 2.5). They then used this information to create recommendations for infrastructure changes that would mitigate these driver errors.

Figure 2.5: Factors contributing to driver error



Source: Wierwille et al. (2002) p.210.

The value of Wierwille's approach for the current purposes is that it is explicitly targeted at infrastructure issues (see Table 2.1). One of those specific infrastructure issues is detailed in Figure 2.6 . Figure 2.7 details the infrastructure changes that could be made in order to eliminate the possibility of this error occurring at this location.

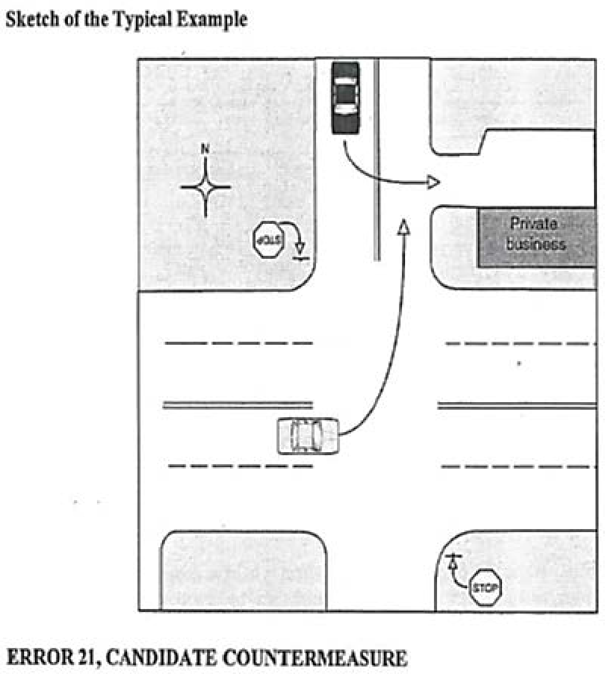
The general approach exemplified in Wierwille et al. (2002) is particularly relevant to the current concerns as the focus is on identifying aspects of road infrastructure that are likely to lead to errors and changes to road infrastructure that can be made to reduce the probabilities of those errors. Unfortunately this analysis is targeted at urban intersections rather than the high speed rural roads that are of concern here. Nevertheless this work does provide a good model for how to proceed to develop an infrastructure-focussed error taxonomy that is capable of pointing to infrastructure changes to mitigate driver error.

Table 2.1: Examples of infrastructure involvement in incidents

Category	Example error included in this report
1 Signals	
1.1 Confusing multiple signals	
1.2 Signals not visible	No. 2
1.3 Signals creating bunching	No. 4
1.4 Uncoordinated signals	
2 Signs	
2.1 Signs readable but ineffective/apparently ignored	No. 6
2.2 Signs unclear/confusing/missing	No. 11
2.3 Stop sign, confusion regarding right-of-way	No. 15
3 Alignment and geormery	
3.1 Intersections in close proximity to one another	No. 17
3.2 Private entrances/exits in/near intersections	No. 21
3.3 Short weaving sections	No. 23, 24, 25
3.4 Short merge/enrance/acceleration lane	
3.5 Visibility difficulties resulting directly from alignment/geomerty	No. 28
3.6 Visitbility difficulties resulting from blockage by other vehicle	No. 31
3.7 Visibility difficulties resulting in encroachment	
4 Delineatiion	No. 38
5 Pedestrian and bicycle interactions	No. 42

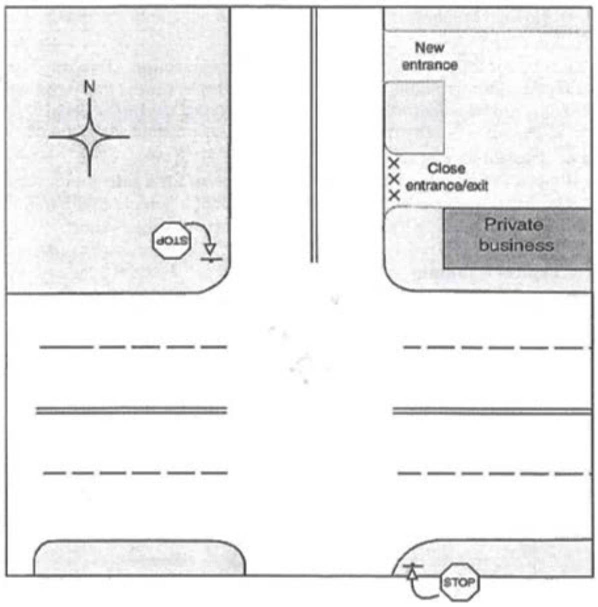
Source: Wierwille et al. (2002) p.115.

Figure 2.6: Specific infrastructure issue creating conflict/error



Source: Wierwille et al. (2002) p.137.

Figure 2.7: Infrastructure solution



Source: Wierwille et al. (2002) p.138.

2.2 Current Approach

The approach taken here draws on the approaches outlined above while filling some of the gaps and avoiding some of the pitfalls that make existing approaches less than ideal for the current purposes.

The key elements to the current approach are:

- A focus on the critical error and contributing causes rather than psychological mechanisms.
- Focus on the infrastructure change required to create a Safe System.
- Consideration of whether there is any risk associated with making the recommended infrastructure changes.
- Situated within a Safe System context.

One question which arises with the current approach is how representative of all crashes (and errors) the sample might be. There are two aspects to this issue. The first is a sample size issue and is addressed via a suitably large sample size (in this case 40 plus a further 20 cases). The second is the extent to which the sample from South Australia is likely to generalise to other jurisdictions. This might be a concern if the project was dealing with urban roads, because there are significant differences between urban road infrastructure (and other factors) across the various Australian jurisdictions. However, the jurisdictional differences with respect to rural high speed roads is likely to be considerably less and as such not a barrier to a reasonably generalizable analysis. It would be useful however to validate this assumption in future if detailed error data becomes available from other jurisdictions.

2.2.1 Methodology

Forty cases from the CASR in-depth crash database were quasi-randomly selected. All crashes within this database were at least injury crashes (i.e. no property-only crashes). Selection criteria were as follows:

- Rural high speed roads.
- No medical condition or drugs/alcohol involvement.
- Period: < 10 years old.

Each case was examined in detail by two experienced road safety professionals (one with road engineering expertise and one with driver behaviour expertise) in an attempt to come to a conclusion about the fundamental error that caused the crash. In addition, an attempt was made to ascertain the immediate cause of that error and also the more distant causes that might have allowed the error to occur. Particular attention was paid to possible infrastructure involvement in this process. Two cases were subsequently excluded from the sample as a result of suspected contributions from drugs/alcohol or medical condition.

Next, an assessment was made of what infrastructure changes could be made in order to discourage such errors and in order to protect drivers better in the event of such a crash. An attempt was also made to specify where the changes should be made in general to mitigate the impact from such crashes in the future.

Finally, an assessment was made of the extent to which the proposed infrastructure changes might run the risk of introducing any additional hazards (dangerous defences in Reason's terminology; Reason 1997) and what should be done to minimise this possibility.

In all cases the two judges reviewed the material separately and came to a conclusion independently. In the small number of cases where there was disagreement (less than 10%) subsequent discussion led to an agreed approach without significant difficulty.

This information was then presented at a workshop.

2.2.2 Workshop

The workshop, held in Melbourne on the 8th August 2011 presented this information to stakeholders and road safety experts. Attendees at the workshop were as follows:

- Maurice Cammack, MRWA
- Paula Norman, DPTI
- Michael Cummins, NZTA
- Colin Morgan, VicRoads
- Jeremy Woolley, CASR
- Mary Lydon, CASR
- Paul Salmon, MUARC
- Chris Jurewicz, ARRB
- Paul Roberts, ARRB
- Jonathan McGuffie, DPTI
- Simon Harrison, DTMR.

The main objectives of the workshop were to communicate the rationale for and structure of the error assessment model and to gain agreement for this approach to error assessment and for the general direction of the project.

2.2.3 Results

A number of issues emerged from the discussion during the workshop.

There was agreement with the general thrust of the project. It was agreed that in order for the project not to become unwieldy that the analysis would continue to be restricted to rural high speed roads, leaving urban environments for future projects.

Three additional issues were identified as requiring some coverage in the project:

1. The ‘selling’ of the Safe System approach by pointing out (and illustrating) how most crashes are caused by genuine errors that anyone could have made. This can be reinforced by demonstrating how the Safe System approach can protect against such errors and will incidentally protect against violations also.
2. Expanding the range of treatments to infrastructure changes that can discourage error (and perhaps violations) in the first place, in addition to treatments designed to protect drivers when they do make an error.
3. Some coverage of non-infrastructure approaches to map out how these might interact and complement infrastructure approaches.

The key action identified was the need to expand the classification table system presented in the workshop to include additional treatments that could positively impact on the proximal and distal causes of crashes.

After taking account of the issues that were raised in the workshop a revised classification table was created. This is shown below (Table 2.2).

In this project, and in creating this table, a number of simplifying assumptions were made in order to make the analysis tractable.

Firstly, with respect to point 2, above, we adopted the simplifying policy of having no overlap between ‘Discourage errors’ treatments and ‘Protect drivers when they make an error’ treatments. Without this simplifying assumption the analysis would have been intractable. This makes some treatment assignments slightly counterintuitive until a number of factors are considered. For example, while a reduction in speed limit will reduce the probability of a driver making an error and also reduce the severity of the consequences of making that error (e.g. make it both less likely that a driver will fail to negotiate a curve correctly and make it easier to recover from that error if they do so fail), a reduction in speed limit was assigned to only the ‘discourage errors’ category. The rationale for this was that, in the cases we analysed, there were a large number of cases where speed contributed to the occurrence of the error and we didn’t want to lose sight of that important fact. This does not mean of course that speed should not be seen as a major treatment to reduce crash severity.

Another example is that of sealed shoulders. In many of the cases we analysed it was clear that sealed shoulders would have protected drivers from the consequences of the error of leaving the travel lane. Sealed shoulders may also have the potential to reduce the probability of drivers making that error in the first place. However, given the large number of these types of errors, we wanted to highlight the very obvious benefit to be gained from sealed shoulders in a ‘protect’ role.

Secondly, the sense we are using ‘protect’ here is the common language meaning and the concept of protection used in this report is quite general. That is, ‘protection from the negative consequences of making an error’. For example, a sealed shoulder offers some protection from the error of a lane excursion. We are not equating ‘protection’ with ‘protection from injury’ when the error results in a crash, although some treatments may offer their protection from the error in that way.

Finally, the actual impact of treatments was not quantified in this project. The results from this project could be finessed further by adding another layer of analysis where empirically-derived Crash Modification Factors (for each treatment and for combinations of treatments) are applied. However the added complexity entailed by this additional step is outside the scope of this project. For the current purposes treatments were selected based on their potential for reducing errors or mitigating the consequences of making an error, for a particular crash scenario, without any weighting with a crash modification factor.

Table 2.2: Error classification scheme

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	**Protect drivers upon making the critical errors**		**Issue**	**Mitigation**
C001	Head-on on curve	Lane excursion	Excess speed	1) Young driver/Inexperience	1) Curve 2) Speed limit	1) Vehicle-activated warning signs 2) Rumble strips on approach 3) Perceptual countermeasures 4) Lane narrowing/ self-explaining road treatments	1) Divided road 2) Centre line wire rope safety barrier (WRSB) on curve	All curves on undivided rural high speed roads	Motorcyclist safety	Motor cycle (m/c) friendly designs
C008	Sideswipe	Simultaneous overtaking	Attempt to overtake multiple vehicles	1) Impatience 2) Inappropriate attentional focus/poor situational awareness/incorrect assumptions about other driver	1) No overtaking provision 2) Broken centre line	1) Simultaneous-overtaking warning signs? 2) Solid centre line	1) Divided road/overtaking provision 2) Centre line WRSB	All undivided rural high speed roads	High speed maneuvers	Lower speed limit
C009	Loss of control (rollover)	Loss of traction/overcorrection on unsealed surface	Excess speed for conditions	1) Inexperience with unsealed roads 2) Inappropriate vehicle 3) Distraction and fatigue	1) Unsealed surface 2) Speed limit	1) Warning signs/speed advisory 2) Lower speed limit 3) Self-explaining road treatments	1) Seal surface 2) Restrict access	All unsealed roads	Risk compensation – increased speed	Perceptual effects/lane narrowing/ self-explaining road treatments

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C011	Head-on	Lane excursion	Driver fell asleep	Fatigue caused by sleep apnea	Undivided road	1) Centre line audio-tactile treatment (ATLM) 2) Rest areas	(1) Divided road (2) Centre line WRSB	All undivided rural high speed roads	Motorcyclist safety	M/c friendly designs
C012	Loss of control (rollover)	Overcorrection after straying onto unsealed shoulder	Deliberate inattention/ skylarking	Young driver/Inexperience	Unsealed shoulder	Warning signs	Seal shoulder	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C013	Loss of control (rollover)	Overcorrection after straying onto unsealed shoulder	1) Poor vehicle control/ inattention 2) Poor delineation	Young driver/inexperience	(1) Unsealed shoulder (2) Inadequate delineation	1) Better delineation 2) Warning signs	Seal shoulder	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C014	Right angle	Failed to give way	Possible disregard of give-way sign	Poor judgment/over familiarity with road	(1) Poor visibility (2) No Stop sign	1) Stop sign 2) Vehicle-activated warning 3) Improve visibility (approach rumble strips) 4) Signalize intersection 5) Change intersection geometry	Roundabout	All uncontrolled intersections	Increase in sideswipes	1) Signalize roundabout 2) Approach treatments to slow traffic

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C018	Loss of control (rollover)	Overcorrection after straying onto unsealed shoulder	Excess speed	Insufficient information	Unsealed shoulder	1) Warning sign 2) Perceptual effects/ self-explaining road treatments	Seal shoulder	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C022	Right angle	Failed to give way	1) Distraction 2) Unfamiliarity with road	1) Other occupants 2) Excitement 3) Non-Australian license 4) Running late	None apparent	1) Vehicle activated warning signs 2) Signalize intersection	Roundabout	All uncontrolled intersections	Increase in sideswipes	1) Signalize roundabout 2) Approach treatments to slow traffic
C027	Head-on	Lane excursion	Distraction (looking for something in passenger foot well)	Insufficient information	None apparent	Centre line ATLM	1) Divided road 2) Centre line WRSB	All undivided rural high speed roads	Motorcyclist safety	M/c friendly designs
C028	Loss of control (hit tree, rollover)	Overcorrection after straying onto unsealed shoulder	Unsafe overtaking	Insufficient information	1) Unsealed shoulder 2) Vertical alignment 3) Road marking	Solid centre line	1) Divided road 2) Seal shoulder 3) WRSB	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C029	Run off road	Evasive maneuver (animal on road)	Poor anticipation	Young driver/inexperience	Roadside hazards	Warning signs (animals on road)	1) Barriers 2) Fence road reserve	All rural high speed roads	Motorcyclist safety	M/c friendly designs

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C030	Run off road	Overcorrection after straying onto unsealed shoulder	Lane excursion by other vehicle	Other vehicle overloaded	1) Horizontal alignment 2) Unsealed shoulder	Truck warning signs	1) Seal shoulder 2) Centre line WRSB on curve 3) Alter curve geometry	All undivided rural high speed roads	Motorcyclist safety	M/c friendly designs
C031	Loss of control (rollover)	Overcorrection after straying onto unsealed shoulder	Lapse of attention	Older driver	1) Unsealed shoulder 2) Embankment	ATLM	1) Seal shoulder 2) Barriers	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C032	Loss of control (rollover)	Overcorrection after straying onto unsealed shoulder	Distraction (bird flying towards windscreen)	Lack of training	1) Unsealed shoulder 2) Poor delineation	Warning signs	Seal shoulder	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C035	Rear end (but see description as not classic RE)	Panic braking	1) Poor decision making 2) Poor vehicle control skill	Young driver/Inexperience	None apparent	Truck warning signs	Separate HV lanes	All freeways	LV use of truck lanes	Automatic number plate recognition (ANPR) cameras
C036	Side swipe	Change into occupied lane	Poor judgment/ failure to look	Older driver	Horizontal and vertical alignment?	Warning signs (LOOK)	Separate HV lanes	All freeways	LV use of truck lanes	ANPR cameras

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C037	Rear end	Fail to stop	Incorrect assumptions and allocation of attention	Over familiarity with road?	Road layout	Warning sign (vehicles may stop)	Improve merge lanes	All freeways	Increased speed in slip lane	Transverse rumble strips
C038	Loss of control (m/c)	Left sealed surface	1) Poor judgment/ perceptual confusion 2) Excess speed	Older driver (NB m/c)?	1) Road layout 2) Marking and delineation 3) Lack of signage	1) Signage clarifying road layout and alignment 2) Better delineation	M/c-friendly barriers	All barriers	Risk compensation – increased speed	Perceptual effects/lane narrowing/ self-explaining road treatments
C039	Run off road	Drove off road	Distraction	Young driver/Inexperience	Road layout?	Centre line ATLM	1) Roadside barriers 2) Centre line WRSB	All rural high speed roads	Motorcyclist safety	M/c friendly designs
C040	Right angle	Failed to give way	Not enough information	1) International driver/used to giving way to left rather than right?	1) Road layout 2) Visibility	1) Road markings 2) Advance warning signs	Roundabout	All uncontrolled intersections	Increase in sideswipes	1) Signalize roundabout 2) Approach treatments to slow traffic
C041	Run off road (rollover)	Fell asleep	Not enough information	Not enough information	Embankment	1) Fatigue warning signs 2) Trivia signs 3) Rest areas	Roadside barriers	All rural high speed roads	Motorcyclist safety	M/c friendly designs

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C042	Run off road	Drove off road	1) Distraction? 2) Poor vehicle control	Young driver/ inexperience	1) Unsealed shoulder 2) Roadside objects 3) Horizontal alignment	1) Curve warning signs 2) Speed advisory	1) Seal shoulders 2) Clear zone 3) Barriers	All rural high speed roads	Motorcyclist safety	M/c friendly designs
C043	Run off road (rollover)	Fell asleep	Lack of sleep	1) Poor fatigue management 2) Young driver	Roadside object (culvert)	1) Fatigue warning signs 2) Centre line ATLMs 3) Rest areas	1) Adequate clear zone 2) Barriers	All rural high speed roads	Motorcyclist safety	M/c friendly designs
C044	Run off road	Fell asleep	Lack of sleep	1) Poor fatigue management 2) Young driver	Roadside object (tree)	1) Fatigue warning signs 2) Centre line ATLMs 3) Rest areas	1) Adequate clear zone 2) Barriers	All rural high speed roads	Motorcyclist safety	M/c friendly designs
C045	Loss of control	Overcorrection after straying into opposing lane	1) Poor vehicle control 2) Speed	Young driver/ inexperience	Roadside object (tree)	1) Lower speed advisory 2) Curve warning 3) Centre ATLM	1) Adequate clear zone 2) Barriers	All rural high speed roads	Motorcyclist safety	M/c friendly designs
C046	Loss of control (rollover)	Lost traction/overcorrection on unsealed surface	1) Poor vehicle control 2) Speed?	Not enough information	1) Unsealed road 2) Embankment 3) Roadside objects	1) Lower speed limit 2) Warning signs	1) Seal surface 2) Barriers	All unsealed roads	Risk compensation – increased speed	Perceptual effects/lane narrowing/ self-explaining road treatments

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C047	Rear end	Failed to appreciate stationary vehicle	1) Distraction? 2) Inadequate work zone practice	Older driver	Unmarked work zone	1) Signage 2) Cone off lane	Temporary barriers	All work zones	Risk compensation – increased speed	Enforcement
C048	Right angle	Failed to give way	Look but did not see?	Not enough information	High speed limit on through road	1) Lower speed limit on through road 2) Entering vehicles warning sign	Roundabout	All uncontrolled intersections	Increase in sideswipes	1) Signalize roundabout 2) Approach treatments to slow traffic
C049	Loss of control (rollover)	None – vehicle component failure	–	–	Road side objects	–	1) Adequate clear zone 2) Barriers	All rural high speed roads	Motorcyclist safety	M/c friendly designs
C050	Rear end	Failure to monitor speed of other traffic	Impatience?	Young driver/inexperience	Lack of separation of vehicle classes	1) Warning signs (slow moving trucks) 2) Lower speed limit	Separate HV lanes	All freeways	LV use of truck lanes	ANPR cameras
C051	U-turn	Fail to give way to approaching traffic	1) Distraction 2) Impatience	Running late?	Undivided road	No U-turn signs	1) Divided road 2) Centre line WRSB	All undivided rural high speed roads	Motorcyclist safety	M/c friendly designs
C052	Loss of control	Lane excursion (other vehicle)	Not enough information	Not enough information	1) Undivided road 2) Roadside objects	1) Lower speed limit 2) Warning signs	1) Divided road 2) Centre line WRSB	All undivided rural high speed roads	Motorcyclist safety	M/c friendly designs

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Indication location	Dangerous defense?	
						Discourage errors	Protect drivers upon making the critical errors		Issue	Mitigation
C053	Loss of control	Lost traction/overcorrection on unsealed surface	1) Poor vehicle control 2) Speed	Inexperience on unsealed roads	1) Unsealed road 2) Roadside objects	1) Lower speed limit 2) Warning signs 3) Self-explaining road treatments	1) Seal surface 2) Barriers	All unsealed roads	Risk compensation – increased speed	Perceptual effects/lane narrowing/ self-explaining road treatments
C054	Loss of control (run off road)	Overcorrection after straying onto unsealed shoulder	1) Poor vehicle control 2) Distraction?	Young driver/ inexperience	1) Unsealed shoulder 2) Roadside objects	1) Lower speed limit 2) Warning signs	1) Seal shoulders 2) Clear zone 3) Barriers	All rural high speed roads	Risk compensation – reduced tracking precision	ATLMs
C055	Rollover (HV)	Rolled vehicle	Excessive speed	Not enough information	Road geometry	1) Lower speed limit 2) Warning signs 3) Self-explaining road treatments	More forgiving road geometry	All HV routes	Risk compensation – increased speed	Perceptual effects/lane narrowing/ self-explaining road treatments
C056	Rear end	Fell asleep?	Lack of sleep	1) Poor fatigue management 2) Younger driver	None	1) Fatigue warning signs 2) Centre line ATLMs 3) Rest areas	–	–	–	–
C059	Right angle	Failed to give way	1) Failed to look? 2) Look but did not see?	Older driver	Speed limit on through road?	1) Lower speed limit on through road 2) Entering vehicles warning sign	Roundabout	All uncontrolled intersections	Increase in sideswipes	1) Signalize roundabout 2) Approach treatments to slow traffic

2.3 Results

The results in Table 2.2 indicate that there were a total of 18 types of critical error that resulted in crashes in the sample of crashes that occurred in this road environment (rural high speed roads). These are indicated below:

- change into occupied lane
- drove off road
- evasive manoeuvre (animal on road)
- fail to give way to approaching traffic
- failed to stop
- failed to appreciate stationary vehicle
- failed to give way
- failure to monitor speed of other traffic
- fell asleep
- lane excursion
- left sealed surface
- loss of traction/overcorrection on unsealed surface
- none – vehicle component failure
- overcorrection after straying into opposing lane
- overcorrection after straying onto unsealed shoulder
- panic braking
- rolled vehicle
- simultaneous overtaking.

As can be seen from Table 2.3, by far the most common type of error is over correction after straying on to the unsealed shoulder. Failing to give way, lane excursion and falling asleep are the next most common errors, but only approximately half as frequent as straying on to the unsealed shoulder. Loss of traction and/or control on unsealed roads also appears to be a not uncommon error. In only one case was there no human error implicated (a vehicle mechanical failure was implicated).

Table 2.3: Critical errors

Error	Frequency
Change into occupied lane	1
Drove off road	2
Evasive manoeuvre (animal on road)	1
Fail to give way to approaching traffic	1
Failed to stop	1
Failed to appreciate stationary vehicle	1
Failed to give way	5
Failure to monitor speed of other traffic	1
Fell asleep	4
Lane excursion	4
Left sealed surface	1
Loss of traction/overcorrection on unsealed surface	3
None – vehicle component failure	1
Overcorrection after straying into opposing lane	1
Overcorrection after straying onto unsealed shoulder	8
Panic braking	1
Rolled vehicle	1
Simultaneous overtaking	1

The results in Table 2.2 suggest numerous vehicle and driver training measures could be taken in order to address some of these errors. However, the central aim of this project is to identify infrastructure countermeasures that have the potential to protect drivers when they make these errors. In total 14 infrastructure countermeasures were identified that would have offered protection in the case of making one or more of the errors that drivers made in the current sample. These countermeasures and the number of cases to which they could have been applied are shown in Table 2.4.

Table 2.4: Infrastructure countermeasures to protect drivers on making an error

Infrastructure countermeasure	Frequency
Centre line WRSB	9
Clear zone	6
Divided road	7
Fence road reserve	1
Geometry changes	1
Heavy vehicle lanes	3
Overtaking provision	1
Restricted access	1
Roundabout	4
Roadside barrier	11
Sealed shoulder	11
Sealed surface	2
Slip lane geometry	1

As can be seen, sealing shoulders, installing roadside barriers and centre line WRSBs would have protected drivers in a substantial number of cases. Provision of adequate clear zones and a divided road layout would also have made a significant contribution to protecting drivers when they made these errors.

As discussed above, while countermeasures that are designed to protect road users should be the preferred approach from a Safe Systems perspective, there is also merit in considering those countermeasures that can discourage errors; because they are often cheaper and less disruptive to install and they may reduce the maintenance costs of the other class of countermeasures. These countermeasures and the number of cases to which they could have been applied are shown in Table 2.5.

Table 2.5: Infrastructure countermeasures to discourage errors

Infrastructure countermeasure	Frequency
Advance warning signs	1
Audio-tactile line marking	1
Better delineation	2
Centre line audio-tactile line marking	7
Change intersection geometry	1
Cone off lane	1
Curve warning signs	2
Entering vehicles warning sign	2
Fatigue warning/trivia signs	5
Improve visibility on approach	1
Lower speed limit	11
No U turn	1
Perceptual countermeasures	2
Rest areas	5
Road markings	1
Rumble strips	1
Self-explaining road treatments	4
Signage clarifying layout	2
Signalise intersection	2
Solid centre line	2
Speed advisory	1
Stop sign	1
Truck warning signs	2
Vehicle activated warning signs	3
Warning signs (various)	14

Clearly, lower speeds and various kinds of warning signs are the categories of countermeasures that, on their own, have the greatest potential to reduce driver errors. audio-tactile line marking and rest areas would also have had the potential to discourage a substantial number of errors.

2.3.1 Reliability and Applicability

In order to test the reliability and applicability of the results obtained here a further 20 cases were randomly selected from the CASR database. The error classification scheme outlined above was applied to these new cases and the extent to which the errors would have been addressed by a subset of treatments was investigated (see Table 2.6).

Discourage errors

The top three treatments to discourage errors are:

- warning signs
- lower speed limit
- audio-tactile line marking.

The top six treatments to discourage errors are:

- warning signs
- lower speed limit
- audio-tactile line marking
- fatigue warning/trivia signs
- rest areas
- self-explaining road treatments.

Protect drivers

The top three treatments to protect drivers are:

- sealed shoulders
- roadside barriers
- centre line WRSBs.

Top six treatments to protect drivers are:

- sealed shoulders
- roadside barriers
- centre line WRSBs
- divided road
- clear zone
- roundabout.

Inspection of Table 2.6 indicates that for the ‘discourage errors’ category, there was 90% agreement for the top three treatments and 85% agreement for the top six treatments. This suggests that there are no major gaps in the treatments identified in this category. For the ‘protect’ category there was a 65% agreement for the top three treatments and 75% agreement for the top six treatments. This suggests that the top three ‘protect’ treatments may need some reassessment.

The gaps here results largely from the need for adequate clear zones to protect motorcyclists where they leave the carriageway. However, it is often impractical or impossible to provide adequate clear zones. A relatively straightforward and well understood approach to this is to deploy barriers with motorcycle friendly barrier modifications. A less well understood approach that may be worthy of further investigation is the provision of motorcycle-specific signage that provides motorcyclists with information that is particularly pertinent to motorcycle riding about road layout and hazards.

Table 2.6: Additional cases reliability test

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Addressed by 'discourage' treatments?		Addressed by 'protect' treatments?	
						Discourage errors	Protect drivers upon making the critical error	Top 3	Top 6	Top 3	Top 6
C060	Run off road	Drove off road	Lane excursion by other vehicle?	Young driver/ inexperience	1) Embankment 2) Horizontal alignment	Warning signs (other direction)	1) WRSBs 2) Centre line WRSBs	YES	YES	YES	YES
C065	Loss of control (m/c)	Left sealed surface	1) Poor vehicle control 2) Speed	Poor judgement	Roadside objects	1) Lower speed advisory 2) Curve warning	Adequate clear zone	YES	YES	NO	NO
C066	Loss of control (m/c)	Left sealed surface	Unsafe overtaking	Young driver/ inexperience	1) Curve 2) Speed limit	1) Speed advisory 2) Curve warning sign	Adequate clear zone	YES	YES	NO	NO
C068	Loss of control (caravan)	Caravan fishtail	Not enough information	1) Older driver 2) Unfamiliarity with caravan	1) Vertical alignment 2) Roadside object (tree in median)	Warning signs	Adequate clear zone	YES	YES	NO	NO
C070	Run off road	Fell asleep	Not enough information	1) Poor fatigue management 2) Young driver	Roadside object (tree)	1) Fatigue warning signs 2) Trivia signs 3) Rest areas	Roadside barriers	YES	YES	YES	YES
C071	Run off road	Fell asleep	Lack of sleep	1) Poor fatigue management 2) Young driver	Roadside object (tree)	1) Fatigue warning signs 2) Centre line ATLMs 3) Rest areas	1) Roadside barriers 2) Centre line WRSB	YES	YES	YES	YES
C072	Loss of control	Overcorrection after straying onto shoulder	Lapse of attention	Young driver	None apparent	ATLM	Adequate clear zone	YES	YES	NO	NO
C074	Loss of control (rollover)	Hit embankment	1) Poor vehicle control/ inattention 2) Excess speed	1) Young driver/ inexperience 2) Unfamiliarity with road	1) Roadside object (embankment) 2) Drainage	Warning signs (slippery surface)	WRSB	YES	YES	YES	YES

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Addressed by 'discourage' treatments?		Addressed by 'protect' treatments?	
						Discourage errors	Protect drivers upon making the critical error	Top 3	Top 6	Top 3	Top 6
C085	Right angle	Failed to stop	Inattention	1) Unfamiliarity with road 2) Under arousal/fatigue?	Line marking (faded stop line)	1) Better line marking 2) Vehicle activated warning signs 3) Rumble strips on approach	Roundabout	YES	YES	NO	YES
C089	Head on	Out of lane (overtaking)	Unsafe overtaking	Perceptual failure	1) Vertical alignment 2) Line marking (inappropriate broken centre line	Solid centre line	Centre line WRSB	NO	NO	YES	YES
C090	Right angle	Failed to give way	Failed to see approaching vehicle	1) Young driver/ inexperience 2) Excessive speed of other vehicle	1) Poor visibility 2) Uncontrolled intersection	1) Improve visibility 2) Give-way sign	1) Roundabout 2) Lower speed limit on through road	YES	YES	NO	YES
C091	Head on (on bend)	Out of lane (loss of control)	Excess speed	Rider inexperience	1) Curve 2) Lack of speed advisory	Speed advisory	Centre line WRSB	YES	YES	YES	YES
C093	Suicide? – Exclude?										
C095	Head on	Out of lane (overtaking)	Unsafe overtaking/ perceptual failure	1) Young driver/ inexperience 2) Excessive speed 3) Drugs	Undivided road	Solid centre line	Centre line WRSB	NO	NO	YES	YES
C097	Rear end	Failed to stop	Failed to see stopped vehicle	Expectancy/set	Undivided road	Warning signs	Reduce speed limit	YES	YES	NO	NO
C099	Loss of control (m/c)	Dropped bike	1) Lack of traction 2) Excess speed?	Inexperience/lack of skill	1) Skid resistance 2) Roadside objects 3) Pothole?	Warning signs	Roadside barriers (m/c friendly)	YES	YES	YES	YES
C101	Alcohol as primary case – exclude?										

Case	Crash description	Immediate cause (critical error)	Proximal cause/s	Distal cause/s	Infrastructure contributions	Infrastructure solutions to:		Addressed by 'discourage' treatments?		Addressed by 'protect' treatments?	
						Discourage errors	Protect drivers upon making the critical error	Top 3	Top 6	Top 3	Top 6
C104	Single vehicle	Drove off road	1) Excess speed 2) Poor vehicle control	Young driver/ inexperience	Roadside objects	Vehicle-activated warning signs	Roadside barriers	YES	YES	YES	YES
C105	Loss of control	Overcorrection after straying onto unsealed shoulder	1) Poor vehicle control 2) Excess speed 3) Distraction	Young driver/ inexperience	1) Horizontal alignment 2) Roadside objects	1) Vehicle-activated warning signs 2) ATLMs 3) Rumble strips	Roadside barriers	YES	YES	YES	YES
C106	Single vehicle	Failed to negotiate bend	1) Poor vehicle control 2) Excess speed	Young driver/ inexperience	1) Road layout 2) Roadside objects	1) Self explaining layout 2) Warning signs	Roadside barriers	YES	YES	YES	YES
C117	Head on	Out of lane	Fell asleep?	1) Poor fatigue management 2) Young driver	None	Centre line ATLM	Centre WRSB	YES	YES	YES	YES
C119	Loss of control	Overcorrection after straying on to wrong side of road	1) Distraction 2) Poor vehicle control	Young driver/ inexperience	Roadside objects	Centre WRSB	Roadside barriers	NO	NO	YES	YES

2.4 Conclusions

The proposed approach has been shown to have utility in classifying driver errors and in pointing to infrastructure countermeasures that have the potential to protect drivers when they make these errors. Furthermore, this approach is relatively easy to use with critical errors at the level of analysis adopted here easily identified from the information in the CASR in-depth crash database.

Interestingly, a surprisingly small number of error types accounted for the majority of crashes, with overcorrection after straying onto the unsealed shoulder being the most common.

Similarly, a relatively small number of treatment types applied in the appropriate location would have protected a large number of drivers who made errors. In particular sealed shoulders, roadside barriers and centre line WRSBs would have been effective.

While the original list of treatments was shown to contain some gaps after the validation study, these gaps pertain largely to motorcyclists and can be plugged via the inclusion of motorcycle friendly infrastructure and motorcycle-specific signage.

Deliberate violations account for up to 25% of all ‘errors’ (depending on exactly how violations are defined) in this analysis. They have not been considered separately because, in every case, the infrastructure solution to these ‘errors’ was also the infrastructure solution to a non-violation error.

Finally, while the CASR database does contain some night-time crashes, it proved difficult to satisfy the other selection criteria and simultaneously include night-time crashes. For this reason the results obtained here may underestimate the impact of improved guidance from reflective materials and from lighting.

3. Trialling the Approach

With the error assessment framework established, this second part of the project is aimed at investigating the feasibility and cost of adapting the road system to protect aberrant road users. While the results from this study do not provide a blueprint that guarantees crash prevention, for the first time they offer a way of estimating the feasibility and cost of various approximations to an ideal system of infrastructure that discourages driver error and protects drivers from the consequences of an error, for a rural road environment in Australia and New Zealand.

3.1 Methodology

The method for achieving this part of the project was to select defined geographical areas and systematically apply the identified treatments so as to model the feasibility and costs associated with providing varying levels of safety in a rural road network.

The following attributes for the study area were considered desirable:

- a rural area in South Australia similar to the environment where the in-depth crashes had been investigated
- a mixture of open plains and hills environments broadly representative of Australian landscapes
- a cross-section of roads in a functional road hierarchy including one high standard rural freeway.

Following the consideration of a range of candidate areas, it was decided to adopt two separate study areas. One area was focussed exclusively on a hills environment and the other on a plains environment. This permitted the areas to be confined to a manageable size whilst still retaining a high proportion of the desired attributes. Both areas measured 10 km by 5 km and contained 50 square kilometres of hills or plains landscapes. Both study areas also fell within the boundary of the in-depth study from which the original crash data was obtained.

3.1.1 Determining Attributes of the Areas

Various attributes in relation to the road and road environments in each area were needed so that treatment cost calculations could be performed. These attributes were obtained from a variety of sources including: the Google Maps viewing platform for aerial and street view perspectives, the CASR in-depth crash database and Department of Planning, Transport and Infrastructure (DPTI) databases. Table 3.1 summarises the road attributes obtained for the study areas.

Table 3.1: Road attributes collected in each area

Attribute	Value	Notes
Total length	Length km	Length of road segments within the study area
Intersections	Number	Number of intersections along the road segment
Speed limit	80, 100, 110 km/h	Posted speed limit for the road segment
Shoulder sealed	Length km	Length of road with sealed shoulders of width greater than 1 metre on both sides of the road
Divided	Yes No	If the road segment consisted of dual carriageway
Barriers	Length km	Length of barriers along the road segment (both sides of road counted individually)
Veg roadside	Length km	Length of roadside vegetation - each side counted separately and summed
Veg middle	Length km	Length of vegetation located in the middle of the roadway – only relevant to divided roads
AADT	Vehicles	Annual Average Daily Traffic – sourced from DPTI maps

Attribute	**Value**	**Notes**
Intersections		
Intersection	Name of intersection road	Name of intersecting road with the road segment
Type	T-junction Cross road Multi-leg	
Legs	3 or 4	Number of legs making up the intersection
Control	Stop Give Way Uncontrolled	Traffic control at the intersection
Seal	Sealed Unsealed	
Turning and slip lanes	Full compliment Left turn only Right turn only None	
Roads		
Road	Name	Name of road that the bend is on
Advisory	30 to 85 km/h 9 None Corner warning	‘9’ denotes that no advisory is needed for that bend Corner warning – sign used without speed advisory
Road hierarchy	Main Route Alternative Route Trafficable Road	Simplified hierarchy to assist with analysis. Trafficable roads consisted of sealed and unsealed roads
Road type	Major Minor	Major roads consist of roads in the Main or Alternative routes category Minor roads consist of roads in the Trafficable roads category
Road authority	LGA SRA	Distinguishes jurisdiction of the road between Local Government Authority or a State Road Authority

Trees that existed within a 10 m area parallel to the road were noted. The length of road lined by trees on both sides and in some cases in the middle of the road were added together providing a total length of vegetation for an individual road. The length of vegetation could therefore theoretically be up to three times the length of the road. Single trees were assumed to occupy a 10 m length and groups of trees were measured directly between the first and last tree along the road.

Linemarking was noted in terms of edgelines, centrelines and lane separation lines. Audio-tactile linemarking was also used as edgelines in the study areas and their presence noted.

Intersections were categorised as major or minor to assist with the analysis scenarios. A major intersection was defined as having two intersecting roads that were classified as either a main route or alternative route; all other intersection types were classified as minor (i.e. any intersections where one leg consisted of a trafficable road category).

The annual average daily traffic (AADT) estimates were only available for the state controlled roads and were obtained from the South Australian Department of Planning, Transport and Infrastructure (DPTI) maps (DPTI 2013).

3.1.2 Detailed Description of the Areas

Plains study area

The plains study area is located 50 km to the south east of the Adelaide GPO. The area is characterised by relatively flat agricultural land and 'Mallee' native vegetation. The major roads in the area include the Goolwa – Callington Road, the Old Princes Highway and the Ferries McDonald Road. These roads are sealed single carriageway bi-directional roads. The study area also contains the South Eastern Freeway which is a high standard dual carriageway road. Land uses in the area include agriculture (mainly wheat and sheep farms), some rural industry and a small rural township with a population of approximately 400 people.

Figure 3.1 shows a map of the area. Roads in the rural town with a speed limit of 60 km/h or less were not included in the study.

Figure 3.1: The plains study area

Source: Google Maps (2012), 'South Australia', map data, Google, California USA.

Overall, the area contained 30.1 km of sealed roads and 29.2 km of unsealed roads. There were a total of 25 intersections, 19 sealed and 6 unsealed. Six intersections were classified as major intersections. A total of 66 individual curves were identified, half of which were unsealed. The road attributes associated with this study area are shown in Table 3.2, Table 3.3 and Table 3.4.

Table 3.2: Plains area road characteristics

	Sealed	Unsealed	Total
Road length (km)	30.1	29.2	59.3
Bends	33	33	66
Junctions			
Merge	2	0	2
Multi-leg (4)	1	0	1
T-junction	13	3	16
Cross roads	3	3	6
Major T-junctions	5	0	5
Major cross roads	1	0	1
Total Junctions	19	6	25

Table 3.3: Sealed roads

Road	Length	Speed limit	Shoulder seal	Barriers	Vegetation (side)	Vegetation (middle)	Line marking	AADT
Main routes								
South Eastern	10.40	110	Outer edge only	Very limited	7.28	5.54	Audio-tactile	12 800
Callington interchange	1.00	110	Inner edge only	None	0.21	–	Standard	1 200
Monarto Interchange	0.83	110	Inner edge only	None	0.31	–	Standard	UK
Goolwa – Callington	3.20	110	None	Only on bridge	0.62	–	Standard	1 600
East Tce	1.13	80	None	Only on bridge	0.83	–	Standard	850
Alternative routes								
Old Princes Hwy	9.30	100	1.1 km only	0.6 km	6.27	–	Faded	950
Ferries McDonald	2.48	80	None	Only on bridge	1.72	–	Only 50% edge lines	UK
Trafficable roads								
Schenscher Rd	1.36	100	None	None	–	–	No edge lining	UK
Harrogate Rd	0.40	100	None	None	–	–	No road markings	UK

Table 3.4: Unsealed roads

Road	Length	Speed limit	Barriers
Ferries McDonald Rd	1.23	100	None
White Rd	0.88	100	None
Bremer Range Rd	10.26	100	None
North Bremer Rd	2.6	100	None
Samuels Rd	0.8	100	None
William Hill Rd	0.07	100	None
Unnamed Rd out of Callington	3.06	100	None
Cemetery Rd	1.3	100	None
Holmes Ln	0.48	100	None
Thomas Cres	6.24	100	None
Highland Rd	0.58	100	None
Browns Rd	0.66	100	None
Frahns Farm Rd	1.07	100	None

Hills study area

The hills study area is located 25 km to the east of the Adelaide GPO. The area is characterised by hills, creeks and rivers and contains a high proportion of native vegetation in the road reserve. The area contains a township of just under 2000 people and two smaller townships of around 300 people each. Land uses in the area include agriculture (wineries and livestock), light industry and tourism. Roads with a speed limit of 60 km/h or less were not included in the study. Figure 3.2 shows a map of the area.

Figure 3.2: The hills study area

Source: Google Maps (2012), ‘South Australia’, map data, Google, California USA.

Overall, the study area contained 47.5 km of sealed roads and 14.6 km of unsealed roads. There were a total of 48 intersections of which 38 were sealed and 10 unsealed. Only two of these intersections where the speed limit was 80 km/h were classified as major. There were a total of 287 bends, of which 197 were on sealed roads and 90 were on unsealed roads. Attributes associated with the study area are listed in Table 3.5, Table 3.6 and Table 3.7.

Table 3.5: Hills area road characteristics

	Sealed	Unsealed	Total
Road length (km)	47.5	14.6	62.1
Bends	197	90	287
Junctions			
Merge	0	0	0
Multi-leg (4)	0	0	0
T-junction	36	9	45
Cross roads	2	1	3
Major T-junctions	1	0	1
Major cross roads	1	0	1
Total junctions	38	10	48

Table 3.6: Sealed roads

Road	Length	Speed limit	Shoulder seal	Barriers	Vegetation (side)	Vegetation (middle)	Line marking	AADT
Main route								
Onkaparinga Valley Rd	3.19	80	Moderate (1 m)	0.5	3.27	–	Standard	2700
Onkaparinga Valley Rd	1.05	100	Moderate (1 m)	None	1.43	–	Standard	2700
Alternative route								
Lobethal-Mt Torrens Rd	0.79	80	None	None	0.83	–	No edge lining	950
Lobethal-Mt Torrens Rd	2.76	100	None	0.40	3.24	–	No edge lining	950
Gumeracha - Lobethal Rd	0.79	80	None	None	0.80	–	No edge lining	1800
Cudlee Creek Rd	1.52	80	Limited	0.84	0.82	–	Standard	1900
Adelaide-Lobethal Rd	3.82	80	None	1.13	5.99	–	Standard	1100
Woodside Rd	0.54	80	Good	None	0.46	–	Standard	4500
Woodside Rd	1.02	100	Good	None	0.64	–	Standard	4500
Trafficable roads								
Hirthe Rd	0.39	100	None	None	–	–	No edge lining	UK
Schubert Rd	0.86	80	None	None	–	–	Limited	UK
Eckeman Rd	0.95	100	None	None	–	–	No edge lining	UK
Springhead Rd	0.51	100	None	None	–	–	No edge lining	UK
Hartaman Rd	1.09	100	None	None	–	–	No edge lining	UK
Jungfer Rd	1.04	80	None	None	–	–	No edge lining	UK
Schoenthal Rd	1.39	80	None	None	–	–	No edge lining	UK
Juers Rd	1.18	80	None	None	–	–	No edge lining	UK
Graeber Rd	1.65	80	None	None	–	–	No edge lining	UK
Newman Rd	0.37	80	None	None	–	–	No edge lining	UK
Newman Rd	1.07	100	None	None	–	–	No edge lining	UK
Buckleys Rd	1.05	80	None	None	–	–	No edge lining	UK
Western Branch Rd	2.13	80	None	None	–	–	No edge lining	UK
Kumnick Hill Rd	1.48	80	None	None	–	–	No edge lining	UK
Tiers Rd	1.28	80	None	None	–	–	No edge lining	UK
Swamp Rd	0.93	80	None	None	–	–	No edge lining	UK
Leslie Rd	0.82	100	None	None	–	–	No edge lining	UK
Neudorf Rd	2.00	80	None	None	–	–	No edge lining	UK
Post office Rd	0.82	80	None	None	–	–	No edge lining	UK
Miller Rd	1.93	80	None	None	–	–	No edge lining	UK
Staffords Rd	2.40	100	None	None	–	–	No edge lining	UK
Croft Rd	0.24	100	None	None	–	–	No edge lining	UK
Coldstore Rd	2.53	80	None	None	–	–	No edge lining	
Fox Creek Rd	0.67	80	None	None	–	–	No edge lining	UK
Edwards Hill Rd	1.30	100	None	None	–	–	No edge lining	UK
Harris Rd	1.93	80	None	None	–	–	No edge lining	UK

Table 3.7: Unsealed roads

Road	Length	Speed limit	Barriers
Marshall Rd	0.22	100	None
Mawson Rd	0.74	100	None
Schocroft Rd	0.05	100	None
Brettig Rd	1.02	100	None
Bracken Ln	0.23	100	None
Jungfer Rd (unsealed)	1.21	100	None
Burns Rd	1.95	100	None
Billy Goat Hill Rd	0.4	100	None
Pedare Park Rd	0.62	100	None
Kumnick Hill Rd (unsealed)	0.32	100	None
Bonython	0.53	100	None
Neudorf Rd (unsealed)	0.74	100	None
Magpie Castle Rd	1.16	100	None
Klopsch Rd	0.77	100	None
Stringy Bark Rd	0.33	100	None
Croft Rd	3	100	None
Forest Rd	0.67	100	None
Joyce Rd	0.62	100	None

3.1.3 Costs Associated with the Treatments

Treatment costs were derived from two main sources. The Australian Road Assessment Program (AusRAP) version 3 countermeasure upgrade costs were used as the basis for the treatment costs. Values were obtained from the rural-medium upgrade category for Victoria as this was regarded as best representing the scale and scope of applied treatments. Where treatments were not listed in the AusRAP table, DPTI was able to supply some cost information in relation to recent real world applications.

3.1.4 Treatment Scenarios

In order to model feasibility and cost a value for a number of variables needed to be chosen. The following table outlines the assumptions made in relation to the application of treatments in the study areas. It is not assumed that these are the only values that make sense and they could be altered to reflect various considerations.

Table 3.8: Assumptions used to estimate treatment application costs in the study areas

Treatment	Application scenario and assumptions	Applied to this road class?			
		Main	Alternative	Trafficable sealed	Unsealed
Advance warning signs at all intersections	Junction advisory sign installed on every approach to an intersection. No account was made for pre-existing signs.	Yes	Yes	Yes	Yes
Alternative curve geometry	The detailed analysis of the geometry of each curve in the study area was beyond the scope of the project. It was therefore assumed that one curve would need to be treated in the plains area and 10% of curves would require treatment in the hills area.	Yes	Yes	Yes	Yes
Audio-tactile line marking	All bends were assumed to have a treatment length of 100 m. Audio-tactile linemarking was costed on the freeway for lane separation lines only as audio-tactile edgelines were already in place.	Yes	Yes	Yes	No
Wide centreline or painted median	All bends were assumed to have a treatment length of 100 m. AusRAP treatment ID #190.	Yes	Yes	Yes	No
Better delineation at junctions	Applied at all sealed junctions regardless of existing linemarking. AusRAP treatment ID #13.	Yes	Yes	Yes	No
Better delineation at bends	Apply edge line marking on both sides on all sealed bends.	Yes	Yes	Yes	No
Change intersection geometry	Addition of median islands and channelisation to the intersection. Median islands of 1.8 m width and 20 m length on each leg. It was assumed that no extra seal width would be required. Cost calculated per square metre of median.	Yes	Yes	Yes	No
Turn lanes	Turning lanes were applied to all intersections that did not already have both left and right turning lanes. Different prices were applied for three and four leg junctions: ▪ AusRAP treatment ID #11 ▪ AusRAP treatment ID #12.	Yes	Yes	Yes	No
Creation of clear zones	Cost of creating a clear zone was applied to the linear length of trees noted along all sides of the road segment. The clearing of vegetation in the median of the freeway was also included. AusRAP treatment ID #41.	Yes	Yes	No	No
Divided roads	Applied to all major roads (either main or alternative routes). AusRAP treatment ID #29.	Yes	Yes	No	No
Roundabouts	AusRAP treatment ID #20.	Yes	Yes	Yes	No
Energy absorbing attenuator on rear of maintenance fleet vehicles	Assumption that application only necessary on the rear vehicle in a convoy. As the study areas were relatively small, it was assumed that only one vehicle needed to be treated in each area.	Yes	No	No	No
Curve advisory signs	Applied on all bends where no pre-existing signs were present. Bends that did not have a speed advisory were also included for upgrading. Each bend used two signs: one on each approach to the bend.	Yes	Yes	Yes	Yes

Treatment	Application scenario and assumptions	Applied to this road class?			
		Main	Alternative	Trafficable sealed	Unsealed
Fatigue warning signs	One sign was applied to each sealed road that completely crossed the study area. The sign was assumed to be similar to an R6-32 (from AS1742.1) with a dimension of 1200 x 800 mm at a cost of $300 per square metre.	Yes	No	No	No
Fence road reserve	Install fencing on both sides of the road reserve that would contain wildlife irrespective of pre-existing fencing.	Yes	Yes	No	No
Improve visibility on approach to junctions	Calculating the sight distances at each site was beyond the scope of the project. It was assumed that 5% of junctions would need to be treated in each area. AusRAP treatment ID #79.	Yes	No	No	No
Improve merge lanes	Applied only to the existing merge lanes on the freeway.	Yes	No	No	No
Lower speed limit	Applied on a per kilometre basis for roads in the study area AusRAP treatment ID #56.	Yes	Yes	Yes	Yes
Ban U-turns	Installation of a U-turn prohibited sign on each leg of an intersection.	Yes	Yes	Yes	No
Road narrowing (via edge lines)	Edgelines applied to both sides of the road at bends with an assumed application length of 100 m.	Yes	Yes	Yes	No
Rest areas	It was assumed that one rest area was required in each study area.	Yes	No	No	No
Indicate priority at all junctions	Installed give way signs and pavement markings at junctions with no traffic control. T-junctions required only one leg to be treated and cross roads required two.	Yes	Yes	Yes	Yes
Rumble strips at junctions	Application of lateral marking on all approaches to junctions. A 100 m treatment length was assumed for each approach.	Yes	Yes	Yes	No
Rumble strips at bends	Application of lateral marking on approaches to bends. A 100 m treatment length was assumed for each approach.	Yes	Yes	Yes	No
Solid centre line	Applied to all sealed roads regardless of pre-existing line-marking. AusRAP treatment ID #1.	Yes	Yes	Yes	No
Seal shoulders	Applied to all sealed bends assuming 100 m of length. Road segments with pre-existing sealed shoulders of at least one metre were excluded. AusRAP treatment ID #48.	Yes	Yes	Yes	No
Seal surface	Applied to the length of all unsealed roads. AusRAP treatment ID #73.	No	No	No	Yes
Separate heavy vehicle lane	Two application scenarios were only applied to the freeway: 1) Constructing an extra lane for exclusive heavy vehicle use. 2) Adding a heavy vehicle lane using linemarking only. The latter assumes that the shoulder can support heavy vehicle traffic and a replacement shoulder is not constructed. AusRAP treatment ID #60. AusRAP treatment ID #1.	Yes	No	No	No

Treatment	Application scenario and assumptions	Applied to this road class?			
		Main	Alternative	Trafficable sealed	Unsealed
Install overtaking lanes	Applied to major roads that only had a single lane in each direction up to a maximum length of 5km (in all cases the length of road segment in the study area to which this was applied was shorter than 5 km). AusRAP treatment ID #60.	Yes	No	No	No
Install roadside barriers	Crash barriers were applied to both sides of the roads that did not already have barriers installed. When only applied to bends, a treatment length of 100 m was assumed on each side of the road segment. AusRAP treatment ID #45.	Yes	Yes	Yes	Yes
Install centreline wire rope barriers	When only applied to bends, a treatment length of 100 m was assumed. AusRAP treatment ID #24.	Yes	Yes	Yes	No
Make existing barriers motorcycle friendly Install motorcycle friendly barriers	Retrofitting all existing barriers to be motorcycle friendly (based on W-beam barrier types). This treatment was applied to main and alternative routes in the hills area and the freeway in the plains area.	Yes	Yes	No	No
Upgrade give way junctions	Convert all junctions with give way signs to stop controlled junctions. T-junctions required one leg to be treated and cross roads required two.	Yes	Yes	Yes	Yes
Truck warning signs	A sign was installed in both directions at 5 km intervals on main and alternative routes. The sign was assumed to be similar to an R6-32 (from AS1742.1) with a dimension of 1200 x 800 mm at a cost of $300 per square metre.	Yes	Yes	No	No
Vehicle activated warning signs (presence of other vehicles)	Installed at junctions and indicate to approaching motorists the presence of other vehicles at the junction. The cost covers the installation for an entire intersection including all approaches.	Yes	Yes	Yes	No
Vehicle activated warning signs (flash when approach speed above a threshold)	Applied at junctions or bends and provide feedback to motorists if exceeding a speed threshold. The cost covers the installation for an entire intersection or bend.	Yes	Yes	Yes	No
Warning signs (various)	Includes five different types of warning signs. It was assumed that one of each type was required in each area.	Yes	Yes	Yes	Yes

3.1.5 Application of the Treatments to the Study Areas

Plains study area

Table 3.9 summarises the costs of applying the treatments based on the length (or number) of sites that the treatment is needed for and the cost per kilometre (or site) of the treatment.

It should be noted that the costs represent general estimates according to the assumptions outlined in Section 3.1.4. Many of the treatments are mutually exclusive and the application of one might cause another to become redundant. For example, if roadside barriers are installed there would be no need to achieve 10 m clear zones.

Table 3.9: Cost of applying individual treatments to the plains study area

Treatment	Application	Units	Cost per unit ($)	Cost of treatment ($)
Junction advisory signs	At all junctions	76	250	19 000
Alter curve geometry	10% of bends	1	600 000	600 000
Audio-tactile line marking	Outside bends	3.3	3 250	10 725
	Centreline of bends	3.3	3 250	10 725
	All edge lines	39.4	3 250	128 050
	All centrelines	18.45	3 250	59 963
	Lane separation	20.8	3 250	67 600
Wide centreline	Bends	3.3	68 000	224 400
	All	18.45	68 000	1 254 600
Improved delineation	Junctions	19	16 000	304 000
	Bends	6.6	8 000	52 800
Median islands (teardrop)	All junctions	55	3 420	188 100
	Major junctions	19	3 420	64 980
Add turn lanes	All junctions	7.57	51 000	386 070
	Major junctions	3.55	51 000	355 000
Clear zones	Major roads	22.78	29 000	660 620
Divided roads	Major roads	16.69	9 000 000	150 210 000
Install a roundabout	Sealed junctions	19	1 000 000	19 000 000
	Major junctions	6	1 000 000	6 000 000
Energy absorbing attenuator on rear of maintenance fleet vehicles	One vehicle	1	30 000	30 000
Curve advisory signs	All bends	88	300	26 400
Fatigue warning signs	Roads crossing area	3	288	864
Fence road reserve	All major roads	56.68	5 000	283 400
Improve visibility on approach	5% of intersections	1	27 000	27 000
Improve merge lanes	Freeway merges	2	550 000	1 100 000
Lower speed limit	Sealed roads	30.1	78 000	2 347 800
	All roads	59.33	78 000	4 627 740
Ban U-turns	All junctions	55	150	8 250
Road narrowing via edge lines	Bend approaches	6.6	8 000	52 800
Rest areas	One per area	1	321 700	321 700
Indicate priority at all junctions	All junctions	14	597	8 358
Rumble strips	Bends (sealed)	66	325	21 450
	Junctions (sealed)	55	325	17 875
Solid centre line	All roads	17.87	4 000	71 480
Seal shoulders	Bends (sealed)	3.3	160 000	528 000
	Sealed roads	23.8	160 000	3 808 000
Seal surface	Unsealed roads	29.23	127 000	3 712 210
Separate heavy vehicle lanes	Freeway – extra lane	10.4	3 842 000	39 956 800
	Freeway – marking	10.4	8 000	83 200
Install overtaking lanes	One major route	4.33	3 842 000	16 635 860
Install roadside barriers	Bends (sealed)	13.2	228 000	3 009 600
	Major roads	30.81	228 000	7 024 680

Treatment	Application	Units	Cost per unit ($)	Cost of treatment ($)
	Sealed roads	56.76	228 000	12 941 280
Install centreline wire rope barrier	Bends (sealed)	3.3	510 000	1 683 000
	Major roads	16.56	510 000	8 445 600
	Sealed roads	30.1	510 000	15 351 000
Install motorcycle friendly barriers	Motorcycle routes?	10.4	55 000	572 000
Increase stop controlled junctions	Give way junctions	12	610	7 320
Truck warning signs	Truck routes	14	250	3 500
Vehicle activated warning signs – presence of other vehicles	Major junctions	6	232 000	1 392 000
	All junctions	19	232 000	4 408 000
Vehicle activated warning signs – speed above a threshold	Major junctions	6	116 000	696 000
	All junctions	19	116 000	2 204 000
	Bends (sealed)	33	116 000	3 828 000
	All bends	66	116 000	7 656 000
Warning signs various (five types)	One sign of each type per study area	5	250	1 250

Hills study area

The same method of applying treatments that was used in the plains area was applied to the hills area (Table 3.10).

Table 3.10: Cost of applying individual treatments to the hills study area

Treatment	Application	Units	Cost per unit ($)	Cost of treatment ($)
Junction advisory signs	At all junctions	147	250	36 750
Alter curve geometry	10% of bends	29	600 000	17 400 000
Audio-tactile line marking	Outside bends	19.8	3 250	64 350
	Centreline of bends	19.8	3 250	64 350
	All edge lines	94.98	3 250	308 685
	All centrelines	47.49	3 250	154 342.5
	Lane separation	0	3 250	0
Wide centreline	Bends	19.8	68 000	1 346 400
	All	47.49	68 000	3 229 320
Improved delineation	Junctions	37	16 000	592 000
	Bends	39.6	8 000	316 800
Median islands (teardrop)	All junctions	113	3 420	386 460
	Major junctions	7	3 420	23 940
Add turn lanes	All junctions	19.34	51 000	1 934 000
	Major junctions	1	51 000	100 000
Clear zones	Major roads	17.48	29 000	506 920
Divided roads	Major roads	15.48	9 000 000	139 320 000
Install a roundabout	Sealed junctions	37	1 000 000	37 000 000
	Major junctions	2	1 000 000	2 000 000
Energy absorbing attenuator on rear of maintenance fleet vehicles	One vehicle	1	30 000	30 000

Treatment	Application	Units	Cost per unit ($)	Cost of treatment ($)
Curve advisory signs	All bends	412	300	123 600
Fatigue warning signs	Roads crossing area	1	288	288
Fence road reserve	All major roads	30.96	5 000	154 800
Improve visibility on approach	5% of intersections	2	27 000	54 000
Improve merge lanes	Freeway merges	0	550 000	0
Lower speed limit	Sealed roads	47.49	78 000	3 704 220
	All roads	62.07	78 000	4 841 460
Ban U-turns	All junctions	113	150	16 950
Road narrowing via edge lines	Bend approaches	39.6	8 000	316 800
Rest areas	One per area	1	321 700	321 700
Indicate priority at all junctions	All junctions	38	597	22 686
Rumble strips	Bends (sealed)	396	325	128 700
	Junctions (sealed)	113	325	36 725
Solid centre line	All roads	47.49	4 000	189 960
Seal shoulders	Bends (sealed)	19.8	160 000	3 168 000
	Sealed roads	45.93	160 000	7 348 800
Seal surface	Unsealed roads	14.58	127 000	1 851 660
Separate heavy vehicle lanes	Freeway – extra lane	0	3 842 000	0
	Freeway – marking	0	8 000	0
Install overtaking lanes	One major route	4.24	3 842 000	16 290 080
Install roadside barriers	Bends (sealed)	57.6	228 000	13 132 800
	Major roads	8.48	228 000	1 933 440
	Sealed roads	94.98	228 000	21 655 440
Install centreline wire rope barrier	Bends (sealed)	19.8	510 000	10 098 000
	Major roads	4.24	510 000	2 162 400
	Sealed roads	47.49	510 000	24 219 900
Install motorcycle friendly barriers	Motorcycle routes?	15.48	55 000	851 400
Increase stop controlled junctions	Give way junctions	8	610	4 880
Truck warning signs	Truck routes	18	250	4 500
Vehicle activated warning signs – presence of other vehicles	Major junctions	2	232 000	464 000
	All junctions	37	232 000	8 584 000
Vehicle activated warning signs – speed above a threshold	Major junctions	2	116 000	232 000
	All junctions	37	116 000	4 292 000
	Bends (sealed)	198	116 000	22 968 000
	All bends	288	116 000	33 408 000
Warning signs various (five types)	One sign of each type per study area	11	250	2 750

3.2 Results

The approach taken was to compare and contrast a number of models, containing various combinations of the identified treatments, to assess the performance and cost of different approximations to a fully Safe System infrastructure.

3.2.1 Total Protection Model

This model tests the consequences of applying the full range of identified 'protect' treatments to create an environment that would have mitigated error consequences in all cases. This model is designed to approximate the infrastructure component of a fully Safe System, within the limitations of the infrastructure technology that is currently available to road authorities.

This model comprises a total of 22 different treatments.

Plains region

For the plains region study area these 22 treatments would need to be applied over 475 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $298 073 758.

The average cost per network SLK is estimated to be $5 026 539.

The average cost per treated km is estimated to be $627 022.

The average cost per square km is estimated to be $5 961 475.

Hills region

For the hills region study area it is estimated that the 22 treatments would need to be applied over 564 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $290 167 557.

The average cost per network SLK is estimated to be $4 672 585.

The average cost per treated km is estimated to be $514 755.

The average cost per square km is estimated to be $5 803 351.

Combined regions

The average cost per network SLK is estimated to be $4 845 480.

The average cost per treated km is estimated to be $566 117.

The average cost per square km is estimated to be $5 882 413.

3.2.2 Partial Protection Model – Top 6 Treatments

The six most common treatments to protect drivers in the event of making an error (sealed shoulders, roadside barriers, centre line WRSBs, divided roads, clear zones and roundabouts) would have mitigated the consequences of the error in approximately 76% of cases.

Plains region

For the plains region study area these six treatments would need to be applied over 243 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $229 812 120.

The average cost per network SLK is estimated to be $3 875 415.

The average cost per treated km is estimated to be $947 640.

The average cost per square km is estimated to be $4 596 242.

Hills region

For the hills region study area it is estimated that the six treatments would need to be applied over 370 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $262 433 100.

The average cost per network SLK is estimated to be $4 225 976.

The average cost per treated km is estimated to be $709 509.

The average cost per square km is estimated to be $5 248 662.

Combined regions

The average cost per network SLK is estimated to be $4 054 738.

The average cost per treated km is estimated to be $803 810.

The average cost per square km is estimated to be $4 922 452.

3.2.3 Partial Protection Model – Top 3 Treatments

The three most common treatments to protect drivers in the event of making an error (sealed shoulders, roadside barriers, centre line WRSBs) would have mitigated the consequences of the error in approximately 63% of cases.

Plains region

For the plains region study area these three treatments would need to be applied over 184 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $54 102 160.

The average cost per network SLK is estimated to be $912 347.

The average cost per treated km is estimated to be $294 706.

The average cost per square km is estimated to be $1 082 043.

Hills region

For the hills region study area it is estimated that the three treatments would need to be applied over 298 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $83 606 180.

The average cost per network SLK is estimated to be $1 346 315.

The average cost per treated km is estimated to be $280 633.

The average cost per square km is estimated to be $1 672 124.

Combined regions

The average cost per network SLK is estimated to be $1 134 336.

The average cost per treated km is estimated to be $285 999.

The average cost per square km is estimated to be $1 377 083.

3.2.4 Comparing Total Protection vs Top 6 vs Top 3

Table 3.11: Comparing Total Protection vs Top 6 vs Top 3

Model	Number of treatments	Potential effectiveness	Cost per SLK	Cost per treated km	Cost per square km	Relative cost-effectiveness (per SLK)	Relative cost-effectiveness (per treated km)	Relative cost-effectiveness (per square km)
Total Protection	22	1	$4 845 480	$566 117	$5 882 413	$4 845 480	$566 117	$5 882 413
Top 6	6	0.76	$4 054 738	$803 810	$4 922 452	$5 335 182	$1 057 645	$6 476 911
Top 3	3	0.63	$1 134 336	$285 999	$1 377 083	$1 800 533	$453 967	$2 185 846

It is apparent from Table 3.11 that the Top 3 model would be the cheapest and also the most cost effective. However, it only provides protection in 63% of cases. On the other hand, the Top 6 model would be almost four times as expensive to implement across the study areas (and nearly as expensive as the Total Protection model), for only a 13% increase in protection and is the least cost-effective of all three models.

3.2.5 Discourage Errors Model – All Treatments

This model tests the consequences of applying the full range of identified ‘discourage errors’ treatments to create an environment that may have prevented the error in all cases.

A total of 27 different treatments comprise this model.

Plains region

For the plains region study area these 27 treatments would need to be applied over 1023 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $94 538 657.

The average cost per network SLK is estimated to be $1 594 244.

The average cost per treated km is estimated to be $92 390.

The average cost per square km is estimated to be $1 890 773.

Hills region

For the hills region study area it is estimated that the 27 treatments would need to be applied over 2650 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $108 899 154.

The average cost per network SLK is estimated to be $1 753 610.

The average cost per treated km is estimated to be $41 094.

The average cost per square km is estimated to be $2 177 983.

Combined regions

The average cost per network SLK is estimated to be $1 675 765.

The average cost per treated km is estimated to be $55 383.

The average cost per square km is estimated to be $2 034 378.

3.2.6 Discourage Errors Model – Top 6 Treatments

The six most common treatments to discourage errors (warning signs, lower speed limit, audio-tactile line marking, fatigue warning/trivia signs, rest areas, self-explaining road treatments) would have had the potential to prevent the crash in approximately 66% of cases.

Plains region

For the plains region study area these six treatments would need to be applied over 172 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $7 569 254.

The average cost per network SLK is estimated to be $127 643.

The average cost per treated km is estimated to be $44 051.

The average cost per square km is estimated to be $151 385.

Hills region

For the hills region study area it is estimated that the six treatments would need to be applied over 290 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $9 620 853.

The average cost per network SLK is estimated to be $154 925.

The average cost per treated km is estimated to be $33 137.

The average cost per square km is estimated to be $192 417.

Combined regions

The average cost per network SLK is estimated to be $141 599.

The average cost per treated km is estimated to be $37 194.

The average cost per square km is estimated to be $171 901.

3.2.7 Discourage Errors Model – Top 3 Treatments

The three most common treatments to discourage errors (warning signs, lower speed limit, audio-tactile line marking) would have had the potential to prevent the crash in approximately 55% of cases.

Plains region

For the plains region study area these three treatments would need to be applied over 161 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $7 193 890.

The average cost per network SLK is estimated to be $121 313.

The average cost per treated km is estimated to be $44 619.

The average cost per square km is estimated to be $143 878.

Hills region

For the hills region study area it is estimated that the three treatments would need to be applied over 249 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $8 983 665.

The average cost per network SLK is estimated to be $144 664.

The average cost per treated km is estimated to be $36 088.

The average cost per square km is estimated to be $179 673.

Combined regions

The average cost per network SLK is estimated to be $133 258.

The average cost per treated km is estimated to be $39 441.

The average cost per square km is estimated to be $161 776.

3.2.8 Comparing 'Discourage Errors' All Treatments vs Top 6 vs Top 3

Table 3.12: Discourage error models comparison

Model	Number of treatments	Potential effectiveness	Cost per SLK	Cost per treated km	Cost per square km	Relative cost-effectiveness (per SLK)	Relative cost-effectiveness (per treated km)	Relative cost-effectiveness (per square km)
Total Discourage	27	1	$1 675 765	$55 383	$2 034 378	$1 675 765	$55 383	$2 034 378
Top 6	6	0.66	$141 599	$37 194	$171 901	$214 544	$56 355	$260 456
Top 3	3	0.58	$133 258	$39 441	$161 776	$229 755	$68 002	$278 924

As expected, the 'discourage errors' treatments are substantially cheaper than the 'protect' treatments. The Top 6 model is the most cost effective and less than 15% of the Total model cost to implement. However, it could impact, at most, 66% of errors.

3.2.9 Hybrid Model – Top 6 'Protect' Plus Top 6 'Discourage'

This model tests the impact of pairing the top six 'protect' treatments and the top six 'discourage errors' treatments (sealed shoulders, roadside barriers, centre line WRSBs, divided roads, clear zones, roundabouts, warning signs, lower speed limit, audio-tactile line marking, fatigue warning/trivia signs, rest areas and self-explaining road treatments).

This combination of treatments would have had the potential to have an impact in approximately 89% of cases; that is, another 13% of cases over and above just the top six 'protect' treatments.

Plains region

For the plains region study area these 12 treatments would need to be applied over 414 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $237 381 374.

The average cost per network SLK is estimated to be $4 003 059.

The average cost per treated km is estimated to be $572 914.

The average cost per square km is estimated to be $4 747 627.

Hills region

For the hills region study area it is estimated that the 12 treatments would need to be applied over 660 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $272 053 953.

The average cost per network SLK is estimated to be $4 380 901.

The average cost per treated km is estimated to be $412 066.

The average cost per square km is estimated to be $5 441 079.

Combined regions

The average cost per network SLK is estimated to be $4 196 337.

The average cost per treated km is estimated to be $474 087.

The average cost per square km is estimated to be $5 094 353.

3.2.10 Hybrid Model – Top 6 'Protect' Plus Additional 'Discourage' Treatments to Address the Gap

This model takes the top six 'protect' treatments and adds the 'discourage' treatments required to impact 100% of cases.

This resulted in the following: sealed shoulders, roadside barriers, centre line WRSBs, divided roads, clear zones, roundabouts, curve advisory signs, fatigue warning signs, lower speed limit, truck-specific warning signs, warning signs.

This combination of 11 treatments has the potential to have an impact on 100% of cases. That is, the addition of five empirically motivated 'discourage' treatments provides the remaining coverage over the 76% provided by the top six 'protect' treatments.

Plains region

For the plains region study area these treatments would need to be applied over 482 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $236 831 874.

The average cost per network SLK is estimated to be $3 993 792.

The average cost per treated km is estimated to be $491 414.

The average cost per square km is estimated to be $4 736 637.

Hills region

For the hills region study area it is estimated that the treatments would need to be applied over 1068 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $271 154 768.

The average cost per network SLK is estimated to be $4 366 421.

The average cost per treated km is estimated to be $253 786.

The average cost per square km is estimated to be $5 423 095.

Combined regions

The average cost per network SLK is estimated to be $4 184 404.

The average cost per treated km is estimated to be $327 653.

The average cost per square km is estimated to be $5 079 866.

3.2.11 Hybrid Model – Top 3 'Protect' Plus Additional 'Discourage' Treatments to Address the Gap

This model takes the top three 'protect' treatments and added the 'discourage' treatments required to impact 100% of cases.

This resulted in the following: sealed shoulders, roadside barriers, centre line WRSBs, improved delineation and road marking at junctions, curve advisory signs, fatigue warning signs, lower speed limit, stop-controlled junctions, truck-specific warning signs, vehicle-activated signs (other vehicle presence) and warning signs.

This combination of 11 treatments has the potential to have an impact on 100% of cases. That is, the addition of eight empirically motivated 'discourage' treatments provides the remaining coverage over the 63% provided by the top three 'protect' treatments.

Plains region

For the plains region study area these 11 treatments would need to be applied over 474 km/instances.

The total cost to apply these treatments to the plains region study area is estimated to be $67 230 184.

The average cost per network SLK is estimated to be $1 133 730.

The average cost per treated km is estimated to be $141 833.

The average cost per square km is estimated to be $1 344 604.

Hills region

For the hills region study area it is estimated that the nine treatments would need to be applied over 1079 km/instances.

The total cost to apply these treatments to the hills region study area is estimated to be $101 972 118.

The average cost per network SLK is estimated to be $1 642 063.

The average cost per treated km is estimated to be $94 464.

The average cost per square km is estimated to be $2 039 442.

Combined regions

The average cost per network SLK is estimated to be $1 393 759.

The average cost per treated km is estimated to be $108 918.

The average cost per square km is estimated to be $1 692 023.

3.2.12 Comparing the Hybrid Models

Table 3.13: Hybrid models comparison

Model	Number of treatments	Potential effectiveness	Cost per SLK	Cost per treated km	Cost per square km	Relative cost-effectiveness (per SLK)	Relative cost-effectiveness (per treated km)	Relative cost-effectiveness (per square km)
Top 6 + Top 6	12	0.89	$4 196 337	$474 087	$5 094 353	$4 714 985	$532 682	$5 723 992
Top 6 + Discourage	11	1	$4 184 404	$327 653	$5 079 866	$4 184 404	$327 653	$5 079 866
Top 3 + Discourage	11	1	$1 393 759	$108 918	$1 692 023	$1 393 759	$108 918	$1 692 023

As can be seen from Table 3.13 the model consisting of the Top 6 ‘Protect’ treatments and the Top 6 ‘discourage errors’ treatments is very expensive and is also not cost-effective, relative to other models. For this reason alternative hybrid models were investigated. The model consisting of the Top 3 ‘Protect’ treatments and eight other treatments, chosen to address the gaps not covered by those Top 3 ‘Protect’ treatments, is much less expensive and is comparatively cost-effective.

3.3 Conclusions – Comparing All Models to Each Other

Table 3.14: All models comparison

Model	Number of treatments	Potential effectiveness	Cost per SLK	Cost per treated km	Cost per square km	Relative cost-effectiveness (per SLK)	Relative cost-effectiveness (per treated km)	Relative cost-effectiveness (per square km)
Total Protect	22	1	$4 845 480	$566 117	$5 882 413	$4 845 480	$566 117	$5 882 413
Top 6 Protect	6	0.76	$4 054 738	$803 810	$4 922 452	$5 335 182	$1 057 645	$6 476 911
Top 3 Protect	3	0.63	$1 134 336	$285 999	$1 377 083	$1 800 533	$453 967	$2 185 846
Total Discourage	27	1	$1 675 765	$55 383	$2 034 378	$1 675 765	$55 383	$2 034 378
Top 6 Discourage	6	0.66	$141 599	$37 194	$171 901	$214 544	$56 355	$260 456
Top 3 Discourage	3	0.58	$133 258	$39 441	$161 776	$229 755	$68 002	$278 924
Top 6 + Top 6 Hybrid	12	0.89	$4 196 337	$474 087	$5 094 353	$4 714 985	$532 682	$5 723 992
Top 6 + Discourage Hybrid	11	1	$4 184 404	$327 653	$5 079 866	$4 184 404	$327 653	$5 079 866
Top 3 + Discourage Hybrid	11	1	$1 393 759	$108 918	$1 692 023	$1 393 759	$108 918	$1 692 023

These results suggest that, in order to mitigate the consequences of all errors in a rural environment, 22 separate treatments would need to be employed, at an estimated cost of nearly $6m per square km. While treatments to discourage the errors that lead to these crashes are not designed to mitigate the consequences of errors, unlike the ‘protective’ treatments, they are significantly cheaper. In order to address all the errors that lead to crashes in this study a total of 27 separate treatments would need to be employed, but at a cost of approximately only one-third of the amount of the estimated cost of the ‘protective’ treatments.

The safest outcome would of course result from installing all of the ‘protect’ and all of the ‘discourage error’ treatments. However this option is prohibitively expensive, as are many of the other options. Installing only the top six ‘discourage errors’ treatments is the most cost-effective option, but has the potential to address only 66% of errors, and, of course, does not provide protection if an error is actually made.

The model consisting of the Top 6 ‘Protect’ treatments and the Top 6 ‘Discourage Error’ treatments has the potential to address 89% of errors (with the ‘protective’ component being 76%), but it is nearly as expensive as the Total Protection model and barely more cost-effective than the Total Protection model.

Perhaps the model with the most potential is the Top 3 + Discourage Hybrid model (sealed shoulders, roadside barriers, centre line WRSBs, improved delineation and road marking at junctions, curve advisory signs, fatigue warning signs, lower speed limit, stop-controlled junctions, truck-specific warning signs, vehicle-activated signs (other vehicle presence) and warning signs). Other than the Top 3 and Top 6 ‘Discourage’ models, this model is the cheapest and most cost-effective. Furthermore, 63% of the effect of this model is in terms of actual protection should an error occur.

4. Contributing to a Safe System through Infrastructure

The Vision Zero approach to road safety requires that road infrastructure is designed to discourage errors and protect road users in the event that errors occur. While the general approach required to achieve this aim is clear, the implementation details, the feasibility and the cost associated with achieving the vision are less clear. This project has begun to clarify these issues and draw some conclusions about how close it is possible to practically approach a Safe System, from an infrastructure perspective, using existing technologies.

The results of the analysis of the in-depth crash data indicated that driver error was implicated in almost every case, to a greater or lesser extent. While violations accounted for up to 25% of cases (depending on how they are defined), the crash type (and often immediate cause) associated with those violations were not different to those associated with non-deliberate errors. This in itself is an important insight because it suggests that, at least for the rural network considered here, there is no need to become caught up in a philosophical discussion about whether a Safe System approach should, or should not, accommodate deliberate violations. It appears, in practice, that the treatment models derived in this project are likely to incidentally protect against violations. However, it should be recalled that the data set on which this investigation is based did not include cases where drink driving or suicide were known to be involved. The treatment models developed in this project may therefore not protect against these forms of harm.

While the results of the analyses performed in this project suggest that it would be very complicated and very expensive to create a fully Safe System utilising existing infrastructure technologies, even in the relatively straightforward rural network examine here, it appears that very worthwhile approximations to a Safe System can be achieved more simply and less inexpensively. For example, implementing only the top three ‘protect’ treatments would have provided protection in 63% of all the errors examined in this study. This model deliverers approximately two thirds of the benefit of the full protection model while costing one quarter as much. Furthermore, adding a number of ‘discourage errors’ treatments to these top three ‘protect’ treatments (improved delineation and road marking at junctions, curve advisory signs, fatigue warning signs, lower speed limit, stop-controlled junctions, truck-specific warning signs, vehicle-activated signs (other vehicle presence) and warning signs) so as to create the potential for discouraging the remaining errors not addressed by the top three ‘protect’ treatments, only increases cost marginally, but improves the cost-effectiveness of the treatment model significantly.

However, even the least expensive and/or most cost effective models are likely to be challenging in terms of the cost involved and the time required to retrofit a network. For this reason a useful strategy may be to adopt a staged approach to implementation and to install one or two of the component treatments from a promising model. For example, centreline WRSBs turn out to be quite important in mitigating the consequences of errors in the rural network studied here and they are a key component of the most promising treatment models. As a result, fitting centre line WRSBs as a first step in a staged approach would be a logical and defensible way to proceed. It would be beneficial in isolation while and allowing the rest of the Safe System to be built around it at a later date without the risk of duplication of function by the later treatments.

Of course, a Safe System is not just about infrastructure and many of the critical errors will be mitigated by developments in vehicle technology. For example, ‘overcorrection’ errors can be moderated by electronic stability control (ESC) and there is good evidence for the effectiveness of ESC (Mackenzie & Anderson 2009). Similarly, developments in driver fatigue detection and warning systems are likely to be very significant in the future in rural environments (Volkswagen 2013). While these technologies may be able to do some of the work of a safe infrastructure at the moment and more and more of that work into the future, until they fully penetrate the fleet and until vehicles are essentially autonomous (self-driving) there will still be a need for a forgiving road environment and a road environment that discourages errors.

To this end, the research presented here begins to provide an evidence-based account of what would be required to achieve a truly Safe System from an infrastructure perspective using existing technology. It also provides a way to derive treatment models that can be compared in terms of their complexity, cost and cost-effectiveness; providing, essentially, a road map for how to move towards a Safe System in the most efficient way.

It is important to note that this research is limited in a number of ways. Most significantly it applies only to rural high speed roads and does not apply to night-time crashes. For this reason future research should attempt to generalise the approach to urban and other road types and to night-time crashes. In addition, it would be very useful to expand the number of cases so as to allow a breakdown by road class and other salient road environment features. This would facilitate the application of the approach to a particular project.

Finally, there are undoubtedly likely to be synergies between this approach and the Australian Risk Assessment Model (ANRAM). For example, it may be that risk ratings can be used to assist in the staged implementation discussed earlier; for example, to help target where treatments should be applied first. It may also be that the current results may be able to finesse the ANRAM algorithms by virtue of the more detailed understanding, obtained here, of the relationship between driver error and infrastructure. Thus this is likely to be fertile ground for both approaches and a future project should investigate the potential of such synergies.

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Austroads

Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia
Phone: +61 2 9264 7088

austroads@austroads.com.au
www.austroads.com.au